University of Nottingham
UK | CHINA | MALAYSIA

Faculty of Engineering
Department of Architecture and Built Environment

User Response to Indoor Thermal Environment in Female High Schools' Buildings in Muscat City, Sultanate of Oman

Thesis submitted to the University of Nottingham for the degree of:
Doctor of Philosophy, 2019

Hanan Al-Khatri
B.Eng., M.Sc.

to Sara,
with love

Table of Content

Table of Content ..... **i**
List of Tables ..... **v**
List of Figures ..... **vii**
List of Acronyms ..... **xi**
List of Notations ..... **xii**
List of Publications ..... **xiii**
Acknowledgement ..... **xiv**
Abstract ..... **xv**
Chapter 1 Introduction **2**

1.1 Research gap 5
1.2 Research aim and importance 6
1.3 Research objectives 8
1.4 Research questions 9
1.5 Research methodology 11
1.6 Contribution to knowledge 11
1.7 Thesis structure 12
1.8 Summary 16
Part 1 Literature Review and Local Context **17**
Chapter 2 Thermal comfort and thermal scales **19**

2.1 Heat balance equation 19
2.2 Thermal comfort definitions 21
2.3 Thermal adaptation 21
2.4 Factors affecting thermal comfort 23
2.4.1 Physical factors of thermal comfort 24
2.4.1.1 Air temperature 24
2.4.1.2 Mean radiant temperature 24
2.4.1.3 Air velocity 26
2.4.1.4 Water vapour pressure 26
2.4.2 Personal factors of thermal comfort 27
2.4.2.1 Clothing level 27
2.4.2.2 Metabolic rate 29
2.4.3 Second order factors 30
2.4.3.1 Gender 30
2.5 Thermal scales and application challenges 31
2.5.1 Thermal sensation scales 31
2.5.2 Thermal preference scales 32
2.5.3 Challenges in applying and translating thermal scales 33
2.5.3.1 Challenges in translating thermal scales into Arabic language 35
2.5.4 Thermal scales in literature 36
2.6 Conclusion 39
Chapter 3 Thermal comfort in educational buildings **42**

3.1 Importance of thermal comfort in educational buildings 42
3.2 Challenges of thermal comfort in educational buildings 43
3.3 Review of thermal comfort in educational buildings 43
3.3.1 Kindergarten and primary schools' level 45
3.3.2 High schools' level 48
3.3.3 Universities' level 50
3.3.4 Mixed studying level 55
3.3.5 Unspecified studying level 58
3.3.6 Thermal comfort in Omani educational buildings 58
3.4 Discussion 59
3.4.1 Climatic distribution, samples' size, and age ranges 59
3.4.2 Methodology 60
3.4.3 Thermal votes and neutral temperature 61
3.4.4 Students' adaptive behaviour 63
3.4.5 Thermal scales' behaviour 63
3.5 Conclusion 64
Chapter 4 Local context and climatic analysis **68**

4.1 Introduction to the Sultanate of Oman ... 68
4.1.1 Topography ... 69
4.1.2 Climatic conditions ... 70
4.1.3 Social and cultural background ... 70
4.1.4 The educational system ... 71
4.1.4.1 The academic year and the typical school day ... 72
4.1.4.2 The school uniform ... 74

4.2 Muscat climatic conditions ... 74
4.2.1 Air temperature ... 74
4.2.2 Relative humidity ... 75
4.2.3 Wind ... 76
4.2.4 Precipitation ... 77
4.2.5 Solar radiation ... 78

4.3 The investigated schools ... 79
4.3.1 Shatti Al-Qurum (SQ) School ... 80
4.3.2 Dohat Al-Adab (DA) School ... 81
4.3.3 Nusiba bint Kaab (NK) School ... 82
4.3.4 Al-Wadi Al-Kabeer (WK) School ... 84
4.3.5 Zubaida Um Al-Ameen (ZA) School ... 86

4.4 Survey selected periods ... 87
4.5 Conclusion ... 88
Part 2 Methodology ... 90
Chapter 5 Methodology and pilot studies' results ... 92

5.1 Classification of thermal comfort studies ... 92
5.1.1 Rational studies ... 93
5.1.1.1 Rational studies' concept ... 93
5.1.1.2 Rational studies' criticism ... 93

5.1.2 Empirical studies ... 94
5.1.2.1 Empirical studies' concept ... 94
5.1.2.2 Empirical studies' criticism ... 94

5.2 Empirical studies' methodology ... 95
5.2.1 Objective measurements ... 96
5.2.1.1 Air temperature ... 97
5.2.1.2 Globe temperature ... 98
5.2.1.3 Air velocity ... 98
5.2.1.4 Water vapour pressure ... 99

5.2.2 Subjective measurements ... 99
5.2.2.1 Questionnaires' design ... 100
5.2.2.2 Questionnaires' pre-test ... 100
5.2.2.3 Preparing data for analysis ... 101
5.2.2.4 Extracting information from thermal surveys ... 101

5.3 Research strategy ... 101
5.4 The experimental protocol ... 102
5.4.1 Introductory lecture ... 104
5.4.2 Selected devices ... 104
5.4.3 Research questionnaires ... 105
5.4.4 Methodology limitations ... 107

5.5 Pilot studies' results ... 107
5.5.1 First pilot study ... 108
5.5.1.1 Objective measurements ... 108
5.5.1.2 Subjective measurements ... 109

5.5.2 Second pilot study ... 110
5.5.2.1 Objective measurements ... 110
5.5.2.2 Subjects ... 114
5.5.2.3 Sensation and preference ... 114
5.5.2.4 Available adaptive opportunities ... 115
5.5.2.5 Subjective categories' widths ... 116
5.5.2.6 Sensation votes against physical variables ... 117

5.6 Conclusion ... 119
Part 3 Results and Conclusions ... 121

Chapter 6 The survey objective results 123

6.1 Central tendency and variability statistics 123
6.2 Relative frequencies 125
6.2.1 Air temperature 125
6.2.2 Globe temperature 126
6.2.3 Air velocity 127
6.2.4 Relative humidity 129

6.3 Proportions 130
6.3.1 Air temperature 131
6.3.2 Globe temperature 132
6.3.3 Air velocity 134
6.3.4 Relative humidity 135

6.4 Hourly Profiles 137
6.4.1 Air temperature 137
6.4.2 Globe temperature 140
6.4.3 Air velocity 140
6.4.4 Relative humidity 143

6.5 Selected classrooms for further analysis 145
6.6 Exploring indoor air temperature relations 146
6.6.1 Indoor air temperature and outdoor air temperature 148
6.6.2 Indoor air temperature and indoor air velocity 148
6.6.3 Indoor air temperature and indoor globe temperature 149

6.7 Thermal conditions based on ASHRAE comfort zone 150
6.8 Conclusion 152
Chapter 7 The survey subjective results 155

7.1 Data preparation 155
7.2 Personal information and activities' levels 156
7.3 Subjective sensations and preferences 158
7.3.1 Satisfaction and comfort levels 158
7.3.2 Thermal sensations and preferences votes 161
7.3.2.1 Determining unsatisfied students 163
7.3.2.2 Central votes' relations with satisfaction and comfort levels 164
7.3.2.3 Preference votes based on thermal sensation 165
7.3.2.4 Thermal votes based on satisfaction and comfort 166
7.3.2.5 Thermal votes based on sitting locations 168
7.3.2.6 Thermal votes based on schools 170
7.3.2.7 Comparing mean votes of thermal sensation 171

7.3.3 Humidity sensations and preferences votes 174
7.3.4 Air velocity sensations and preferences votes 175

7.4 Students' adaptive behaviour 176
7.4.1 Available adaptive opportunities 177
7.4.2 Perceived control impact 179
7.4.3 Usage time of selected adaptive opportunities 180

7.5 Conclusion 181
Chapter 8 Collective understanding of thermal phrases and scales' behaviour .. 187

8.1 Collective understanding of ASHRAE sensation phrases 187
8.1.1 Translations of ASHRAE scale phrases 187
8.1.2 Comparing categories' means 191
8.1.2.1 Categories' means based on sensations' order 192
8.1.2.2 Categories' means based on season 194

8.1.3 Thermal comfort equivalent 196

8.2 Behaviour of translated ASHRAE, Bedford, and Nicol scales 197
8.2.1 Categories' widths 200
8.2.1.1 Comparing categories' widths within each scale 201
8.2.1.2 Comparing categories' widths from different scales 201

8.2.2 Middle categories' shift from the thermal continuum centre 202
8.2.3 Categories' symmetry 202
8.2.4 Accuracy of categories' boundaries 202
8.2.5 Stability of sensation scales 203

8.2.6 Actual centres and basic statistics of translated thermal votes 204

8.3 Conclusion 205
Chapter 9 Survey results integration 208

9.1 Calculating indoor operative temperatures 208
9.1.1 Central tendency and variability statistics 209
9.1.2 Exploring indoor operative temperature relations 212

9.2 Correlations between physical variables and subjective votes 213
9.2.1 Thermal sensation and preference votes 214
9.2.2 Humidity sensation and preference votes 217
9.2.3 Air velocity sensation and preference votes 218

9.3 Correlations between subjective votes 219
9.4 Calculating neutral temperature by a simple linear regression 220
9.4.1 Students' thermal sensitivity 222
9.4.2 Temperatures' steps to change mean thermal sensation 225
9.4.3 Concerns regarding the constructed regression model 226

9.5 Calculating neutral temperature by Griffiths' method 228
9.5.1 Recalculating temperature steps 230
9.5.2 Exploring neutral temperature relations 230

9.6 Calculating acceptability limits 231
9.7 Conclusion 233
Chapter 10 Conclusions and recommendations 238

10.1 Research conclusions 238
10.1.1 Literature review conclusions 239
10.1.2 Local context and pilot studies' conclusions 240
10.1.3 Evaluating classrooms' thermal conditions 241
10.1.4 Thermal scales' explorations 244
10.1.5 Integrating objective and subjective measurements 245

10.2 Research limitations 247
10.3 Research recommendations and future work 248
References 252
Appendix 1.1 266
Appendix 5.1 268
Appendix 5.2 270
Appendix 5.3 271
Appendix 5.4 276
Appendix 5.5 277
Appendix 5.6 278
Appendix 5.7 279
Appendix 8.1 281
Appendix 9.1 285
Appendix 9.2 286
Appendix 9.3 291

List of Tables

Table 2.1: Subjective reactions to air movement 26
Table 2.2: ASHRAE and Bedford thermal sensation scales 32
Table 2.3: McIntyre and Nicol thermal preference scales 33
Table 2.4: Different Arabic translations of ASHRAE thermal sensation phrases 35
Table 3.1: A summary of the reviewed studies in kindergarten and primary schools' level 46
Table 3.2: A summary of the reviewed studies in high schools' level 48
Table 3.3: A summary of the reviewed studies in universities' level 51
Table 3.4: A summary of the reviewed studies in mixed studying level 55
Table 4.1: Average number of rainy days 78
Table 4.2: Average daily sunshine hours 79
Table 5.1: Required and desired accuracy levels of sensors for thermal comfort studies 96
Table 5.2: Arabic translation of introductory questions as used in the distributed questionnaires 106
Table 5.3: Arabic translations of scales' categories as used in the distributed questionnaires 107
Table 5.4: Summary of the first questionnaire answers 109
Table 5.5: Mean, standard deviation, and range of sensation and preference votes (N = 266). 115
Table 5.6: Steps of air and globe temperatures 119
Table 6.1: Basic statistics of summer study measurements 124
Table 6.2: Basic statistics of winter study measurements 124
Table 6.3: Questionnaires' distribution times 137
Table 6.4: Classrooms with measurements outside the dominant ranges 145
Table 6.5: Basic statistics of the physical variables of the selected classrooms for further analysis 146
Table 6.6: Basic statistics of indoor air temperature 147
Table 6.7: Percentages of measured data within ASHRAE comfort zone, [%] 152
Table 7.1: Numbers of distributed and excluded questionnaires 156
Table 7.2: Students' evaluation of their thermal ambience and status 159
Table 7.3: Percentages of thermally unsatisfied students 163
Table 7.4: P-values for the association between satisfaction, comfort, central sensation votes, and (no change) preference 165
Table 7.5: Students' distribution on sensation categories based on satisfaction and comfort levels 167
Table 7.6: Students' distribution on preference categories based on satisfaction and comfort levels 168
Table 7.7: P-values for the relation between satisfaction and comfort levels with sitting location 169
Table 7.8: Different values of the mean thermal sensation vote in each classroom . 173
Table 7.9: Relative frequency of using available adaptive opportunities 177

Table 8.1: Thermal sensations' equivalents before merging, after merging, and from the second questionnaire 191
Table 8.2: Statistics of thermal sensations (N = 245) 192
Table 8.3: First set statistics – ASHRAE order (N = 81) 193
Table 8.4: Second set statistics – another order (N = 164) 193
Table 8.5: First set statistics - summer (N = 163) 195
Table 8.6: Second set statistics - winter (N = 82) 195
Table 8.7: Cumulative proportions, probits, and standard errors of thermal categories in summer 199
Table 8.8: Cumulative proportions, probits, and standard errors of thermal categories in winter 199
Table 8.9: Categories' centres of ASHRAE, Bedford, and Nicol scales in summer and winter studies 204
Table 8.10: Basic statistics of thermal sensation votes 205
Table 9.1: Basic statistics of indoor mean radiant and operative temperatures 209
Table 9.2: Basic statistics of indoor operative temperature of each classroom 211
Table 9.3: Pearson's correlation coefficients of individual thermal votes and indoor air temperature 214
Table 9.4: Pearson's correlation coefficients of mean thermal votes and indoor air temperature 216
Table 9.5: Pearson's correlation coefficients of individual humidity votes and indoor relative humidity 217
Table 9.6: Pearson's correlation coefficients of mean humidity votes and indoor relative humidity 218
Table 9.7: Pearson's correlation coefficients of individual air velocity votes and indoor air velocity 218
Table 9.8: Pearson's correlation coefficients of mean air velocity votes and indoor air velocity 219
Table 9.9: Pearson's correlation coefficients between the subjective votes 220
Table 9.10: Selected thermal sensitivities reported in previous studies 223
Table 9.11: Thermal sensitivities of individual votes and concurrent temperatures .. 225
Table 9.12: Required steps of air, globe, and operative temperatures to change mean thermal sensation 226
Table 9.13: Regression models of individual thermal sensation votes and concurrent indoor air temperature based on schools 227
Table 9.14: Neutral temperature estimated by different Griffiths' slopes 229
Table 9.15: Temperature steps using Griffiths' method 230
Table 9.16: Thermal acceptability limits 232
Table 9.17: Percentages of indoor temperatures within acceptability limits 232
Table 10.1: Results of exploring some relations related to classrooms' thermal conditions 244

List of Figures

Figure 1.1: Approaches to achieve thermal comfort 2
Figure 1.2: Relative frequency of Omani population based on regions for the range (5-24) years old 8
Figure 1.3: The relationship between research's aim, objectives, and questions 10
Figure 1.4: The structure of the thesis 13
Figure 2.1: Thermal interaction between human body and the surroundings 19
Figure 2.2: Ground cover determines solar radiation available to heat air 24
Figure 2.3: Loose clothing allows for heat loss through air movement 28
Figure 3.1: Relative frequency of samples' size 60
Figure 3.2: The distribution of the integrated thermal sensation scales 61
Figure 3.3: The distribution of optimum temperatures 62
Figure 4.1: Oman geographical location 68
Figure 4.2: Diverse topography of Oman 69
Figure 4.3: Annual maximum and minimum air temperature and relative humidity 70
Figure 4.4: Education development in Oman 71
Figure 4.5: The schedule of 2015/2016 academic year 73
Figure 4.6: Female students' uniform in Omani governmental high schools 74
Figure 4.7: Monthly mean, maximum, and minimum air temperature for 2001-2014 75
Figure 4.8: Monthly mean, maximum, and minimum relative humidity for 2001-2014 75
Figure 4.9: Wind rose of mean air velocity [m/s] for 2006-2010 76
Figure 4.10: Distribution of wind direction for 2006-2010 77
Figure 4.11: Monthly mean and maximum precipitation for 2001-2014 77
Figure 4.12: Hourly mean of solar radiation for 2001-2007 in: (a) summer, and (b) winter 78
Figure 4.13: The geographical distribution of the selected schools with reference to Muscat International Airport 79
Figure 4.14: The groups of the investigated schools 80
Figure 4.15: Schematic plans of Shatti Al-Qurum (SQ) School 80
Figure 4.16: Selected photos from Shatti al-Qurum (SQ) School 81
Figure 4.17: Schematic plans of Dohat Al-Adab (DA) School 82
Figure 4.18: Selected photos from Dohat Al-Adab (DA) School 82
Figure 4.19: Schematic plans of Nusiba bint Kaab (NK) School 83
Figure 4.20: Selected photos from Nusiba bint Kaab (NK) School 84
Figure 4.21: Schematic plans of Al-Wadi Al-Kabeer (WK) School 85
Figure 4.22: Selected photos from Al-Wadi Al-Kabeer (WK) School 85
Figure 4.23: Schematic plans of Zubaida Um Al-Ameen (ZA) School 86
Figure 4.24: Selected photos from Zubaida Um Al-Ameen (ZA) School 87
Figure 4.25: Climatic classification of 2015/2016 academic year 88
Figure 5.1: The logic of heat balance model 93
Figure 5.2: Classifications of thermal comfort surveys 96
Figure 5.3: Whirling or sling hygrometer 97
Figure 5.4: Kata thermometer 98

Figure 5.5: Experimental protocol followed in this research 103
Figure 5.6: Questionnaires' distribution sequence in summer and winter studies 104
Figure 5.7: Distribution sequence of the first and second questionnaires 106
Figure 5.8: Investigated classroom's layout and sensors' location 108
Figure 5.9: The physical variables during 1st pilot study 109
Figure 5.10: Relative frequency of thermal, humidity, and air velocity: (a) sensation votes and (b) preference vote 110
Figure 5.11: Hourly profiles of indoor: (a) air temperature, (b) globe temperature, (c) air velocity, and (d) relative humidity 112
Figure 5.12: Indoor and outdoor mean and instantaneous: (a) air temperature, (b) globe temperature, (c) air velocity, and (d) relative humidity 113
Figure 5.13: Relative frequency of thermal, humidity, and air velocity: (a) sensation votes and (b) preference votes 115
Figure 5.14: Students' adaptive behaviour: (a) available opportunities and (b) usage time 116
Figure 5.15: Translated scales' categories on the thermal continuum 117
Figure 5.16: Regression between thermal sensation votes and: (a) indoor air temperature and (b) indoor globe temperature 118
Figure 5.17: Residuals of thermal sensation votes: (a) indoor air temperature and (b) indoor globe temperature 118
Figure 6.1: Relative frequency of indoor air temperature: (a) summer-ASHRAE (N = 1025), (b) summer-Bedford (N = 1031), (c) winter-Bedford (N = 580), and (d) winter-ASHRAE (N = 572) 125
Figure 6.2: Relative frequency of outdoor air temperature: (a) summer-ASHRAE (N = 336), (b) summer-Bedford (N = 349), (c) winter-Bedford (N = 197), and (d) winter-ASHRAE (N = 194) 126
Figure 6.3: Relative frequency of indoor globe temperature: (a) summer-ASHRAE (N = 1023), (b) summer-Bedford (N = 1031), (c) winter-Bedford (N = 580), and (d) winter-ASHRAE (N = 572) 127
Figure 6.4: Relative frequency of outdoor globe temperature: (a) summer-ASHRAE (N = 336), (b) summer-Bedford (N = 347), (c) winter-Bedford (N = 197), and (d) winter-ASHRAE (N = 194) 127
Figure 6.5: Relative frequency of indoor air velocity: (a) summer-ASHRAE (N = 950), (b) summer-Bedford (N = 998), (c) winter-Bedford (N = 580), and (d) winter-ASHRAE (N = 572) 128
Figure 6.6: Relative frequency of outdoor air velocity: (a) summer-ASHRAE (N = 333), (b) summer-Bedford (N = 347), (c) winter-Bedford (N = 197), and (d) winter-ASHRAE (N = 194) 129
Figure 6.7: Relative frequency of indoor relative humidity: (a) summer-ASHRAE (N = 1025), (b) summer-Bedford (N = 1031), (c) winter-Bedford (N = 580), and (d) winter-ASHRAE (N = 572) 130
Figure 6.8: Relative frequency of outdoor relative humidity: (a) summer-ASHRAE (N = 336), (b) summer-Bedford (N = 347), (c) winter-Bedford (N = 197), and (d) winter-ASHRAE (N = 194) 130
Figure 6.9: Proportions of indoor air temperature: (a) summer-ASHRAE, (b) summer-Bedford, (c) winter-Bedford, and (d) winter-ASHRAE 132
Figure 6.10: Proportions of outdoor air temperature: (a) summer-ASHRAE, (b) summer-Bedford, (c) winter-Bedford, and (d) winter-ASHRAE 132

Figure 6.11: Proportions of indoor globe temperature: (a) summer-ASHRAE, (b) summer-Bedford, (c) winter-Bedford, and (d) winter-ASHRAE 133
Figure 6.12: Proportions of outdoor globe temperature: (a) summer-ASHRAE, (b) summer-Bedford, (c) winter-Bedford, and (d) winter-ASHRAE 134
Figure 6.13: Proportions of indoor air velocity: (a) summer-ASHRAE, (b) summer-Bedford, (c) winter-Bedford, and (d) winter-ASHRAE..... 135
Figure 6.14: Proportions of outdoor air velocity: (a) summer-ASHRAE, (b) summer-Bedford, (c) winter-Bedford, and (d) winter-ASHRAE..... 135
Figure 6.15: Proportions of indoor relative humidity: (a) summer-ASHRAE, (b) summer-Bedford, (c) winter-Bedford, and (d) winter-ASHRAE 136
Figure 6.16: Proportions of outdoor relative humidity: (a) summer-ASHRAE, (b) summer-Bedford, (c) winter-Bedford, and (d) winter-ASHRAE 137
Figure 6.17: Hourly profile of indoor air temperature for selected classrooms: (a) summer-ASHRAE, (b) summer-Bedford, (c) winter-Bedford, and (d) winter-ASHRAE..... 139
Figure 6.18: Hourly profile of indoor globe temperature for selected classrooms: (a) summer-ASHRAE, (b) summer-Bedford, (c) winter-Bedford, and (d) winter-ASHRAE..... 141
Figure 6.19: Hourly profile of indoor air velocity for selected classrooms: (a) summer-ASHRAE, (b) summer-Bedford, (c) winter-Bedford, and (d) winter-ASHRAE .. 142
Figure 6.20: Hourly profile of indoor relative humidity for selected classrooms: (a) summer-ASHRAE, (b) summer-Bedford, (c) winter-Bedford, and (d) winter-ASHRAE..... 144
Figure 6.21: Indoor air temperature against outdoor air temperature (a) summer-ASHRAE, (b) summer-Bedford, (c) winter-Bedford, and (d) winter-ASHRAE .. 148
Figure 6.22: Indoor air velocity against indoor air temperature (a) summer-ASHRAE, (b) summer-Bedford, (c) winter-Bedford, and (d) winter-ASHRAE 149
Figure 6.23: Indoor globe temperature against indoor air temperature (a) summer-ASHRAE, (b) summer-Bedford, (c) winter-Bedford, and (d) winter-ASHRAE .. 150
Figure 6.24: Indoor thermal conditions on ASHRAE 55 psychrometric chart of Muscat city: (a) summer-ASHRAE, (b) summer-Bedford, (c) winter-Bedford, and (d) winter-ASHRAE..... 151
Figure 7.1: Students' age distribution in: (a) summer study and (b) winter study 156
Figure 7.2: Students' distribution based on their activities at 15 minutes before distributing the questionnaires in: (a) summer study and (b) winter study 158
Figure 7.3: Students' distribution based on satisfaction and comfort levels..... 160
Figure 7.4: Students' distribution on satisfaction and comfort categories based on their schools 161
Figure 7.5: Relative frequency of: (a) TSV-summer, (b) TPV-summer, (c) TSV-winter, and (d) TPV-winter 162
Figure 7.6: Distribution of preference votes on sensation categories: (a) summer-ASHRAE, (b) summer-Bedford, (c) winter-Bedford, and (d) winter-ASHRAE .. 166
Figure 7.7: Relative frequency of: (a) TSV-classroom centre, (b) TSV-near windows, (c) TPV-classroom centre, and (d) TPV-near windows 169
Figure 7.8: Distribution of thermal sensation votes based on schools: (a) summer-ASHRAE, (b) summer-Bedford, (c) winter-Bedford, and (d) winter-ASHRAE .. 170
Figure 7.9: Distribution of thermal preference votes based on schools: (a) summer-ASHRAE, (b) summer-Bedford, (c) winter-Bedford, and (d) winter-ASHRAE .. 171

Figure 7.10: Relative frequency of: (a) HSV-summer, (b) HPV-summer, (c) HSV-winter, and (d) HPV-winter 174
Figure 7.11: Relative frequency of: (a) HSV and (b) HPV of (ZA-G2) classroom in summer study 175
Figure 7.12: Relative frequency of: (a) AVSV-summer, (b) AVPV-summer, (c) AVSV-winter, and (d) AVPV-winter 176
Figure 7.13: Relative frequency of predicted concentration periods 179
Figure 7.14: Relative frequency of adaptive actions under AC failure 180
Figure 7.15: Time distribution of windows opening, AC switching on, and fans switching on 181
Figure 8.1: Relative frequency of unmerged translated phrases 189
Figure 8.2: Common phrases between merged translated phrases 190
Figure 8.3: Distribution of means' 99% confidence intervals (N = 245) 192
Figure 8.4: Means of thermal sensations in the first, second, and total sets 194
Figure 8.5: Distribution of means' 99% confidence intervals in the first and second sets 194
Figure 8.6: Means of thermal sensations in the first, second, and (Pitts, 2006) sets 196
Figure 8.7: Distribution of means' 99% confidence intervals in first and second sets 196
Figure 8.8: Relative frequency of sensations equivalent to comfort 197
Figure 8.9: Thermal categories' widths of ASHRAE, Bedford, and Nicol scales in summer 199
Figure 8.10: Thermal categories' widths of Bedford, ASHRAE, and Nicol scales in winter 200
Figure 8.11: Levels of comparing categories' widths in the survey 200
Figure 8.12: Comparing categories' widths of sensation scales 203
Figure 9.1: Indoor operative temperature against indoor air temperature: (a) summer-ASHRAE, (b) summer-Bedford, (c) winter-Bedford, and (d) winter-ASHRAE .. 212
Figure 9.2: Indoor operative temperature against indoor globe temperature: (a) summer-ASHRAE, (b) summer-Bedford, (c) winter-Bedford, and (d) winter-ASHRAE 213
Figure 9.3: Correlation between indoor air temperature and: (a) indoor globe temperature (N = 1085), (b) indoor operative temperature (N = 1085) 221
Figure 9.4: Mean thermal sensation votes against indoor air temperature (N = 45) . 222
Figure 9.5: Relative frequency of thermal sensation votes (N = 1085) 224
Figure 9.6: Influence of Griffiths' slope on neutral temperature: (a) G = 0.48 against G = 0.05 and (b) G = 0.48 against G = 0.25 230
Figure 9.7: Neutral temperature correlations with mean indoor temperatures: (a) air neutral temperature and indoor air temperature, (b) globe neutral temperature and indoor globe temperature, and (c) operative neutral temperature and indoor operative temperature 231
Figure 10.1: Relationships between research questions, part (3) chapters, and chapter (10) sections 239

List of Acronyms

AC	Air conditioning
ASHRAE	American Society of Heating, Refrigeration, and Air-Conditioning Engineers
AVPV	Air velocity preference vote
AVSV	Air velocity sensation vote
BEC	Basic education curriculum
CFC	Chlorofluorocarbon gases
CIBSE	Chartered Institution of Building Services Engineers
CO_2	Carbon dioxide
DA	Dohat Al-Adab School
DA-F1	Classroom 01 on the first floor at Dohat Al-Adab School
DA-G1	Classroom 01 on the ground floor at Dohat Al-Adab School
DA-G2	Classroom 02 on the ground floor at Dohat Al-Adab School
DVCC	Displacement ventilation with cooling coil
EC	Evaporative cooling
GES	General education system
GHG	Greenhouse gas
HA	Hil Al-Awamer School
HVAC	Heating, ventilation, and air conditioning
IEQ	Indoor environmental quality
MJ	Al-Mubailaa Al-Janubia School
MVCC	Mixing ventilation with cooling coil
NK	Nusiba bint Kaab School
NK-F1	Classroom 01 on the first floor at Nusiba bint Kaab School
NK-G1	Classroom 01 on the ground floor at Nusiba bint Kaab School
NK-G2	Classroom 02 on the ground floor at Nusiba bint Kaab School
NV	Natural ventilation
PBEC	Post-basic education curriculum
PMV	Predicted mean vote
$_{e}$PMV	Extended predicted mean vote
PMV_{10}	Predicted mean votes with modified metabolic rate
PPD	Percentage of unsatisfied people
RHSV	Relative humidity sensation vote
RHPV	Relative humidity preference vote
SCATs	Smart controls and thermal comfort project
SQ	Shatti Al-Qurum School
SQ-F1	Classroom 01 on the first floor at Shatti Al-Qurum School
SQ-G1	Classroom 01 on the ground floor at Shatti Al-Qurum School
SQ-G2	Classroom 02 on the ground floor at Shatti Al-Qurum School
S1950	Site with altitude 1950 m
S0135	Site with altitude 135 m
TPV	Thermal preference vote
TSV	Thermal sensation vote
$TSV_{,mean}$	Mean thermal sensation vote
UA	Ummamah bint Abi Al-Aas School
UAE	United Arab Emirates
UHI	Urban heat island
UK	United Kingdom
WK	Al-Wadi Al-Kabeer School
WK-F1	Classroom 01 on the first floor at Al-Wadi Al-Kabeer School
WK-F2	Classroom 02 on the first floor at Al-Wadi Al-Kabeer School
WK-S1	Classroom 01 on the second floor at Al-Wadi Al-Kabeer School
ZA	Zubaida Um Al-Ameen School
ZA-G1	Classroom 01 on the ground floor at Zubaida Um Al-Ameen School
ZA-G2	Classroom 02 on the ground floor at Zubaida Um Al-Ameen School
ZA-F1	Classroom 01 on the first floor at Zubaida Um Al-Ameen School

List of Notations

AV	Air velocity	m/s
C	Convection heat loss per unit area	W/m^2
C_{res}	Convective heat loss due to respiration	W/m^2
d	Globe diameter	m
E	Evaporation heat loss per unit body surface area	W/m^2
E_{res}	Evaporative heat loss due to respiration	W/m^2
G	Griffiths' slope	-
h_c	Convective transfer coefficient	W/m^2K
h_r	Linear radiation transfer coefficient	W/m^2K
K	Heat transfer by conduction	W/m^2
M	Metabolic free energy production per unit body area	W/m^2
N	Sample size	-
P_a	Water vapour pressure	kPa
P_{as}	Saturated water vapour pressure	kPa
r	Pearson's correlation coefficient	-
R	Radiative heat loss per unit area	W/m^2
R^2	Coefficient of determination	-
RH	Relative humidity	%
S	Rate of heat storage per unit area	W/m^2
SD	Standard deviation	-
T_a	Air temperature	°C
T_c	Comfort (neutral) temperature	°C
T_{com}	Adaptive neutral temperature	°C
T_e	Equivalent temperature	°C
T_g	Globe temperature	°C
T_m	Modified temperature	°C
$T_{n,g}$	Griffiths' neutral temperature	°C
$T_{n,r}$	Regression neutral temperature	°C
T_o	Operative temperature	°C
T_{op}	Operative temperature	°C
T_r	Mean radiant temperature	°C
T_{set}	Standard effective temperature	°C
v	Air velocity	m/s
W	External mechanical work per unit area	W/m^2

Greek

Φ_c	Heat loss by convection from surface of clothed body	W
Φ_e	Heat loss by evaporation from surface of clothed body	W
Φ_k	Heat flow by conduction from surface of clothed body	W
Φ_m	Metabolic rate per m^2 of body surface	W
Φ_r	Heat loss by radiation from the surface of clothed body	W
Φ_{rc}	Heat exchange by convection in respiratory tract	W
Φ_{re}	Heat exchange by evaporation in respiratory tract	W
Φ_s	Body heat storage	W
Φ_w	Rate of performance of external work	W

In this thesis, air velocity and air speed are used interchangeably to mean air speed. There is no actual concern about the direction of air movement unless mentioned so.

List of Publications

Al-Khatri, H., Alwetaishi, M. & Gadi, M. B., 2019. Exploring the thermal comfort experience and adaptive opportunities of Omani female and Saudi male high school students. Submitted to a special issue (Adaptive thermal comfort) of Energy and Buildings Journal.

Al-Khatri, H. & Gadi, M. B., 2019. Investigating the behaviour of ASHRAE, Bedford, and Nicol thermal scales when translated into the Arabic language. *Building and Environment.* 151:348-355.

Al-Khatri, H. & Gadi, M. B., 2018. Collective understanding of ASHRAE thermal sensation phrases among Arab students. In *10th Windsor Conference - Rethinking comfort.* Windsor: NCEUB (Network for Comfort and Energy Use in Buildings): 357-370.

Al-Khatri, H. & Gadi, M. B., 2018. Investigating thermal conditions in female high schools in Muscat, Sultanate of Oman. In *SEES 2018 - 7th Annual International Conference on Sustainable Energy and Environmental Sciences.* Singapore: GSTF (Global Science and Technology Forum), DOI: 10.5176/2251-189X_SEES18.11.

Acknowledgement

I have been fortunate to be supervised by Dr. Mohamed Gadi for the second time. The first was in 2013 when I studied MSc. Renewable energy and Architecture. He has been inspiring me since then. I am deeply grateful for the constructive comments, invaluable guidance, and great support he generously provided throughout the study period. His encouragement and trust are highly appreciated.

I also would like to take the opportunity to express my sincere appreciation to Prof. Michael Humphreys, Prof. Richard de Dear, Prof. Fergus Nicol, and Prof. Gail Brager for their valuable feedback regarding my work on the collective understanding of thermal comfort scales upon participation in the 10th Windsor conference: Rethinking Comfort. I also extend my thanks to Dr. Marcel Schweiker and Dr. Madhavi Indraganti for the stimulating discussions during the conference regarding different aspects of my research.

My gratitude goes to Sultan Qaboos University for the generous financial support during my study and for the high confidence to select me as the first female junior lecturer in the College of Engineering since its opening in 1986. I also thank all staff of the Ministry of Education in the Sultanate of Oman and the principals, teachers, and students of the participated schools. The research was not possible without their kind participation.

My sincere gratitude is extended to my colleagues Dr. Noor Alhuda AlSaqri, Dr. Mamdooh Alwetaishi, Dr. Ahmed Shohan, Dr. Rami Zein Elabdein, Mrs. Sara Mohamed, Mr. Faisal Alosaimi, Mr. Aasem Alabdullatief, Mr. Abdullah Bagasi, Mr. Daniel Gomez, Mr. Isaias Hernandez Carrillo, and Ms. Dafne Gaviria Arcila for the inspiring discussions. Thank you all for making the study period an enjoyable journey. Many thanks go to Ms. Thouraia Al-Farei, Ms. Khalsa Al-Rawahi, and Ms. Jehad Alshanty for their time and support.

My sincere gratitude and deep appreciation are for Mum, Dad, my sisters, my brothers, and all the family members for their support and encouragement. Special thanks to Dad for teaching me the alphabets and encouraging me to read. Special thanks to Mum for standing by my side and for taking care of my daughter during the study period. I always stand on solid ground because of her deep belief in me. Finally, my endless love and gratitude go to my brave little girl, Sara, for her endless kindness and patient. Forever thanks for her little prayers and wishes, countless drawings and small gifts, funny stories and jokes, and for being my girl and my best friend ever.

Abstract

Satisfying thermal comfort requirements in educational buildings is positively related to students' health and productivity. Yet, the extreme climatic conditions in Oman and the abundance of fossil fuels combined with the lack of regional design standards resulted in heavy reliance on air conditioning systems and, therefore, huge consumption of energy. Regional thermal comfort research is promising in improving buildings' thermal performance. Often, the research is adapted to the local context by translating the thermal scales; yet, this may influence the scales' behaviour negatively. In this research, the thermal conditions of female high schools' students and their perception of ASHRAE sensation scale are investigated in addition to exploring the behaviour of ASHRAE, Bedford, and Nicol scales when translated into the Arabic language. A fieldwork survey was performed in Muscat city in summer and winter. Outdoor and indoor air temperature, globe temperature, air velocity, and relative humidity were measured and the students' subjective votes were collected. A simple linear regression model was constructed and Griffiths' method was applied. Besides, the successive categories method was applied to explore the scales' behaviour.

Dominant narrow ranges of indoor air temperature were revealed besides uncomfortable conditions based on the ASHRAE psychrometric chart of Muscat. However, a direct evaluation of the thermal conditions revealed that around 66%-83% of the students were satisfied with a preference of cooler conditions. Although the students exhibited a relatively heavy reliance on air conditioning units, they were able to lower this reliance in the scenario of air conditioning failure. The neutral temperature was almost 23.5 °C, 23.6 °C, and 23.5 °C expressed in indoor air, globe, and operative temperatures respectively. Applying a Griffiths' slope of 0.48/K, the respective temperatures were 24.8 °C, 25.0 °C, and 24.9 °C approximately. The students exhibited overlapping in understanding some sensations and the majority considered the three central sensations as equivalents to comfort. Besides, exploring the translated scales' behaviour revealed their deviations from the original assumptions. Considering the estimated acceptability limit, it is recommended to maintain the classrooms' air temperatures in the range of 23.1-26.6 °C. Increasing the students' awareness of adaptive actions is recommended besides conducting further explorations to confirm the results regarding thermal conditions involving male students and increasing the sample size. The formation of Arabic thermal scales is recommended as well as investigating the influence of adopting phrases like (cool and not acceptable) and (warm and not acceptable) instead of (cool) and (warm) respectively.

Chapter (1):
Introduction

Chapter 1 Introduction

"Nothing is as dangerous in architecture as dealing with separated problems. If we split life into separated problems, we split the possibilities to make good building art." – Alvar Aalto

Thermally comfortable buildings have a positive impact on the occupants' productivity. However, designing such buildings is not an easy task considering that satisfying thermal comfort demands requires considerable amounts of energy (Nematchoua et al., 2014; Yang et al., 2014). It is estimated that buildings consume around 48% of the total global energy (Thapa et al., 2016). Buildings, especially energy efficient ones, should achieve thermal comfort consuming the minimum possible amount of non-renewable energies (Meier et al., 2002). This is due to the resulted greenhouse gases (GHG) emissions and their contribution to the global warming and climate change (Bölük & Mert, 2014; de Dear & White, 2008). Satisfying thermal comfort demands can be achieved via passive design strategies, active design strategies, or a combination as presented in Figure 1.1. Applying passive strategies requires a comprehensive appreciation of the climatic features of buildings' sites. In addition, it requires a good understanding of users' thermal demands. This understanding can be obtained by conducting regional thermal comfort studies considering the subjective nature of thermal comfort (Al-Khatri & Gadi, 2014).

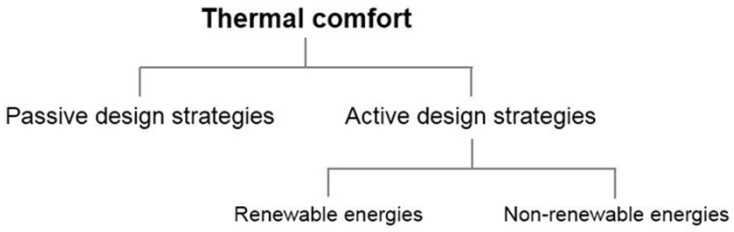


Figure 1.1: Approaches to achieve thermal comfort

The Arabian Gulf region includes six countries which are Oman, United Arab Emirates (UAE), Saudi Arabia, Bahrain, Qatar, and Kuwait. In most buildings in this region, the balance between modernity and comfort on one hand and energy efficiency on the other is unfortunately partially achieved. For instance, uncomfortable thermal and visual environments were reported in many glazed towers in UAE (Aboulnaga, 2006). The energy consumption levels per household in Abu Dhabi, the capital city of UAE, are among the highest globally (Giusti & Almoosawi, 2017). This is mainly owing to importing international architectural styles

without modifying them to consider the local climatic conditions (Katodrytis, 2015; Said & Abdeirahman, 1989 in Zurigat et al., 2003). In addition, the ecological footprint per person in all Gulf countries exceeds the global level, which is currently estimated at 1.7 global hectares. The ecological footprint per person measures the balance between the resources such as land and water required for covering the resources consumed by a population in addition to absorbing the generated waste. Qatar is the first globally with around 15.7 global hectares per person. Following are UAE, Bahrain, Kuwait, Oman, and Saudi Arabia with almost 9.8, 8.7, 7.6, 6.3, and 6.0 global hectares respectively (Global Footprint Network, 2018).

Considering the extreme climatic conditions of the Arabian Gulf region, it is not surprising that buildings rely heavily on air conditioning systems to provide the required levels of thermal comfort. Indeed, these systems are integrated into all buildings despite their different types (Qader, 2009). Based on a survey carried out in Oman, air conditioning units were used in all bedrooms besides more than 60% of kitchens, living, and guest rooms of the explored residential buildings (Majid et al., 2014). In another survey, most participants reported daily operation of air conditioning units of around 20-24 hours during summer in Muscat, the capital city of Oman (Al-Gharibi, 2016), which illustrates the consumption of huge energy amounts for cooling in Oman (Al-Hinai et al., 1993). Indeed, air conditioning systems are estimated to consume more than 70% of the electrical energy in most Omani buildings. The majority of the used systems depend on the vapour compression technique (Zurigat et al., 2003) that releases chlorofluorocarbon (CFC) gases. These gases deplete the ozone layer and, hence, are related to the climate change phenomenon. Adding to this, the main source of domestic electrical energy in Oman is fossil fuels like natural gas and oil (Al-Badi et al., 2011).

Furthermore, the Gulf countries are considerable contributors of the GHG emissions globally taking into account their relatively small populations and large production of oil and gas (Abdul-Wahab et al., 2015a; Qader, 2009). The processes of fossil fuels extraction and electricity production are the main sources for these emissions (Qader, 2009). Moreover, a recent study indicated that there was an increase in the GHG emissions in Oman (Abdul-Wahab et al., 2015b), which was possibly reflected in the climatic events and changes that occurred in the country in the last few years. Examples include the increase in heat waves, droughts, diurnal temperatures, hot days' number, and cyclones' damage power (Abdul-Wahab et al., 2015a). It is worth to mention that

climate change is estimated to double the damage power of tropical cyclones to exceed US $50 billion annually (Mendelsohn et al., 2012).

Since 2000, Muscat city was subjected to two tropical cyclones, namely Gonu in June 2007 and Phet in June 2010. Despite that a tropical cyclone occurred in May 1977 and resulted in 105 deaths (Alhinai, 2011) compared with 49 deaths resulted from Gonu cyclone, the latter is considered as the worst natural disaster occurred in the Arabian Gulf region. Lasted for two days, Gonu cyclone left 20,000 people homeless, damaged the infrastructure services severely, and caused a cost of around US $4 billion according to the estimations of the Omani authorities. In Muscat alone, the first day of the cyclone resulted in damaging almost 35% of telecommunications networks, 30% of mobiles networks, and 90% of roads. Around 27% and 23% of the city areas lost electric power and water supply respectively (Al-Shaqsi, 2010). Considering Phet cyclone, it caused the death of 24 people (Al-Shaqsi, 2010). A list of the recorded tropical cyclones, storms, and depressions that affected Oman, as obtained from the Omani General Directorate of Meteorology, is displayed in Appendix 1.1. Additionally, the air temperature in Muscat increases because of the urban heat island (UHI) impact. Based on a study conducted to explore this phenomenon in Muscat, the maximum increase in air temperature follows sunset by around seven hours in summer. The study identified the heat released from air conditioning systems as a significant contributor to the urban heat island, specifically in Muscat's urban areas (Charabi & Bakhit, 2011).

Several studies highlighted the effect of the climatic and cultural background on thermal comfort demands. One of the earliest studies dated back to 1975 in which indoor comfortable temperatures of British and Iraqi participants were estimated at 17 °C and 32 °C respectively (Humphreys, 1976). Indeed, the different neutral temperatures reported by many studies conducted in different climates and societies can be considered as an indication for the necessity of performing micro-level studies of thermal comfort (Zomorodian et al., 2016). Additionally, the definition of thermal comfort as provided by the American Society of Heating, Refrigeration, and Air-Conditioning Engineers (ASHRAE) highlights the psychological impact role, which is influenced by social and cultural factors (Singh et al., 2011; Hwang et al., 2009; Chappells & Shove, 2005).

The extreme climatic conditions in Oman combined with the lack of well-established regional standards resulted in the current situation of widespread and heavy reliance on air conditioning systems and the consumption of huge energy amounts and their consequences. It

should be admitted that conducting regional thermal comfort studies may not provide an optimum solution for this problem; however, it can contribute towards reducing the gap between the current situation and an optimum one. The findings of these studies, including the neutral temperature and acceptability limits, can be considered as a design target for architects and engineers. This target affects early design decisions and, therefore, affects the buildings' thermal performance and its consequences. It is noteworthy that the successful application of thermal comfort studies requires their adaptation to the local context. This is usually achieved by translating the applied questionnaires, which highlights the importance of accurate translation of thermal scales.

1.1 Research gap

A literature review conducted by the researcher with the objective of exploring indoor and outdoor thermal comfort studies performed in Oman revealed a lack of research, especially in educational buildings. The search keywords were defined as (thermal comfort or thermal acceptability or thermal sensation or temperature preference or comfort temperature or neutral temperature) and (Muscat or Oman). Science Direct, Scopus, Engineering Village (Compendex), and Web of Science (Science citation index) databases were searched. Conference papers and grey literature were excluded owing to the difficulty in searching these sources as well as to avoid duplications because most conference papers are often published in research journals. Besides, an important reason is the usual lack of peer-review of conference papers.

Despite the several studies resulted from this review, the majority were irrelevant. For instance, some studies were about thermal comfort in other countries like (Daneshvar et al., 2013; Al-ajmi, 2010), whereas others discussed renewable energy utilisation in the Gulf countries such as (Bhutto et al., 2014; Alnaser & Alnaser, 2011). Additionally, some studies were about design strategies in Oman and other countries like (Al-Azri et al., 2013a; Al-Sallal, 1998). Nevertheless, three studies were interesting. Two of them (Abdul-Wahab et al., 2015c; Zurigat et al., 2003) are discussed in Section 3.3.6. The third study was conducted with the aim of exploring the comfort range of sleeping environments of Omani people in two hot dry cities, namely Nizwa and Al-Rustaq. Air temperature and relative humidity were measured in four houses and a questionnaire was distributed among 300 subjects. The study revealed that Omani people prefer cold sensations as almost 90% of the participants reported being (cold), (cool), or (neutral) without expressing thermal discomfort. Further research was recommended to support the findings considering the limited sample size (Majid et al., 2014).

Regardless of their importance in thermal comfort studies, there is a relative lack of research regarding thermal scales. Yet, an increasing number of researchers exhibited interest in studying scales in the recent few years. Several aspects of scales were explored in different contexts including investigating the scales assumptions' stability (Schweiker et al., 2017; Pitts, 2006), neutrality and comfort relations (Shahzad et al., 2018; Humphreys, 2008; Pitts, 2006), scales' interpretation (Fuchs et al., 2018; Schakib-Ekbatan et al., 2018; Humphreys, 2008; Pitts, 2006), and scales' influence on the accuracy of thermal comfort results (J. Wang et al., 2018). Some studies compared different thermal scales such as (Koelblen et al., 2017; Lee et al., 2010) and some suggested new scales like (Buratti et al., 2016; Jazizadeh et al., 2013). Moreover, there is almost an absence of research regarding thermal scales in the Arabic context. This lack is combined by variations in the international Arabic version of thermal phrases available in (Parsons, 2014) and those applied in different studies such as (Alwetaishi, 2015; Shohan, 2015; Sufeljen, 2014; Saleh, 2011; Farghal & Wagner, 2008).

The current research attempts to fill the knowledge gap regarding thermal comfort studies in Oman, especially in educational buildings. It, additionally, attempts to investigate thermal scales in Arabic context. Indeed, up to the researcher's level of knowledge, this research is the first attempt to explore Arabic subjects' interpretation of thermal phrases with reference to ASHRAE sensation phrases and it is the first attempt to explore thermal scales behaviour when translated into the Arabic language.

1.2 Research aim and importance

With reference to the research field of thermal comfort, there is a relative lack of studies conducted in educational buildings generally and in high schools specifically. Such studies are important considering the relatively long time students spend in classrooms and the direct effect of thermal comfort on their health and performance (Singh et al., 2018; de Dear et al., 2015; Katafygiotou & Serghides, 2014a). Up to the level of knowledge of the researcher, no studies in this regard were carried out in Omani schools. Hence, the research at hand attempts to take the lead step by aiming to explore the thermal conditions of female students in high school buildings in Muscat city and their perceptions of thermal scales. Thermal sensation and preference scales are an important tool in thermal comfort studies. With the global spread of such studies, the translated scales change their behaviour by deviating from the original assumptions, which negatively affect the results like thermal sensitivity and neutral temperature. Up to the researcher's level of knowledge, this study is the first attempt to investigate the collective understanding of

thermal scales among Arab subjects and the scales' behaviour when translated into the Arabic language.

As mentioned earlier, the subjective nature of thermal comfort requires regional research, which is what the study at hand attempts to achieve. It attempts to feed the pool of thermal comfort research in arid climate generally and in the Arabic region specifically. It, additionally, provides useful data, based on a relatively long-term field work, about thermal comfort conditions in Oman considering the lack of specialised local standards or guidelines. Defining the local limits of thermal acceptability is essential towards reducing the energy consumption and the resulted emissions of GHG (Cao et al., 2016; de Dear et al., 2015).

This thesis presents the findings of the first thermal comfort study in Omani schools up to the researcher's level of knowledge. The previous discussion highlighted the association between energy consumption in Omani buildings and thermal comfort, which justifies the selection of this study focus. Indeed, the associated effects of consuming energy in buildings are among the main derives of thermal comfort research. The task of optimising energy consumption and promoting it in public buildings, especially schools, is crucial taking into consideration the absence of specific ownership. This is the case owing to the high energy demands in such buildings and, thus, high potential for energy savings. Further, the energy conservation message spreads widely to different sectors of the society (Dias Pereira et al., 2014a).

Muscat city was selected for this research due to the high density of population and construction rates compared with other cities in Oman. The latest statistics indicated that the population of Muscat city reached 1,459,249 persons in 2017, which formed around 32% of the total population in Oman. Considering the ages between 5 and 24 years old, Muscat had the second highest population with a minor difference from North Al-Batinah Governorate as plotted in Figure 1.2. However, the population density in Muscat exceeded 360 per km^2 compared to 94 persons per km^2 in North Al-Batinah (NCSI, 2018). It is noteworthy that males' population in Muscat for the same age range was higher than that of females. Yet, the choice of female high schools for the current research is consistent with the conservative nature of the Omani society.

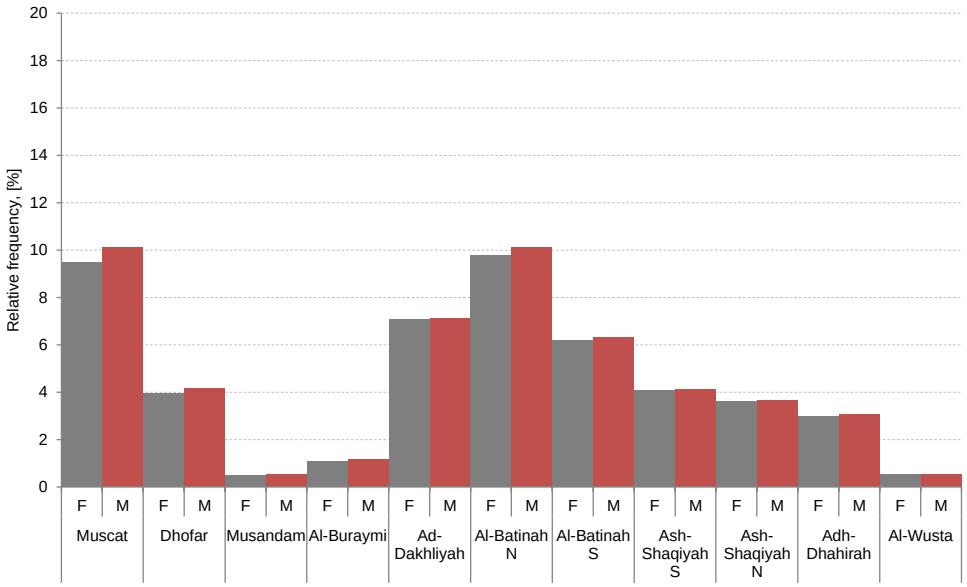


Figure 1.2: Relative frequency of Omani population based on regions for the range (5-24) years old [Reproduced from (NCSI, 2018)**]**

1.3 Research objectives

Five objectives were defined in order to achieve the research aim. These objectives are:

- **To calculate the neutral temperature of the investigated students:**
  The objective variables measured by the sensors besides the subjective votes obtained from the questionnaires will be used to calculate the neutral temperature of the students. Identifying this temperature is important to enhance the students' health and productivity. Additionally, it will assist in calculating the required amount of cooling energy more precisely.

- **To evaluate the current thermal conditions in the explored classrooms:**
  A combination of the physical measurements and the results of the questionnaires will provide an indication of the students' responses to the classrooms' thermal environments. Exploring these responses assists in determining the need for modifying the classrooms' thermal conditions.

- **To investigate the collective understanding of ASHRAE sensation scale among the students:**
  Translating thermal scales may require some manipulation to maintain the expressions associated with the original thermal phrases. In order to enhance this manipulation, one of the

distributed questionnaires explores the students' understanding of ASHRAE thermal sensation scale.

- **To study the behaviour of the translated thermal scales:** Integrating two sensation scales and a preference scale in the distributed questionnaires provides an opportunity to explore the behaviour of the translated scales. Any deviation in the scales' behaviour from their original assumptions affects the results of thermal comfort studies negatively.

- **To explore the consistency of applying different subjective thermal scales:** Applying ASHRAE and Bedford sensation scales on the same participants besides integrating two direct questions regarding comfort level in the questionnaires allow for investigating the differences between the scales and the used measures of comfort. This comparison contributes to the current knowledge regarding thermal scales. Besides, it contributes towards more accurate application of thermal scales and, eventually, more accurate results of thermal comfort studies.

1.4 Research questions

The research at hand attempts to answer the following questions:

- What is the neutral temperature of the investigated students?
- What are the acceptability limits of the investigated students?
- What are the thermal conditions of the investigated students?
- Is there a difference between the satisfaction and comfort for the investigated students?
- What is the influence of the students' sitting location on their thermal comfort and sensation?
- How aware are the students about the availability of adaptive opportunities other than operating air conditioning units?
- Does students' understanding of ASHRAE sensation phrases differ from the original assumptions of the scale?
- What thermal sensations are considered by the investigated students as equivalents to thermal comfort?
- How do the scales change their behaviour when translated into Arabic language?
- Are the translated versions of ASHRAE and Bedford sensation scales equivalent?

Figure 1.3 summarises the relationship between the research aim, objective, and questions.

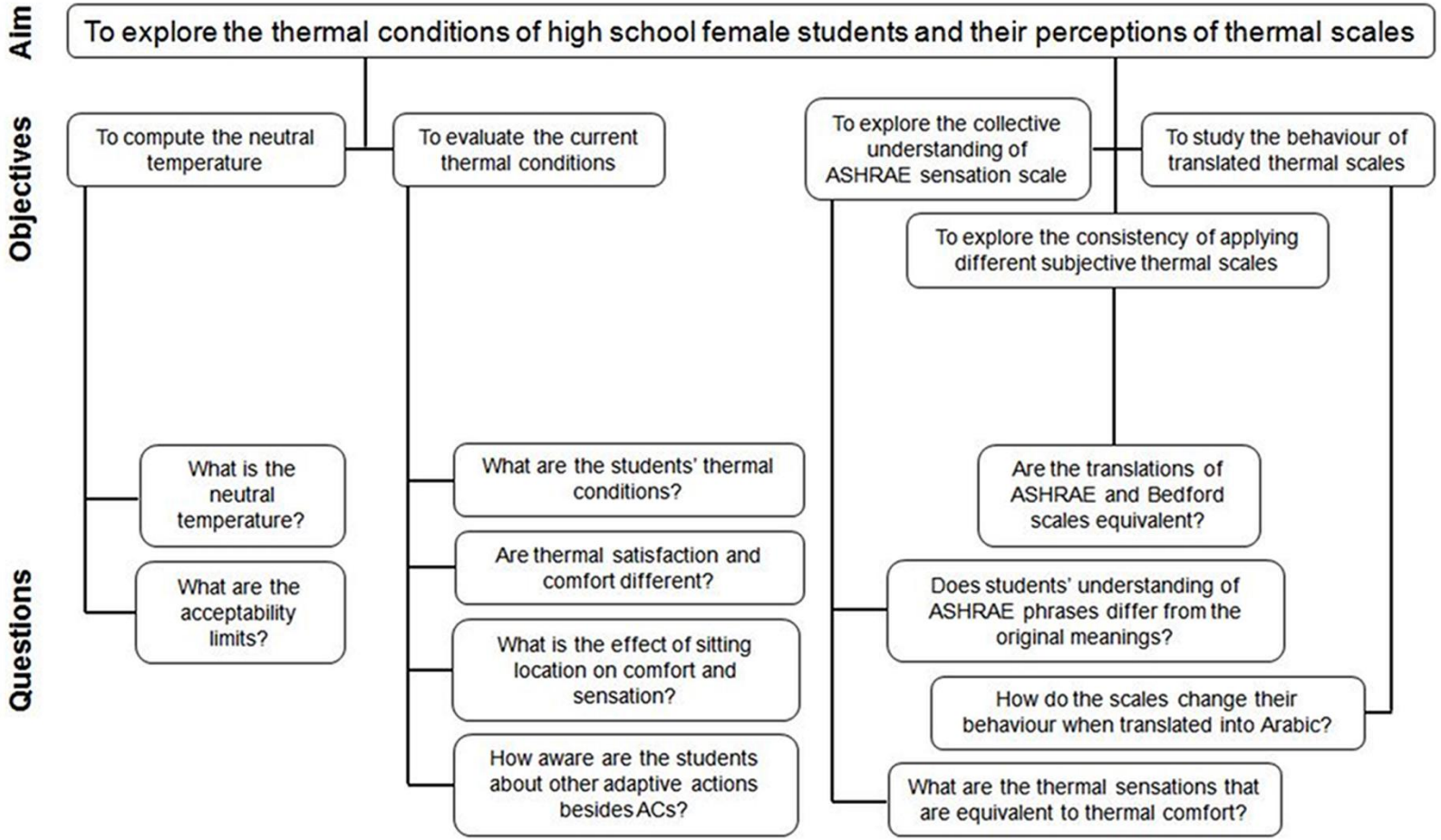


Figure 1.3: The relationship between research's aim, objectives, and questions

1.5 Research methodology

This research adopted a mixed method to achieve the two parts of its aim. A quantitative method was applied in the field study of thermal comfort that collected objective and subjective data from the explored students. The former data were recorded by sensors that measured indoor and outdoor air temperature, globe temperature, air velocity, and relative humidity. The subjective data represented students' responses to the thermal environments of the classrooms and were collected by questionnaires. In specific, the sensation votes of thermal conditions, humidity levels, and air velocity levels were identified by ASHRAE or Bedford thermal scales and the corresponding preferences were specified by Nicol scale. It is noteworthy that modified versions of these scales were adopted for humidity and air velocity levels. Considering the second part of the aim, a qualitative method was adopted to explore the students' collective understanding of the thermal phrases of ASHRAE sensation scale. This understanding was examined against the original assumptions of the scale borrowing quantitative research tools represented in two self-completion questionnaires.

1.6 Contribution to knowledge

Conducting micro-level studies of thermal comfort is essential for enhancing the understanding of the field and, thus, optimising energy consumption in buildings and reducing the related environmental and economic consequences. This thesis presents an investigation of the thermal conditions of Omani female students in high schools' buildings and their perception of thermal scales. It enhances the understanding of thermal comfort in different aspects including contributing to the current knowledge of:

- Thermal comfort in Oman, the Arabic region, and the hot arid climate regions,
- Thermal comfort of female participants,
- Thermal comfort in air-conditioned spaces and in educational buildings,
- Adaptive behaviour in educational buildings,
- The collective understanding of thermal scales among Arab subjects, and
- The behaviour of translated thermal scales

The research findings, besides those of other regional studies, can form a base to establish regional standards of comfort that considers the climatic and social nature of the region. Moreover, the explorations of thermal scales in this thesis provide an example of applying the

successive categories method to understand the behaviour of thermal comfort scales.

1.7 Thesis structure

This thesis consists of ten chapters. In Chapter 1, an overview of the problem that forms the main motivator to conduct this research is presented. Additionally, the research aim, objectives, and questions are presented highlighting the research importance and the knowledge gap it attempts to fill. Besides, the structure of the thesis is presented.

The remaining nine chapters are distributed into three parts as demonstrated in Figure 1.4. These are the literature review and local context part, methodology part, and results and conclusions part. Three chapters are contained in the first part. Chapter 2 starts with a brief discussion of the heat balance equation and it reviews thermal comfort definitions, classification of adaptation processes, and the physical and personal factors that affect thermal comfort including second-order factors like gender. In the last section, the thermal sensation and preference scales are discussed presenting the challenges in applying and translating them with a special focus on translation into the Arabic language.

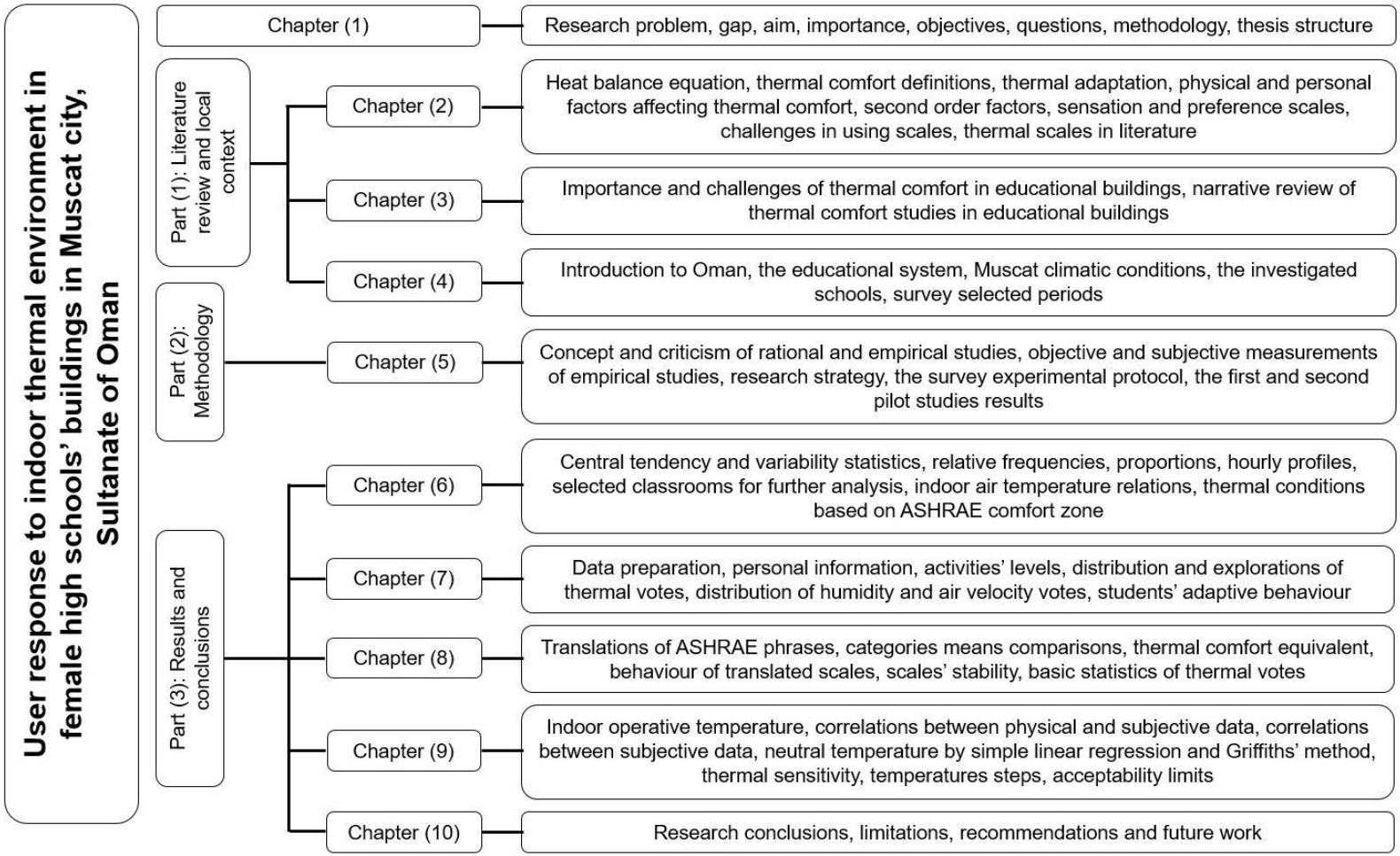


Figure 1.4: The structure of the thesis

Chapter 3 discusses thermal comfort in educational buildings. It starts with a brief presentation of the importance of thermal comfort for students considering its influence on their health and productivity and highlighting the challenges of achieving thermal comfort in educational buildings. The chapter reviews selected studies of thermal comfort in educational buildings attempting to answer some questions regarding their climatic distribution, followed approaches, and findings. The review is classified according to the study level into the kindergarten and primary schools' level, the high schools' level, the universities' level, the mixed studying level, and the unspecified level. A special section presents two studies conducted in Omani educational buildings.

The local context of the research is presented in Chapter 4 that starts with an overview of the Sultanate of Oman and its topography, climatic conditions, social and cultural conditions, and the educational system. Besides, the climatic conditions of Muscat city are discussed in detail presenting air temperature, relative humidity, wind, precipitation, and solar radiation. The investigated schools are presented based on the collected observations during the survey. The chapter is concluded with a brief discussion of the selected periods to conduct the survey.

The second part of the thesis consists of Chapter 5 that starts by classifying thermal comfort studies into rational and empirical studies illustrating their concepts and criticising them. Then, the methodology of the empirical studies and the objective and subjective measurements are reviewed. Considering the former measurements, some of the available sensors in the market are presented and the recommended levels of accuracy are highlighted. For the latter, issues related to questionnaires' design and pre-testing are highlighted besides data preparation for analysis and information extraction. The second section of the chapter focuses on the research strategy and the experimental protocol. In specific, it presents the introductory lecture and the selected sensors with a focus on the selection process and criteria. Moreover, it presents the different questionnaires distributed in the survey and the integrated translations of thermal phrases. This part is concluded by the limitations of the followed methodology and the last part of the chapter presents the outcomes of the two pilot studies.

The third part of the thesis consists of the remaining five chapters. The objective findings of the survey, i.e. the physical measurements, are presented in Chapter 6. Different approaches are implemented in presenting the results like computing central tendency and variability statistics and plotting the relative frequencies, proportions, and hourly profiles of air temperature, globe temperature, air velocity, and relative humidity. Based on that, the explored classrooms with similar thermal

conditions are identified for further analysis. Moreover, the correlations between the measured variables are explored through plotting indoor air temperature against outdoor air temperature, indoor air velocity, and indoor globe temperature. The chapter concludes by comparing the measured thermal conditions with the comfort zone of Muscat city as identified by ASHRAE Standard 55.

The subjective results of the survey are discussed in Chapter 7 starting with a description of data preparation for analysis and the personal information of the students and their activities' levels. The overall levels of satisfaction and comfort are compared and their dependence is investigated by Fisher's exact test. Furthermore, the distributions of subjective sensation and preference votes are plotted and discussed. A special focus on thermal votes is expressed in exploring different methods to determine the percentages of unsatisfied students, the relations between central categories' votes and the levels of satisfaction and comfort, and the preference votes' distribution on sensation categories. Additionally, thermal votes' distribution based on the satisfaction levels, comfort levels, sitting locations, and schools are investigated. The students' adaptive behaviour is explored in the last section highlighting the usage frequency of the available adaptive opportunities, the influence of perceived control, and the usage time of selected actions.

Chapter 8 discusses the findings regarding the thermal scales' interpretation and behaviour in two sections. The first discusses the students' collective understanding of ASHRAE sensation phrases. The findings of two questionnaires are presented highlighting the difference between the Arabic translations provided by the students and the internationally agreed translation. Besides, the sensations' locations on the thermal continuum, as provided by the students, are compared with the original assumptions. The chapter presents comfort equivalents as defined by the students. In the second section, the behaviour of the translated ASHRAE, Bedford, and Nicol thermal scales is explored. The successive categories method is applied to determine the categories' widths, the central categories' shift from the thermal continuum centre, and the categories' symmetry.

The objective and subjective results of the survey are integrated into Chapter 9 that starts by calculating indoor operative temperature and exploring its correlations with indoor air and globe temperatures. In addition, the relations of thermal, humidity, and air velocity sensations and preferences votes with the corresponding physical variables are explored. The effect of thermal sensation on determining humidity and air velocity sensations and preferences is additionally investigated.1

Moreover, the neutral temperature is determined by a simple linear regression and by Griffiths' method. Considering the former method, the students' thermal sensitivity is computed in terms of air, globe, and operative temperatures and it is compared with neutral temperatures of previous studies conducted in a context similar to that of the current research. Besides, the temperatures' steps required to change the mean thermal sensation are computed. Concerns regarding this method are presented and, accordingly, neutral temperatures are recalculated applying Griffiths' method. The chapter is concluded by calculating the limits of thermal acceptability at 80% and 90% levels of satisfaction.

The research is concluded in Chapter 10 by emphasising the most important findings in an attempt to present the answers to the research questions in one context. Research limitations are discussed followed by some recommendations to improve the research as well as some suggestions for future studies. It is worth mentioning that some details and extended data regarding the topics discussed in the previous chapters are attached in the appendices.

1.8 Summary

In this chapter, the importance of establishing thermal comfort studies in Oman was highlighted emphasising the association between these studies and energy consumption for cooling purposes and its consequences. The research aim was discussed in detail identifying the knowledge gap that the research attempts to fill. The aim was broken down into five objectives that were discussed and the research questions were listed. Additionally, the research importance was briefly presented as well as the reasons for selecting Muscat city and the investigated sample of buildings and participants. The research methodology was briefly introduced and the thesis structure was illustrated with a relatively detailed description of the content of the other chapters.

Part (1):

Literature Review and Local Context

Chapter (2):

Thermal Comfort and Thermal Scales

Chapter 2 Thermal comfort and thermal scales

Thermal comfort is centred on maintaining the core temperature of human body constant at approximately 37 °C. People achieve this by regulating their thermal relations with the surroundings, which is known as thermoregulation, via performing several conscious and unconscious processes (Nicol et al., 2012; Koch-Nielsen, 2007). Obviously, failure in doing this has negative consequences, which may justify the interest in thermal comfort from different research fields including architecture, psychology, physiology, physics, and sociology.

The definitions of thermal comfort and adaptation opportunities are reviewed in this chapter preceded with an overview of the heat balance equation. Additionally, the factors that influence thermal comfort are discussed. The discussion is supported, when appropriate, by relatively recent research results. Besides, thermal scales are discussed because of their essential role in thermal comfort studies. The challenges associated with their application, particularly when translated to Arabic, are illustrated. Finally, the chapter is concluded by a discussion of the major approaches of thermal comfort studies.

2.1 Heat balance equation

The human body is in continuous interaction with its surroundings as illustrated in Figure 2.1. This interaction is usually represented by the heat balance equation that is expressed by the Chartered Institution of Building Services Engineers (CIBSE) as (CIBSE, 2015, p. 1.8):

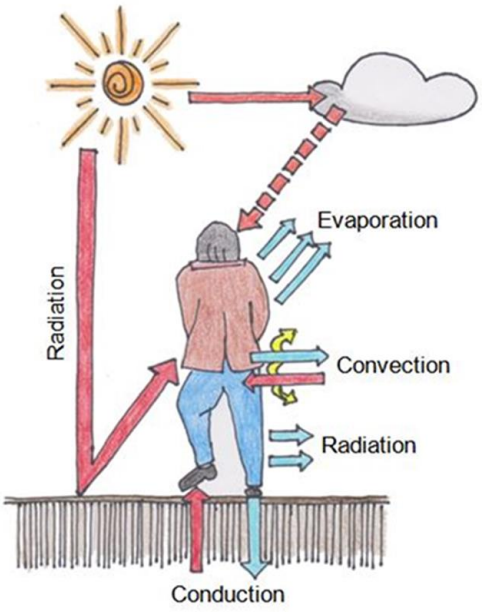


Figure 2.1: Thermal interaction between human body and the surroundings [Reproduced from (Konya & Vandenberg, 2011, p. 28)]

$$\Phi m - \Phi w = \Phi rc + \Phi re + \Phi k + \Phi r + \Phi c + \Phi e + \Phi s \quad (2.1)$$

Where:

Φ_m is metabolic rate per m^2 of body surface, [W]
Φ_w is rate of performance of external work, [W]
Φ_{rc} is heat exchange by convection in respiratory tract, [W]
Φ_{re} is heat exchange by evaporation in respiratory tract, [W]
Φ_k is heat flow by conduction from surface of clothed body, [W]
Φ_r is heat loss by radiation from the surface of clothed body, [W]
Φ_c is heat loss by convection from surface of clothed body, [W]
Φ_e is heat loss by evaporation from surface of clothed body, [W]
Φ_s is body heat storage, [W]

A conceptual form of the equation is (BS EN ISO 11399, 2001, p. 13):

$$M - W = C + R + E + C_{res} + E_{res} + S \quad (2.2)$$

Where:

M is metabolic free energy production per unit body area, [W/m^2]
W is external mechanical work per unit area, [W/m^2]
C is convection heat loss per unit area, [W/m^2]
R is radiative heat loss per unit area, [W/m^2]
E is evaporation heat loss per unit body surface area, [W/m^2]
C_{res} is convective heat loss due to respiration, [W/m^2]
E_{res} is evaporative heat loss due to respiration, [W/m^2]
S is rate of heat storage per unit area, [W/m^2]

In another form, the equation is (Parsons, 2014, p.33):

$$M - W = E + R + C + K + S \quad (2.3)$$

Where:

K is heat transfer by conduction, [W/m^2]

Despite its form, the heat balance equation consists of three major components, namely the heat generated by human body, heat transfer from and to the ambience, and heat storage (Parsons, 2014). Referring to the second component, it occurs through conduction, convection, radiation, and evaporation. Generally, conductive heat transfer has a limited effect that requires human skin to directly contact a surface. The transfer rate is mainly determined by the surface conductivity (Konya & Vandenberg, 2011). The rate of convective heat transfer depends on air velocity, air temperature, skin temperature besides the clothing surface temperature (CIBSE, 2015; Konya & Vandenberg, 2011; Brown, 2010; Brown & Gillespie, 1995). Moreover, radiation heat input is either short-wave from direct sun or long-wave from surrounding objects. The

direction of heat transfer is determined by the difference in temperature of human skin and surrounding objects (Konya & Vandenberg, 2011; Brown & Gillespie, 1995). Correlating negatively with water vapour content in air, evaporation occurs normally at two levels, namely inside lungs and at skin surface (Brown, 2010; Brown & Gillespie, 1995).

2.2 Thermal comfort definitions

Thermal comfort has several definitions, which indicates the notable interest it has received. For instance, ASHRAE definition is 'that condition of mind which expresses satisfaction with the thermal environment and is assessed by subjective evaluation' (ASHRAE, 2017, p. 9.1). In another definition, thermal comfort is 'a state in which there is no driving impulses to correct the environment by behaviour' (Hensen, 1991, p. 2.4). It is, additionally, defined as 'the sensation of well-being of an individual in a specific environment' (Koch-Nielsen, 2007, p. 32).

The previous definitions view thermal comfort as a psychological experience (Höppe, 2002). From a physiological perspective, it is the minimum reaction from the thermal receptors to temperature or its changes. These receptors are distributed in the skin and a part of the brain known as the hypothalamus (Mayer, 1993). Besides, a physical definition of thermal comfort is a condition in which human body is in thermal balance with the ambience provided that metabolic processes keep both skin temperature and sweat rate within comfortable ranges (Fanger, 1972 in Höppe, 2002).

Although some studies distinguish between comfort and neutrality, they are widely considered equivalent. Indeed, the central sensations on ASHRAE scale, and the equivalences on other scales, are assumed to represent thermal comfort (Givoni, 1998). This equivalence may be based on Fanger's definition of comfort as 'a condition where people prefer neither warmer nor cooler' (Fanger, 1972 in Feriadi & Wong, 2004). It is worth mentioning that neutrality is defined as 'that situation in which people describe themselves as neither cool nor warm' (CIBSE, 2015, p. 1.23).

2.3 Thermal adaptation

Thermal adaptation processes involve all actions taken by people to acclimatise themselves to the ambient thermal conditions (Nicol et al., 2012; Nikolopoulou & Steemers, 2003; Brager & de Dear, 1998). Defined by the available adaptive opportunities, these processes affect thermal comfort level (Nikolopoulou et al., 2001). Choosing a certain adaptive action is limited by effectiveness, ease, and related economic consequences (Mishra & Ramgopal, 2013). Like comfort, it is possible

to classify the adaptive processes into psychological, physiological, and physical processes.

Psychological adaptation opportunities have a greater impact on thermal comfort compared to physiological opportunities (Brager & de Dear, 1998). They include the natural appearance of internal spaces, known as naturalness, that increases the probability of accepting wide ranges of thermal conditions. Naturalness is widely achieved by vegetation presence and landscape viewing (Nikolopoulou & Steemers, 2003) and it is related to the expectation of designers' responsibility in creating comfortable indoor environments. Expectation is another psychological adaptive action. It was found that people in mechanically ventilated buildings have less tolerance of temperature variations compared with those in naturally ventilated buildings (Brager & de Dear, 1998). Peoples' expectations are affected by their thermal experiences and usually assist them in accepting ambient conditions via decisions such as consuming cool or hot drinks, changing postures, or changing clothing. In this regard, a Chinese questionnaire explored the effect of thermal history on acceptability and comfort and revealed that adaptation to improved thermal conditions is relatively easy compared with lowering expectation of thermal ambience (Luo et al., 2016a). Another study investigated the influence of participants' thermal history through unifying clothing levels, which encourages psychological and physiological adaptation. Exposure to cool conditions resulted in higher sensitivity as participants maintained a narrow comfort range. The study concluded that the thermal history of cool experiences weakens thermal adaptation (Ning et al., 2016).

Furthermore, exposure time affects thermal perception as people tend to accept uncomfortable environments if they spend short periods in such spaces. This is obvious in outdoor spaces as people generally decide their stay time freely. This decision and other similar decisions such as switching on or off fans or air conditioning units, opening or closing windows, changing posture or clothing level, are part of what is known as the perceived control that positively correlates to accepting thermal conditions (Singh et al., 2011; Nikolopoulou & Steemers, 2003; Nikolopoulou et al., 2001). As noticed, most psychological adaptation mechanisms affect people's perception and, thus, their acceptance of thermal environment through adaptive actions or influencing tolerance.

Physiological adaptation is reached through frequent contact with the sources of thermal stress. Eventually, this frequent contact reduces the sensitivity to that stress. This type of adaptation can take several years in the form of genetic adaptation or a few weeks or days in the form of acclimatisation (Nikolopoulou & Steemers, 2003; Brager & de

Dear, 1998). Another form of physiological adaptation is responding to the thermal demands of human body through blood circulation inside surface vessels. Under a low core temperature, skin heat loss is reduced through contracting vessels to minimise blood circulation. This process is known as vasoconstriction and if it is not sufficient, shivering starts to raise body heat. Oppositely, vasodilatation occurs when the core temperature rises. The blood movement increases as vessels expand to increase the surface heat loss. Additional increases in core temperature produce sweat that evaporates to decrease the core temperature (Nicol et al., 2012; BS EN ISO 11399, 2001).

Besides, physical or behavioural adaptation includes consuming food, closing of opening windows besides changing activity, posture, or clothing (Singh et al., 2011; Nikolopoulou & Steemers, 2003; Brager & de Dear, 1998). This type of adaptation is classified as interactive and reactive. The former involves altering the surrounding environment, whereas the latter deals with personal status alterations (Nikolopoulou & Steemers, 2003).

The availability and utilisation of the adaptive opportunities are partially restricted by the buildings' architectural design in addition to the climatic, social, economic, and organisational conventions (Mishra & Ramgopal, 2013; Peeters et al., 2009). Besides, the adaptive saturation is defined as the limit at which a certain adaptive mechanism is not helpful anymore. It is widely reached with clothing. After a certain limit, altering clothing level to modify sensation is not possible due to social and fashion reasons.

2.4 Factors affecting thermal comfort

Thermal comfort is influenced by several factors like gender, age, health status, body shape, cultural and social backgrounds, thermal expectations and experiences, and even personality type. Besides, it is affected by the opportunities available to modify thermal surroundings such as opening or closing windows, moving towards or far from wind or sun, and changing insulation and activities levels (Hamzah et al., 2018; Szokolay, 2014; Mishra & Ramgopal, 2013; Nicol et al., 2012; Auliciems & Szokolay, 2007; Koch-Nielsen, 2007).

Psychological variables, like expectation, have a major impact on thermal sensation (Höppe, 2002). Indeed, the psychological component is partially responsible for the complexity of thermal comfort because it is, unlike physiological and physical components, immeasurable (Singh et al., 2011; Nikolopoulou & Steemers, 2003). This is consistent with the identification of the six major factors that affect thermal comfort; four of these factors are physical and one is physiological. They are air

temperature, mean radiant temperature, air velocity, water vapour pressure, insulation level, and metabolic level. More details follow below.

2.4.1 Physical factors of thermal comfort

2.4.1.1 Air temperature

Air temperature is defined as ‘the temperature of the air around the human body’ (BS EN ISO 7726, 2001). An alternative definition is ‘the temperature of the air surrounding the human body which is representative of that aspect of the surroundings which determines heat flow between the human body and the air’ (Parsons, 2014, p. 16). It has a strong effect on indoor environments (Szokolay, 2014; Montazami & Nicol, 2013) and, mainly, on convective heat exchange (Givoni, 1998). A strong positive correlation relates thermal comfort and air temperature with a coefficient of around r = 0.939 (Metje et al., 2008). In general, a temperature step of 3 K approximately is required to change the thermal sensation of a sedentary person by one category (Nicol et al., 2012).

Besides, outdoor air temperature is influenced by the ground cover (Konya & Vandenberg, 2011) as the latter defines the reflected amount of solar radiation. It may worth mentioning that the radiation reflected from surfaces like paving, grass, and bare ground can vary from 35% to 20% approximately (Koch-Nielsen, 2007) as illustrated by Figure 2.2.

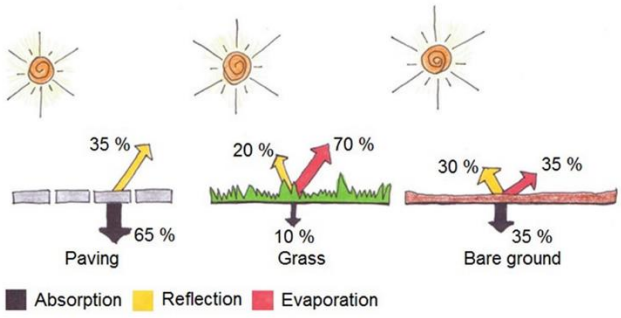


Figure 2.2: Ground cover determines solar radiation available to heat air [Reproduced from (Koch-Nielsen, 2007, p. 25)]

2.4.1.2 Mean radiant temperature

Affecting radiative heat interaction, mean radiant temperature has a significant influence on thermal comfort (Halawa et al., 2014). It is defined as ‘the uniform surface temperature of a radiantly black enclosure in which a small radiantly black sphere would exchange the same amount of radiant heat as in the actual non-uniform space’ (ASHRAE, 2010, p. 3). Another definition is ‘the temperature of a uniform enclosure with which a small black sphere at the test point would have the same radiation exchange as it does with the real

environment' (Parsons, 2014, p. 17). Some definitions replace the black sphere with a person like those of (ASHRAE, 2017) and (CIBSE, 2015).

The radiative impact on thermal comfort is not limited to solar radiation. Inside certain types of buildings, such as commercial centres, lighting lamps have a considerable effect on the employees' thermal comfort. In this regard, a new theoretical model to quantify the influence of lamps radiation was suggested. Comparing model and experimental findings revealed their consistency and, hence, the model usefulness (Arslanoglu & Yigit, 2016). An attempt to explore the influence of solar radiation on thermal comfort of cars' passengers revealed a relatively considerable change in the Predicted Mean Vote (PMV) of 0.5 unit approximately (Moon et al., 2016). Besides, a study exploring students' awareness of thermal comfort found that around 60% were exposed to solar radiation from closed windows. Accordingly, heat complaints were reported by almost 48.3% of the students (Puteh et al., 2012). Another study compared the influence of solar and long-wave radiation from a black body by exposing nine male subjects to three scenarios, namely solar radiation, black body radiation, and combined radiation. It was found that long-wave radiation has a limited effect on comfort and mean skin temperature and, therefore, it can be computed from the current standards (Hodder & Parsons, 2008).

For an accurate estimation of solar radiation effect, it is necessary to determine both the plane and mean radiant temperatures. The former temperature accounts for asymmetrical radiation and its calculation is not essential unless radiation is important in the explored environment (Parsons, 2014; Nicol et al., 2012). Considering the mean radiant temperature, several calculation methods and instruments are available (ASHRAE, 2017). However, it is seldom included in air-conditioning calculations, which may affect thermal comfort demands negatively. The reason is mainly the complicated methods and expensive sensors required for accurate estimations (Halawa et al., 2014). Comparing the performance and accuracy of selected sensors and methods revealed the difficulty of obtaining reliable values in moderate environments despite following the recommendations of the international standards (d'Ambrosio Alfano et al., 2013a). Because of its accountability and affordability, the globe temperature method is widely used to calculate the mean radiant temperature as follows (Nicol et al., 2012, p. 94):

$$T_r = [(T_g + 273)^4 + (1.2 \times 10^8 \, d^{-0.4}) \, v^{0.6} \, (T_g - T_a)]^{0.25} - 273 \qquad (2.4)$$

Where:

T_r is mean radiant temperature, [°C]

T_g is globe temperature, [°C]

d is globe diameter, [m]
v is air velocity, [m/s]
T_a is air temperature, [°C]

Furthermore, replacing the mean radiant temperature by the globe temperature is acceptable, especially in the absence of highly accurate sensors. The globe temperature represents the human body equilibrium under the influence of convective and radiant heat exchanges. Its use avoids inaccurate values of mean radiant temperature and, therefore, of operative temperature that is computed from both air and mean radiant temperatures (ASHRAE, 2017; Nicol et al., 2012).

2.4.1.3 Air velocity

Air velocity is directly related to the convection and evaporation rates from skin. It alters the skin temperature provisionally and changes clothing surface resistance and, thus, increases heat loss (Parsons, 2014; Szokolay, 2014; Uğursal & Culp, 2013a). Its impact on thermal comfort is commonly addressed by its square root and mainly defined by heat transfer direction (Nicol et al., 2012). For instance, the impact of airflow on thermal comfort was strongly negative in an outdoor thermal survey in the United Kingdom (UK) with a correlation coefficient of almost r = -0.933 (Metje et al., 2008). Oppositely, exploring the same impact in warm conditions and under high metabolic rates found that the percentage of unsatisfied people was lower than that predicted by the international standards by almost 75% (Uğursal & Culp, 2013a).

Indoor air movement should be controlled to avoid the negative effect of turbulence that results from fluctuations in air speed and direction. This is of special importance in offices (CIBSE, 2015; Koch-Nielsen, 2007) and similar buildings. Turbulence intensity is the ratio between the standard deviation of air velocity and the mean air velocity (Parsons, 2014). Sensory reactions to air movement are illustrated in Table 2.1. It is noteworthy that although velocities beyond 1.5 m/s are considered annoying, indoor velocities up to 2 m/s are allowable in hot conditions (Szokolay, 2014).

Table 2.1: Subjective reactions to air movement [Reproduced from (Szokolay, 2014, p. 16)]

Air velocity, [m/s]	x < 0.1	0.1 ≤ x < 0.2	0.2 ≤ x < 0.5	0.5 ≤ x < 1.0	1.0 ≤ x < 1.5	1.5 ≤ x
Subjective reaction	Stuffy	Unnoticed	Pleasant	Awareness	Draughty	Annoying

2.4.1.4 Water vapour pressure

Water vapour pressure is the weight of the water component in the atmosphere. Indoor human activities inside buildings contribute to the

water vapour content (Jokl, 2002). Water vapour pressure determines evaporation effectiveness that, in turn, depends on the available content of water vapour at an identical temperature to that of skin compared with the water vapour content in the surrounding space. Except in hot and humid climates, water vapour pressure has generally a limited effect on thermal comfort (CIBSE, 2015; Mishra & Ramgopal, 2015; Szokolay, 2014; Nicol et al., 2012; Konya & Vandenberg, 2011; Brown, 2010).

Relative humidity is widely reported in thermal comfort studies. It is the ratio between the partial pressure of water vapour to the saturated water vapour pressure. Defining its acceptable boundaries is still under research. Yet, some standards suggest 45% and 60% in summer and 30% and 40% in winter (Katafygiotou & Serghides, 2014b). Based on the studies of climate chambers, the influence of high relative humidity on thermal acceptability and sensation was noticeable when combined with high levels of metabolic rates (Fountain et al., 1999). Besides, a strong negative influence was revealed under high air temperature (Jing et al., 2013). Thus, high levels of relative humidity seem to be tolerable provided that other factors are within the comfort zone. It is noteworthy that water vapour pressure is computed from relative humidity as follows (Nicol et al., 2012, p. 98):

$$P_{as} = 0.611 \exp [17.27\ T_a / (T_a + 273)] \quad (2.5)$$

$$P_a = P_{as}\ RH/100 \quad (2.6)$$

Where:

P_{as} is saturated water vapour pressure, [kPa]
T_a is air temperature, [°C]
P_a is water vapour pressure, [kPa]
RH is relative humidity, [%]

As noted from these equations, water vapour pressure is related to air temperature and, therefore, solar radiation. Indeed, air temperature determines, in nonlinear relation, the maximum amount of water vapour hold in the air. Additionally, the saturated water vapour pressure at a certain temperature is the pressure of maximum amount of water vapour that the atmosphere can hold at that temperature (Szokolay, 2014; Nicol et al., 2012; Konya & Vandenberg, 2011; Brown, 2010).

2.4.2 Personal factors of thermal comfort

2.4.2.1 Clothing level

The clothing level of a certain ensemble is the total effect of the different pieces that are assumed to distribute uniformly over the human

body. It is estimated in (clo) unit that represents the required insulation to achieve comfort for a seated person at 21 °C. Generally, an official business suit, a shirt, and an underwear are used to represent 1 clo that is equal to almost 0.155 m^2K/W or a U-value of almost 6.45 W/m^2K (CIBSE, 2015; Szokolay, 2014; Nicol et al., 2012).

Clothing adjustments are responsible for tolerating wide ranges of temperature extending between 18 °C and 27 °C (Parsons, 2002) and they affect the convective, evaporative, and radiative heat interactions. Taking convection into account, the looseness of traditional Arabic clothing in hot climates, for instance, allows for heat loss by air movement that increases convection rates as illustrated in Figure 2.3. Besides, evaporative heat loss occurs at clothing level as clothing absorbs moisture from the skin, which means that another evaporative heat loss can occur at skin level. Considering radiation, clothing forms a layer that insulates the body from heat gain or loss in hot or cold climates respectively. It is worth to mention that the effectiveness of these mechanisms depends on the temperature difference between body and air (Nicol et al., 2012; Al-ajmi et al., 2008; Koch-Nielsen, 2007).

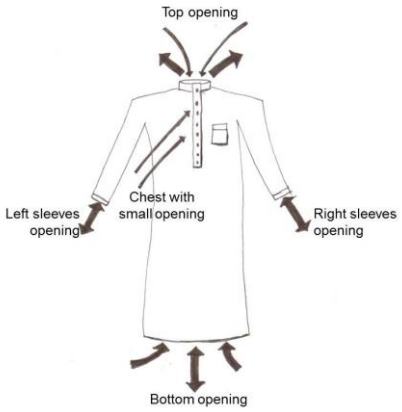


Figure 2.3: Loose clothing allows for heat loss through air movement [Reproduced from (Al-ajmi et al., 2008)]

Clothing selection is determined by climatic, social, and cultural factors. In this regard, the effects of outdoor, operative, and weighted mean ambient temperatures on clothing levels of kindergartens children were explored to reveal a strong influence of the operative temperature (Nam et al., 2015). Besides, it is important to calculate the clothing area factors of non-Western ensembles as differences of around 3%-29% resulted when comparing the predictions of an equation adopted by the international standards with the findings of advanced methods. Clothing area factor is the ratio of surface area of a clothed person to that of a nude one. It should be mentioned that the effect of these variations on thermal insulation values was minor (Al-ajmi et al., 2008).

It is noteworthy that an additional value should be added to the clothing insulation of seated people to account for chairs' effect. In addition, the air layers trapped between clothing layers and those close to the skin are assumed to contribute to the total clothing insulation. However, a full understanding of the contribution of this air layer is not available, which results in errors of around ±20%. These errors affect the calculations of PMV and similar indices considerably (Nicol et al., 2012; BS EN ISO 11399, 2001) and they mainly resulted from the static procedure used to compute the tabulated data of insulation levels as it ignores the influence of body and air movement (Havenith et al., 2002).

2.4.2.2 Metabolic rate

Metabolic rate is defined as 'the rate of transformation of chemical energy into heat and mechanical work by metabolic activities within an organism, usually expressed in terms of unit area of the total body surface' (ASHRAE, 2010, p. 3). It is a heat gain mechanism expressed in (met) units where 1 met is equivalent to 58.2 W/m^2 and represented by the heat emitted by a seated person at rest (CIBSE, 2015; Szokolay, 2014; Nicol et al., 2012). In thermal comfort studies, it is recommended to record previous activities prior to at least 15 minutes as the effect of some activities may continue for almost one hour after finishing the activity (Nicol et al., 2012; ASHRAE, 2010). An investigation of comfort sensitivity to physical and personal factors concluded that metabolic rate and clothing level have a considerable effect. Moreover, simple, and even only mental tasks, may cause changes in metabolic rate that affect comfort negatively (Hasan et al., 2016).

Wrong estimations of metabolic rates may result in errors of 50% approximately, especially for unusual activities (CIBSE, 2015). Indeed, the inaccurate estimations of metabolic rate are generally considered as the main reason for the inaccurate predictions of the PMV model (Luo, Zhou, et al., 2016b). In this regard, a relatively recent study proposed a correction coefficient to improve the tabulated data accuracy (Broday et al., 2014). Although the study focused on a certain type of activities, following their methodology may result in correction coefficients for other activity levels. The inaccuracy of metabolic tabulated estimations is mainly owing to their ignorance of the individual variations between people. These variations result from the differences in performance method, adaptation, and exposure time to the environment in which activities are carried on. This inaccuracy was proven by comparing correlations between actual thermal votes and PMV when the metabolic rate was measured by a metabolic analyser, calculated by equations, and estimated from tables (Broday et al., 2014). Unfortunately, accurate

estimations of metabolic rate require methods that may be impractical in real conditions (Havenith et al., 2002).

Traditionally, metabolic rate was considered as a constant that depends mainly on activity level. However, a recent study revealed its increase in response to air temperature deviations from neutrality under a constant clothing level. An increase of around 16% is required to compensate for a drop in air temperature of 10 °C (Luo et al., 2016b). In another study, the metabolic rate fluctuations under varying physical variables were explored. The findings revealed that thermal comfort is maintained for a metabolic rate level of 1.22 met under 29 °C air temperature and 40% relative humidity. Moreover, it was revealed that air temperature has a negative linear effect on metabolic rate followed by relative humidity and air velocity respectively. The latter exhibits a positive correlation. Additionally, raising air temperature beyond 24 °C restricts metabolic rate fluctuations (Yang et al., 2016).

2.4.3 Second order factors

Besides the factors discussed above, thermal comfort is affected by other factors including daily climatic fluctuations, adaptation level, age, gender (ASHRAE, 2017), health status (Tham & Fadeyi, 2015), and body shape (Nicol et al., 2012). For instance, heavy people can tolerate cold conditions better compared with light people (Nicol et al., 2012). Considering health status, fulfilling the thermal requirements of asthmatic people guarantees satisfying those of non-asthmatic people as the former group exhibit higher thermal sensitivity towards low air temperatures (Tham & Fadeyi, 2015). Additionally, it is predicted that elevating temperature by one unit may result in increasing the outbreak of meningitis and measles diseases by 6 and 19 persons respectively (Sawa & Buhari, 2011). Besides, age has an effect on thermal comfort preferences. Compared with adults, children prefer lower comfort temperature and narrower comfort range by 3.3 °C and 0.5 °C roughly in winter and summer respectively. This is mainly due to their higher metabolic rates per unit weight. In general, children are less satisfied with their surroundings possibly owing to the lack of awareness and control of adaptive opportunities (Nam et al., 2015).

2.4.3.1 Gender

Several studies investigated the differences in thermal comfort requirements based on subjects' gender. On one hand, standards view these variations as marginal referring to studies like those of Fanger (1982), Fanger and Langkilde (1975), and Nevins and others (1966). According to these studies, females balance their lower metabolic rate by lower skin temperature and lower evaporative loss. In general,

females' preference for higher ambient temperatures is justified by their relatively lower clothing level (ASHRAE, 2017; CIBSE, 2015). Besides, a study performed in a primary school revealed that both girls and boys had similar thermal sensations despite their different clothing levels. It is thought that girls used certain mechanisms to tolerate cool conditions (Humphreys, 1977).

On the other hand, the thermal sensations of sixteen males and sixteen females were explored under identical clothing levels, metabolic rates, and environmental conditions. Despite the similarity in thermal demands of both genders, it was noted that male participants tolerated cool conditions better. The sensitivity of female participants may be due to their general sensitive nature (Parsons, 2002). This sensitivity was confirmed in other studies that revealed females' sensitivity to cold conditions and males' sensitivity to hot conditions (Nam et al., 2015; Katafygiotou & Serghides, 2014a; Schellen et al., 2013; Karjalainen, 2007). The neutral temperature of Chinese females was higher by around 1 °C although their clothing levels were higher (Wang, 2006a). In addition, females are affected by the skin temperature of extremities like hands, upper arms, and forearms (Schellen et al., 2013) and their votes change with a slower rate per temperature change compared with males. This low sensitivity is justified by the behavioural actions taken by females like clothing change concurrently with temperature change (Yan & Yang, 2014). In general, females are more critical regarding the quality of indoor thermal conditions. Hence, satisfying them thermally would, in general, cover males' thermal requirements (Kim et al., 2013; Karjalainen, 2012).

Possible reasons for the different thermal comfort requirements between genders include variations in psychological sensitivity, different ratio of body surface area to mass, and cultural differences including awareness of clothing role (Parsons, 2002). Indeed, cultural differences were responsible for females' neutrality in a survey conducted in Indian apartments; they had better control over their surroundings as they spend a relatively long time at home (Indraganti & Rao, 2010). It is obvious that understanding thermal comfort variations among genders require more investigations. For a comprehensive appreciation of these variations, it is crucial to view the results considering the social, cultural, and physiological factors (Messing & Stellman, 2006).

2.5 Thermal scales and application challenges

2.5.1 Thermal sensation scales

The sensitivity to thermal conditions is known as thermal sensation and it is generally considered as a determination of thermal comfort

(Givoni et al., 2003). As a psychological experience, thermal sensation is related to people's feelings about their surroundings (Parsons, 2014) and it is affected by their thermal experiences and expectations (Höppe, 2002). Voting a thermal sensation requires people to feel, evaluate, and express their thermal states using thermal scales. It is possible to consider these word-based scales as numerical measures of subjective experience because the thermal votes obtained from the distributed questionnaires are usually expressed in numerical form for analysis purposes.

Among several sensation scales found in the literature (Schweiker et al., 2017; Lee et al., 2010), ASHRAE and Bedford scales are widely used. Both scales consist of seven categories that are usually converted during analysis into a numerical range from (-3) to (+3) as displayed in Table 2.2. Most studies use seven categories scales because of their international acceptance that facilitates comparing the results. However, few exceptions like (Metje et al., 2008; Nikolopoulou et al., 2004) used five categories scales. Some standards encourage using nine categories, by adding (very cold) and (very hot) categories to ASHRAE sensation scale for instance, even in moderate environments (Schweiker et al., 2017).

Table 2.2: ASHRAE and Bedford thermal sensation scales

	-3	-2	-1	0	+1	+2	+3
ASHRAE	Cold	Cool	Slightly cool	Neutral	Slightly warm	Warm	Hot
Bedford	Much too cool	Too cool	Comfortably cool	Comfortable neither warm nor cool	Comfortably warm	Too warm	Much too warm

2.5.2 Thermal preference scales

Mainly owing to cultural and climatic reasons, thermal preferences often deviate from neutrality (Humphreys & Hancock, 2007; Pitts, 2006). Consequently, preference scales are introduced to clarify this deviation (Nicol et al., 2012). Table 2.3 displays McIntyre and Nicol scales that are widely used to report thermal preferences. Sometimes, ASHRAE sensation scale with a modified question is used to evaluate thermal preferences. Compared with McIntyre, scales that have more than three categories are preferred owing to the frequent absences of votes in end categories, which may affect the findings negatively (Humphreys et al., 2016; Feriadi & Wong, 2004). Furthermore, thermal preference scales are more complicated compared with sensation scales; participants need to evaluate their current thermal state first and then determine the preferred state, which may lead to confused answers (Humphreys et al., 2016).

Table 2.3: McIntyre and Nicol thermal preference scales

	-2	-1	0	+1	+2
McIntyre	-	Warmer	No change	Cooler	-
Nicol	Much warmer	A bit warmer	No change	A bit cooler	Much cooler

2.5.3 Challenges in applying and translating thermal scales

In spite of the continuous implementation of thermal scales, there are some challenges in applying them. These challenges may be classified into those related to scales in their English or original form and those related to the translated versions. The reasons for these challenges include the difference between neutrality and comfort, the influence of the climatic and cultural background, and participants' difference in realising thermal sensations and their distribution on the thermal continuum (Pitts, 2006). Other reasons include the variations that result from translation. Translating thermal scales has a positive impact on the participation rate as it adapts scales to the local context (Mishra & Ramgopal, 2013; Singh et al., 2011). However, deviations from the original English scales exist due to the absence of equivalent sensations in the translated languages or the differences in the impressions associated with these sensations (Humphreys, 2008).

Examples of such challenges include the statistical evidence on the different interpretations of ASHRAE sensation scale (Humphreys & Hancock, 2007). Another is the use of a numerical system to describe a psychological experience (Nicol et al., 2012). Some studies attempt to overcome this via using continuous scales like (de Dear et al., 2015). According to McIntyre cited in (Schweiker et al., 2017), employing continuous scales may reflect accurate sensations, especially under slight or slow variations of temperature. However, such scales may be impractical, introduce errors (Nicol et al., 2012), and reduce the results' accuracy (J. Wang et al., 2018).

The exchangeable use of ASHRAE and Bedford scales is widely accepted although the former scale assumes that thermal comfort is equivalent to any sensation from the central categories (i.e. slightly cool, neutral, and slightly warm), whereas the latter integrates (comfort) in its categories. The inequality between neutrality and comfort was statistically proven in a study that requested the subjects to identify thermal comfort along ASHRAE scale. The findings indicated that neutrality was cooler than comfort for the involved participants. It is noteworthy that the study was conducted in winter with a majority of English participants (Pitts, 2006). Besides, some studies highlighted few discrepancies in the exchangeable use of ASHRAE and Bedford scales (Mishra & Ramgopal, 2013; Wong & Khoo, 2003; Wong et al., 2002). For instance, accepting thermal surroundings was higher by around

20% using Bedford scale compared with ASHRAE in a study that took place in a high school in Singapore. In this study, thermal acceptability and the votes in the central categories were assumed to be equivalent (Wong & Khoo, 2003). However, scales' difference may be due to their use in that study as ASHRAE scale was applied to evaluate ambience temperature and Bedford scale was applied to evaluate thermal sensation. In another study that compared Indonesian translations of both scales, variations in votes' distribution were revealed. In specific, ASHRAE votes distributed relatively evenly, whereas Bedford votes clustered in central categories. Accordingly, the researchers concluded that ASHRAE scale had a better behaviour (Feriadi & Wong, 2004), which may justify the use of ASHRAE data in their analysis. However, applying successive categories method indicated that Bedford scale behaved better (Humphreys et al., 2016) and, thus, computing neutral temperature using its data may lead to conclusions with higher accuracy. Further, a similar clustering of thermal votes using Bedford scale in the central categories compared with ASHRAE scale was reported in (Hamzah et al., 2018).

The clustering behaviour of Bedford votes may reflect a lack of sensitivity (Lee et al., 2010) and the reasons for this distribution pattern are not clearly known. It may be due to people variation about thermal ambience perception or thermal scales interpretation (Schweiker et al., 2017). Another possible reason is the integration of (comfort) in the central categories; usually, people tend to keep themselves thermally comfortable as indicated by the adaptive principle.

Considering the challenges associated with translation, translated thermal scales deviate from the assumptions of the English scales and, consequently, change their behaviour. Examples of these deviations include the divergence of the middle category centre from (zero), unequal width of categories, and asymmetrical categories. Such changes were reported when translating ASHRAE and Nicol scales into French, Swedish, Portuguese, and Greek languages (Humphreys et al., 2016; Humphreys, 2008). Similar changes in scales' behaviour were revealed in a study that translated both scales into Japanese and compared their behaviour with a Japanese scale (Humphreys et al., 2016; Rijal et al., 2014).

It should be mentioned that these variations in scales' behaviour are not attributed to translation effect solely. Climatic background and acclimatisation can be considered as other contributors (Humphreys et al., 2016). In this regard, a recent study explored the climatic effect on thermal responses and terms of Bangladeshi and Japanese subjects. A translated version of ASHRAE 11-points scale was integrated in the

distributed questionnaire besides imaginary thermal scenarios at which participants should describe their sensations. Significant variations in thermal sensations were reported, which emphasises the impact of the climatic background (Khatun et al., 2017).

In general, comparing the behaviour of thermal scales includes making assumptions regarding subjects' responses or conditions. For instance, some studies assumed that different participants, answering questionnaires with different scales, have almost similar responses under identical conditions like (Lee et al., 2010). Other attempts like (Wong & Khoo, 2003) involved distributing a questionnaire with more than one thermal sensation scale to the same subjects. Theoretically, neither approach is correct owing to participants' change in the former study and the time lag in the latter. Besides, distributing more than one sensation scale within the same questionnaire increases the risk of participants' boredom due to questions repetition.

2.5.3.1 Challenges in translating thermal scales into Arabic language

An internationally agreed translation of ASHRAE sensation scale to the Arabic Language is available (Parsons, 2014). However, the methodology of formulating this translation is not clear nor the dialect it considers. A comparison of this version with other translations of the ASHRAE scale as used in recent studies is displayed in Table 2.4. The translations agreed with the international version in two phrases except (Shohan, 2015) and (Sufeljen, 2014); the respective agreement was in three and one phrases. It should be mentioned that two Arabic terms were provided for (warm) and (hot) in (Shohan, 2015), whereas the translations of (slightly warm) and (warm) were exchanged in (Sufeljen, 2014). Besides, the head question of these studies, except (Sufeljen, 2014), requested the subjects to evaluate their ambience or comfort.

Table 2.4: Different Arabic translations of ASHRAE thermal sensation phrases

ASHRAE phrases	Cold	Cool	Slightly cool	Neutral	Slightly warm	Warm	Hot
International translation	شديد البرودة	بارد	خفيف البرودة	طبيعي	خفيف الحرارة	حار	شديد الحرارة
(Alwetaishi, 2015)	بارد جدا	بارد	بارد بعض الشيء	مرتاح	دافئ	حار	حار جدا
(Shohan, 2015)	شديدة البرودة	باردة	مائلة للبرودة قليلا	مريحة	مائلة للدفء قليلا	ساخنة أو حارة	ساخنة أو حارة جدا
(Sufeljen, 2014)	بارد جدا	بارد	بارد قليلا	معتدل	ساخن	ساخن قليلا	ساخن جدا
(Saleh, 2011)	بارد جدا	بارد	بارد قليلا	مريح	حار قليلا	حار	حار جدا
(Farghal & Wagner, 2008)	بارد جدا	بارد	بارد بعض الشيء	معتدلة	حار بعض الشيء	حار	حار جدا

Besides, the translations in Table 2.4, including the international version, used the Arabic meaning of (hot) as an equivalent to (warm) and, consequently, replaced (hot) by (very hot). Therefore, the thermal continuum ranges covered by these translations are different from that of ASHRAE scale. The reason may be to convey a negative impression as the Arabic meaning of (warm) can be considered as a desirable sensation, especially in winter. In other words, maintaining the literal translation of (warm) may lead to a positive impression outside the widely accepted range of comfort (i.e. slightly cool to slightly warm). In this regard, it should be mentioned that the Arabic literal translation of (warm) was used as an equivalent to (slightly warm) sensation in (Alwetaishi, 2015) study.

Considering the cold side, the range between (cold) and (cool) is often described by one phrase possibly reflecting the influence of the warm climatic conditions dominant in the Arabic region. Consequently, (cold) was replaced by (very cold) in Table 2.4 translations. Besides, the currently used phrase for (cool) is often a desirable sensation in some Arabic countries, including Oman, especially in summer. It is obvious that these translations do not convey the impressions of the original English phrases outside the comfort range. Yet, it should be highlighted that this range is assumed and, thus, further investigations are recommended (Humphreys et al., 2016), particularly in the Arabic region. Similar manipulation was applied to the warm side phrases in the French, Greek, and Portuguese languages in the Smart Controls and Thermal Comfort (SCATs) project (Humphreys, 2008).

Besides, ASHRAE scale, in its seventh categories form, is mainly applicable in thermally moderate environments. For extreme conditions, (very cold) and (very hot) categories are added (Humphreys et al., 2016). Hence, considering Table 2.4 translations as equivalent to the English phrases of ASHRAE scale may be doubtful, despite their attempts to convey similar impressions.

2.5.4 Thermal scales in literature

In general, there are few studies concerned with thermal scales (Fuchs et al., 2018) despite their wide application in thermal comfort studies. Reviewing the literature revealed recent investigations about different aspects of thermal scales including people interpretation of thermal scales (Fuchs et al., 2018; Schakib-Ekbatan et al., 2018; Humphreys, 2008; Pitts, 2006), examining the scales' assumptions (Schweiker et al., 2017; Pitts, 2006), the relationship between comfort and neutrality (Shahzad et al., 2018; Humphreys, 2008; Pitts, 2006), uncertainty of thermal comfort measurements related to thermal scales

and survey protocol (J. Wang et al., 2018), comparing different thermal scales (Koelblen et al., 2017; Lee et al., 2010), and proposing new scales (Buratti et al., 2016; Jazizadeh et al., 2013). As noted, most studies were published during the last year.

People vary in their interpretation of thermal scales, which was noted in studies like (Schweiker et al., 2017; Pitts, 2006). These variations include the differentiation between phrases, identification of the phrases' positions and distances, and the concepts associated with each sensation. From a statistical point of view, people's variations in identifying the positions of and the distances between ASHRAE sensation phrases were not random. This implies that comfort is not necessarily related to the three central thermal sensations as widely assumed. Interestingly, grouping participants based on these variations can increase the prediction accuracy of thermal comfort models (Fuchs et al., 2018). In this regard, the generalisation of thermal votes was questioned based on the different conceptions and experiences associated with the sensation phrases of ASHRAE scale (Schakib-Ekbatan et al., 2018).

Regarding the scales' assumptions, it was revealed that the assumptions of equal categories' widths and comfort range may not be valid and the used scale type (ordinal or continuous) affects survey results. This implies that temperature steps, which are the temperature changes required to move by one thermal sensation, are not necessarily uniform (Schweiker et al., 2017). However, these findings may require further examination considering the sample size of the experiment.

Besides, the degree of which thermal neutrality can be considered as an indication of thermal comfort was investigated by a recent study conducted in Norwegian and British offices. The study highlighted that ASHRAE definition of thermal comfort does not refer to neutrality; yet, several studies of thermal comfort considered them as equivalents. The results confirm the difference between comfort and neutrality as around 36% and 60% of the participants in the questionnaires and interviews respectively wanted different sensations than neutrality (Shahzad et al., 2018), which was highlighted in other studies (Humphreys, 2008; Pitts, 2006).

Moreover, the effect of survey protocol, including the number of subjects and the number of votes per subject, and questionnaire characteristics, including scale type (continuous or discrete) and categories' number, on the intra-individual and subjective measurement uncertainty was investigated. The intra-individual variation refers to the

change in the one participant votes under similar thermal conditions. It is advised to use discrete thermal scales of no more than 7-points to reduce the intra-individual variations. Increasing the number of votes per person has a positive influence on decreasing the subjective measurement uncertainty and a recommended number is 40 votes per person (J. Wang et al., 2018).

Some researchers investigated the assumption of equivalence between the different thermal scales (Koelblen et al., 2017; Lee et al., 2010). The former study highlighted the absence of a well-established base to compare thermal sensation scales. The researchers suggested considering the scales with an equal number of categories equivalent although they differ in the associated phrases. Besides, they suggested unifying the length of scales with different categories number by categories' redistribution (Koelblen et al., 2017). Obviously, this attempt involves changing the original widths of categories besides assuming equality between extreme sensations. It is worth to mention that such equality lacks evidence. Moreover, exploring scales' behaviour, by applying the successive categories method, may reveal some variations in the scales' behaviour despite their equal number of categories. In another study, the application of a categorical scale, a visual analogue scale, and a combined scale with visual analogue and categorical features was explored by integrating them in a questionnaire besides an accompanied experiment. The scales were translated into Korean and Japanese languages to suit participants' mother tongues. It was found that verbal scales expressed thermal sensations more precisely and exhibited higher correlations with indoor air temperature compared with visual scales (Lee et al., 2010).

Furthermore, ASHRAE seven categories scale was compared with a thirteen categories scale that had 0.5 category width. The comparison revealed a statistically significant difference between scales as the new scale exhibited better efficiency. The efficiency was determined by comparing the percentage of participants with (neutral) sensation and (no change) preference in both scales. Based on its lower percentage, the new scale was considered more accurate (Buratti et al., 2016). Its finer categories resulted in an accurate reporting of sensations and, thus, a better understanding of participants' thermal conditions. Yet, exploring the practicality of the new scale is recommended as the number of categories may affect response rate negatively. In general, it is thought that increasing scales categories beyond seven does not improve their precision (Nicol et al., 2012). Additionally, an application was designed to collect users' thermal preference votes promptly using their smartphones or computers. The integrated scale implemented

ASHRAE phrases except (slight cool) and (slightly warm). The results indicated the application success in fulfilling its purpose. Additionally, the accompanied field study revealed that preference votes were mostly influenced by the ambient temperature (Jazizadeh et al., 2013). It is worth mentioning that exploring the properties of the used scale was out of scope in that study.

2.6 Conclusion

Thermal comfort, as a multidisciplinary topic, has received wide interest from many researchers with different specialities. This has been reflected in its several definitions presented in this chapter including psychological, physical, and physiological definitions. Likewise, thermal adaptation opportunities have different forms including psychological opportunities that have an important influence on thermal comfort.

The effects of air and mean radiant temperatures, air velocity, and water vapour pressure besides clothing and activity levels on thermal comfort are well recognised in the literature. However, they differ in their influence amount. For instance, it is convenient to replace the mean radiant temperature by globe temperature, especially in the absence of high accuracy sensors. Likewise, the effect of water vapour pressure on comfort is comparatively limited except in hot humid environments. In addition, thermal comfort is affected by other secondary factors. For instance, considering gender's impact in this chapter revealed the vague role it has. Unlike earlier studies of thermal comfort, more recent studies reported different thermal sensations for female and male participants despite their relatively equal insulation levels. Therefore, additional studies are necessary for a better understanding of gender role in formulating thermal sensation and comfort.

Besides, the overview of thermal sensation and preference scales discussed in this chapter highlighted some challenges associated with their application. To investigate the effect of translation, some scales used in a selected sample of Arabic studies were examined. Their variation from the international version was revealed. This version, itself, is questioned because its formation and the dialect it considers are not obvious. Moreover, the investigated translations, including the international version, covered different ranges on the thermal continuum compared with the original ASHRAE scale. They, additionally, may convey some positive impressions outside the assumed comfort range. This may suggest developing Arabic thermal sensation scales or, at least, modify the current translations of ASHRAE scale. A suggested approach is to request the participants to list and classify all possible words that are used to describe thermal sensations. Additionally, further

investigations are required to explore the impact of using new phrases. For instance, phrases that are literally translated as (cool and not acceptable) and (warm and not acceptable) may be used instead of (cool) and (warm) to avoid possible desirable impressions outside the comfort range.

Chapter (3):

Thermal Comfort in Educational Buildings

Chapter 3 Thermal comfort in educational buildings

The topic of thermal comfort in educational buildings has received wide attention from many researchers around the world, especially in the last few years. Different aspects of the thermal environment in educational buildings were studied including its impact on students' performance, the efficiency of different ventilation systems, and the challenges of achieving thermal comfort in educational spaces. This attention reflects the importance of satisfying thermal comfort demands in classrooms and its association with students' performance and health. Yet, it should be mentioned that few review papers discussing this topic were published, which may indicate the relatively small amount of research in classrooms.

In this chapter, a narrative review conducted by the researcher is presented discussing some issues related to the climatic distribution of thermal comfort studies in educational buildings, their methodologies, results' presentation, students' adaptive behaviour, and thermal scales' behaviour. A special focus is given to the studies that investigated thermal comfort in educational buildings in Oman. The discussion of the narrative review is preceded by a brief presentation regarding the importance of achieving thermal comfort in educational buildings and the accompanying challenges.

3.1 Importance of thermal comfort in educational buildings

The impact of indoor environment on occupants' productivity and health has received continuous attention from many researchers. This is because people spend more than 90% of their time inside buildings. For students, the estimated time spent inside schools is around 30% (De Giuli et al., 2012). The influence of schools' indoor conditions is not limited to the students only; rather it is extended to the whole society in both short and long terms (Pistore et al., 2015; Mendell & Heath, 2005).

In this regard, a literature review was carried out to investigate the effect of schools' environments on students' performance. The review focused on the influence of heating, ventilation, and air conditioning (HVAC) system, indoor pollutants, building characteristics, and thermal conditions on attendance rates and performance levels. The findings revealed a positive impact of inadequate ventilation level and nitrogen dioxide level on absenteeism rates and weak performance respectively (Mendell & Heath, 2005).

Several studies related improper conditions of classrooms to health symptoms like headache, lack of concentration, and breathing

difficulties. Such symptoms affect learning abilities negatively (Ferreira & Cardoso, 2014; Montazami & Nicol, 2013; Puteh et al., 2012; Wong & Khoo, 2003). The classrooms' occupation rates were positively related to carbon dioxide (CO_2) concentrations and, thus, to health problems (Ferreira & Cardoso, 2014). Indeed, ventilation rate is negatively related to students' density and mean indoor air temperature. Besides, the performance of primary schools' students, especially in mathematics, was affected by ventilation rate (Toyinbo et al., 2016). This association between ventilation rate and performance in mathematics and reading tests was revealed in a study that suggested a combination of adequate air conditioning, ventilation, heating, and surface cleaning to enhance students' health and performance (Haverinen-Shaughnessy et al., 2015).

Moreover, the impact of HVAC system on students' performance was investigated in six classrooms in Denmark. The classrooms were mechanically ventilated and windows' opening was not restricted. It was found that decreasing indoor air temperature by 1 °C and doubling the rate of fresh air supply increased the performance level by 2% and 8% respectively (Wargocki & Wyon, 2006).

3.2 Challenges of thermal comfort in educational buildings

Despite its importance, achieving thermally comfortable conditions in educational buildings, especially schools, is associated with specific challenges that are related to the students or to the buildings. Examples of the challenges related to students include overcrowding and general restrictions on clothing and activity levels (Issa et al., 2011; Corgnati et al., 2009; Wargocki & Wyon, 2006; Wong & Khoo, 2003). It is worth mentioning that students' density in a typical classroom can exceed that of office employees by almost four times (Katafygiotou & Serghides, 2014b). Besides, the lack of awareness regarding the efficiency of the available adaptive opportunities among students may increase thermal dissatisfaction. Considering the challenges associated with buildings, the absence of or improper temperature control, weak distribution of air, low rates of fresh air exchange, poor maintenance, lack of cleaning services, and air pollution represent the major challenges (Issa et al., 2011; Wargocki & Wyon, 2006). It should be mentioned that a good architectural design that implements passive techniques has a vital role in achieving thermal comfort or at least reducing the gap towards achieving it.

3.3 Review of thermal comfort in educational buildings

A narrative review was carried out with the aim of exploring the published literature regarding thermal comfort in educational buildings.

The majority of the reviewed studies like (Kim & de Dear, 2018; Liu et al., 2017; Wang et al., 2017; Cao et al., 2016; Teli et al., 2012) are considered as typical empirical thermal comfort studies, i.e. thermal surveys that measure objective factors affecting thermal comfort and participants' thermal perception. Additionally, few studies that focused on other aspects like (Shan et al., 2016; Almeida & de Freitas, 2015; Puteh et al., 2012; Wong & Jan, 2003) were included in the review as they searched thermal comfort via measuring physical variables and distributing subjective questionnaires. In total, 50 studies were reviewed besides 4 review papers.

Some questions regarding aspects related to the reviewed studies were defined in order to achieve the review aim. They were related to the climatic distribution, methods and followed approaches of thermal comfort, and results and their presentation. A special focus was on the measured physical variables and the used subjective scales. Besides, the patterns of students' thermal sensations and preferences were explored in addition to the presentation of the results. The latter was explored to identify any common procedures followed in the reviewed studies as this facilitates results' comparison. In addition, the review investigated if any studies were conducted in the Arabic region focusing on the translated thermal scales and their interpretation.

The review was performed using keywords of (thermal preference, or thermal sensation, or thermal acceptability, or neutral temperature, or comfort temperature, or thermal comfort) and (school, or classroom, or student). The searched databases included Science Direct, Scopus, Abstracts in New Technology and Engineering, and Civil Engineering Abstracts. The reviewed studies are discussed in the following sections according to the study level, namely kindergartens and primary schools' level, high schools' level, universities' level, mixed studying level, and unspecified studying level.

It should be mentioned that few review papers discussed thermal comfort in educational buildings, which may reflect the relatively small number of thermal comfort studies conducted in this type of buildings despite the speciality of their occupants. Recently, a narrative review based on 81 research articles reported a general thermal dissatisfaction among students despite their study level or the classrooms' ventilation mood. The sensitivity of high schools' students to outdoor temperature fluctuations was the highest. According to the researchers, this was the case due to the restrictions on clothing levels. It was found that the availability of adaptive opportunities has a positive effect on increasing satisfaction. Additionally, changing sensation votes requires different steps of temperature in spite of the studying level (Singh et al., 2018). It

is possible to relate the variations in temperature steps to the social and cultural background impact. Besides, the review paper emphasised the importance of establishing specialised design standards for educational buildings to consider students' age and studying levels.

Indeed, the inappropriateness of the currently available standards for classrooms' environments was highlighted by another review paper that was based on 48 papers from peer-reviewed journals. Most of the reviewed papers reported a discrepancy between the students' thermal preferences and the standards' comfort zones; the explored students exhibited a general preference towards cool environments. Besides, the variations in the reported neutral temperatures highlighted the necessity of micro-level thermal comfort studies. According to the researchers, raising students' awareness is crucial for energy savings in educational buildings (Zomorodian et al., 2016).

Moreover, the complexity of satisfying thermal, acoustical, visual, and air quality demands in schools was emphasised in another review paper that investigated some design issues in UK schools based on case study analysis. An optimum design is reached when the balance between the required indoor conditions for optimum performance on one hand and saving energy demands on the other is reached. To achieve this design, it is crucial to consider implementing appropriate technology, understanding occupants' interaction with their ambience, increasing buildings' adaptability, optimising indoor climatic variables and their impact on energy consumption. Additionally, an environmental circle was proposed as a design tool to assist in realising and considering the complex relations between design components and comfort factors (Montazami et al., 2015).

Moreover, schools' energy consumption was reviewed with the aim of identifying global energy benchmarking. The latter is an indicator of the consumed energy in any building according to its operational characteristics. The review findings indicated that energy consumption differs based on study level. For instance, a high school in the UK consumes less energy than a primary school by around 14%. It is worth mentioning that comparing schools' energy consumptions globally is not possible because of the lack of knowledge regarding energy resources, which is required to convert consumption into primary energy (Dias Pereira et al., 2014a).

3.3.1 Kindergarten and primary schools' level

Table 3.1 presents the reviewed studies that were conducted in kindergartens and primary schools. They form 20% of the total reviewed studies and come from temperate and continental climates with different

seasonal distribution and ventilation modes. It is noted that only two studies conducted in kindergartens were reviewed perhaps owing to the keywords used in the search. It should be mentioned that the sample size in this table, and the following tables, represents the number of analysed thermal responses regardless of the participants' number.

Table 3.1: A summary of the reviewed studies in kindergarten and primary schools' level

Study	Sample size	Age	Season	Ventilation mode	Location	Climate	Neutral temperature, [°C]
(Korsavi & Montazami, 2018)	600	9-11	Whole year	NV	UK, Coventry	Temperate	-
(Nam et al., 2015)	994	4-6	Whole year	NV	Korea, Seoul	Continental	-
(De Giuli et al., 2014)	62	9-11	Winter + Spring	Heating radiators	Italy, Padova	Temperate	-
(Yun et al., 2014)	119	4-6	Spring	NV during survey	Korea, Seoul	Continental	-
(Fabbri, 2013)	78	4-5	-	-	Italy, Reggio Emilia	Temperate	-
(De Giuli et al., 2012)	614	9-11	Spring	NV	Italy, Venice	Temperate	-
(Teli et al., 2012)	1300	7-11	Summer	NV	UK, Hampshire	Continental	20.5* – 23.0*
(Mors et al., 2011)	2166	9-11	Winter + Spring + Summer	NV + heating system	Netherlands	Temperate	-
(Zeiler & Boxem, 2009)	174	-	Winter	Different systems	Netherlands	Temperate	-
(Humphreys, 1977)	262	7-9	Summer	NV	UK	Temperate	T_a: 24

*Comfortable temperature based on outdoor running mean temperature

Because of the lack of specialised standards that consider the students' age effect in kindergarten and primary schools, many studies were conducted to compare the students' actual responses with the international standards' predictions. The results revealed variations between the actual responses and the predictions of both PMV and adaptive approach models. In a study conducted in the UK, the former and latter models resulted in responses that were above the actual responses by almost 4 °C and 2 °C respectively (Teli et al., 2012). Similar variations were reported in another study carried out in Netherland. The maximum difference between the actual votes and the PMV was 1.5 scale units (Mors et al., 2011). Similarly, the actual sensation votes were below PMV predictions in an investigation of the effect of buildings' active thermal systems on thermal comfort (Zeiler & Boxem, 2009). Likewise, the results of an Italian survey of indoor environmental quality (IEQ) confirmed the variations between the actual mean vote and PMV. Besides, the study revealed that indoor conditions were thermally uncomfortable starting in May when the indoor operative temperature exceeds 30 °C (De Giuli et al., 2014).

In this regard, a thermal comfort survey was performed in naturally ventilated classrooms in a kindergarten in Korea with the purpose of gathering data for a new PMV model suitable for children. It was found that most thermal sensation votes fell within (warm) and (slightly warm) categories and, consequently, the comfort temperature for children was lower than that of adults by almost 3 °C. Besides, the girls' comfort temperature was lower by around 1°C compared with that of boys (Yun et al., 2014). One of the early thermal comfort studies in primary schools compared the comfort range of primary school students with that of adults. The study was performed during the summer in the UK in naturally ventilated classrooms with no restrictions on any adaptive actions. The results indicated that the students' comfort range was slightly wider than that of adults and thermal discomfort mainly occurred because of the fluctuations in air temperature (Humphreys, 1977).

Moreover, indoor thermal conditions were investigated in naturally ventilated schools in Italy. Improper thermal conditions and high CO_2 levels were revealed. The study recommended a building management system as teachers determine indoor conditions mostly (De Giuli et al., 2012). This recommendation is supported by studies that investigated students' adaptive behaviour and its impact on thermal comfort and indoor climatic variables. Among these, a recent study from the UK revealed that only around 20% of the adaptive actions in classrooms were performed by students, which highlights the importance of their involvement in the adaptive behaviour. Besides, the percentages of opening windows was positively correlated to the outdoor and indoor temperatures with correlation coefficients of around +0.592 and +0.539 respectively (Korsavi & Montazami, 2018). It is worth mentioning that the method of calculating the percentages of windows' opening was not specified. Exploring the clothing level impact, a study carried out in three primary schools in Netherland confirmed the use of clothing as a seasonal adaptive action through a change of insulation values by around 0.6 clo from winter to summer (Mors et al., 2011). Moreover, exploring the clothing level characteristics in Korean kindergartens revealed that the insulation level had a relatively stronger relationship with the 4 days weighted mean operative temperature compared with the respective mean indoor or outdoor air temperatures. Besides, the thermal sensitivities to cool and warm conditions were higher in female and male students respectively. The study confirmed previous research findings regarding the difference in the comfort zone between children and adults (Nam et al., 2015).

Additionally, a comparison was performed between the objective measurements and children's subjective evaluation in a Kindergarten in

Italy. Compared with adults, children preferred cooler environment possibly owing to their higher metabolic rate and insulation level. Other possible reasons include the influence of mean radiant temperature and relative humidity as children are closer to the floor and have higher breathing rate (Fabbri, 2013).

3.3.2 High schools' level

In this studying level, the papers summarised in Table 3.2 are 22% of the reviewed studies. They were mainly conducted in the temperate and tropical climates with one study from the continental climate. As observed, the neutral temperature was not reported in most studies.

Table 3.2: A summary of the reviewed studies in high schools' level

Study	Sample size	Age	Season	Ventilation mode	Location	Climate	Neutral temperature, [°C]
(Hamzah et al., 2018)	1594	11-18	Summer	NV	Indonesia, Makassar	Tropical	T_o: 29
(Loreti et al., 2015)	-	13-14	Winter	-	Italy	Temperate	-
(Pistore et al., 2015)	130	-	Whole year	NV	Italy, Treviso	Temperate	T_o: 25.88, 24.65, 25.49
(Katafygiotou & Serghides, 2014a)	100	-	Whole year	AC + Central heating	Cyprus, Limassol	Temperate	-
(Katafygiotou & Serghides, 2014b)	185	-	Whole year	Heating system	Cyprus	Temperate	-
(Dias Pereira et al., 2014b)	45	16-19	Spring	NV	Portugal, Beja	Temperate	-
(Puteh et al., 2012)	60	-	-	-	Malaysia, Malacca	Tropical	-
(Mumovic et al., 2009)	-	-	Winter	Different systems	UK	Temperate	-
(Wong & Jan, 2003)	196	-	Summer	NV	Singapore	Tropical	-
(Wong & Khoo, 2003)	506	13-18, 26-30, 46-50	Summer	NV	Singapore	Tropical	T_o: 28.8
(Auliciems, 1969)	2500	11-16	Winter	-	UK, Reading	Continental	T_e: 16.5 T_a: 17.1 T_g: 17.6

Key: T_e = Equivalent temperature

One of the early studies that investigated thermal comfort in high schools was conducted in 1969. Measured at 60% level of satisfaction, the optimum air temperature was estimated between 15 °C and 21°C. Ventilation inadequacy was considered as a major reason for thermal discomfort in the investigated classrooms (Auliciems, 1969). Ventilation effect on thermal comfort, indoor air quality, and acoustic performance was explored in high English schools. It was revealed that thermal conditions were acceptable despite the divergence of the measured temperatures from the recommended ranges perhaps because of the insufficient control of the heating systems. The study concluded that achieving a successful design that responds to the demands of thermal

comfort, acoustical comfort, and ventilation is challenging (Mumovic et al., 2009). Indeed, the findings of a study carried out in 9 high schools in Cyprus indicated that the thermal, acoustical, and air quality conditions were below average levels. For instance, 70% approximately of the students were (cold) and (very cold) in winter. In summer, almost 37% were (warm) and around 43% were (hot) and (very hot) (Katafygiotou & Serghides, 2014b).

In this regard, the total building performance of a high school in Singapore, including thermal conditions, was investigated. The results revealed that when electric fans were in operation, the mean air temperature, mean relative humidity, and mean air velocity were above the levels recommended by the design handbooks in Singapore. Yet, these thermal conditions were acceptable for 83.2% approximately of the participants. The study highlighted the importance of considering all aspects of comfort when designing educational buildings as decisions on one aspect have possible effects on the others (Wong & Jan, 2003). The characteristics of the building envelope determine its thermal performance to a large extent. The lack of insulation in a school building envelope in Cyprus resulted in students' dissatisfaction and the thermal sensations differed significantly based on the students' gender. Further, it was revealed that students' sitting locations influence their thermal sensation (Katafygiotou & Serghides, 2014a). The impact of sitting location on thermal satisfaction was reported in a study conducted in Malaysia. Unsatisfied students were around 48% and those reported being (hot) were almost 46%. Most of the complaints were due to sitting close to windows and, accordingly, being subjected to solar radiation. In addition, the study related thermally uncomfortable classrooms to some health problems. For instance, 17%, 20%, and 68% approximately of the students had breathing difficulties, asthmatic syndrome, and stress respectively (Puteh et al., 2012).

Indoor air quality affects ventilation adequacy as demonstrated in a study performed in high schools in Italy. It was revealed that CO_2 levels were high and the acoustical and illuminance demands were unsatisfactory, which resulted in uncomfortable indoor conditions. In specific, the actual thermal sensation votes clustered in the cold side of the scale, whereas PMV were almost (neutral) in all classrooms (Loreti et al., 2015). The deviation of thermal predictions was reported in another Italian survey performed where the operative temperature fell within or negligibly above category I of the UNI EN 15251. However, a good agreement was found between the actual responses and the results of a dynamic simulation (Pistore et al., 2015). Interestingly, another study performed in Portugal revealed thermal comfort among

the investigated students although measured temperatures exceeded standards' ranges. The students were adapted to CO_2 levels despite their high concentrations resulted from depending on natural ventilation during the survey (Dias Pereira et al., 2014b). Similarly, thermal comfort was reported in another study despite the hot conditions. Indeed, 86% approximately of the explored students expressed thermal acceptance; yet, 72% roughly preferred cooler conditions. The PMV overestimated the thermal sensations compared with the actual sensation and comfort votes that were gathered by ASHRAE and Bedford scales respectively (Hamzah et al., 2018).

Additionally, the behaviour of ASHRAE and Bedford scales was compared in a study conducted in Singapore. The former scale was used as a sensation scale and the latter was used as a comfort scale. The findings indicated a difference between the scales as most votes clustered in the cool side of ASHRAE scale and in the three central categories of Bedford scale. Based on the comfort zone of ASHRAE standard 55, the classrooms' conditions were uncomfortable although they were acceptable to the students. In addition, an overestimation in sensation votes was reported when the PMV was applied (Wong & Khoo, 2003).

3.3.3 Universities' level

With reference to the reviewed literature, it is noted that many thermal surveys in educational buildings were conducted in universities perhaps due to the convenient access available to most researchers. In Table 3.3, a summary of 18 studies is presented. The majority of these studies were performed in naturally ventilated buildings in temperate and tropical climates.

Table 3.3: A summary of the reviewed studies in universities' level

Study	Sample size	Age	Season	Ventilation mode	Location	Climate	Neutral temperature, [°C]
(Ali et al., 2018)	459	-	Whole year	NV	Nigeria, Kano	Hot arid	Warm & wet, T_{com}: 27.8 Cool & dry, T_{com}: 27.0 Hot & dry, T_{com}: 30.5
(Krawczyk et al., 2017)	267	-	Autumn	NV	Poland, Bialystok + Spain, Cordoba	Continental + Temperate	Poland, T_o: 21.7-22.3 Spain, T_o: 23.3-24.8
(Kuru & Calis, 2017)	235	-	Winter	-	Turkey, Izmir	Temperate	-
(Cao et al., 2016)	740	17-37	Winter	Shanghai (no space heating), Others (district space heating)	China, Shanghai + Beijing + Harbin	Temperate + Continental	Shanghai, T_o: 22.74 Beijing, T_o: 22.01 Harbin, T_o: 21.95
(Shan et al., 2016)	39	-	-	MVCC + DVCC	Singapore	Tropical	-
(Thapa et al., 2016)	1147	18-29	Whole year	NV	India, Darjeeling	Temperate	S0135, $T_{n,r}$: 28.7, $T_{n,g}$: 28.3 S1950, $T_{n,r}$: 20.8, $T_{n,g}$: 19.7
(Abdallah, 2015)	269	-	Summer	NV	Egypt, Assiut	Hot arid	T_o: 29.1 (PMV), T_o: 27.5 (Adaptive)
(Amin et al., 2015)	71	-	Winter	AC	Malaysia, Batu Pahat	Tropical	-
(Mishra & Ramgopal, 2015)	67	19-26	Spring + Autumn	NV	India, Kharagpur	Tropical	T_o: 29.8
(Lee et al., 2012)	312	18-55	-	AC	Hong Kong	Temperate	-
(Cao et al., 2011)	206	17-above 25	Whole year	NV + AC	China, Beijing	Continental	Summer, T_o: 26.8 Winter, T_o: 20.7
(Yao et al., 2010)	3000	16-40	Whole year	NV	China, Chongqing	Temperate	T_a: 21.2
(Corgnati et al., 2009)	-	-	Autumn + Summer	NV	Italy, Turin	Temperate	-
(Cheng et al., 2008)	1219	16-28	Summer	NV + AC	Taiwan	Tropical	T_o: 24.5
(Karyono, 2008)	20	19-24	-	AC	Indonesia, Bandung	Tropical	T_a: 24.7 T_g: 25.7 T_o: 25.4 T_{set}: 26.1
(Zhang et al., 2007)	1273	-	Spring	NV	China, Hunan + Sheng	Temperate	T_o: 21.5
(Hwang et al., 2006)	1294	-	Summer	NV + AC	Taiwan	Tropical	T_{set}: 26.3
(Chung & Tong, 1990)	134	-	-	AC	Hong Kong	Temperate	T_m: 24.9

Key: T_{com} = Adaptive neutral temperature, MVCC = Mixing ventilation with cooling coil, DVCC = Displacement ventilation with cooling coil, S0135 = Site with altitude 135 m, S1950 = site with altitude 1950m, $T_{n,r}$ = Regression neutral temperature, $T_{n,g}$ = Griffiths' neutral temperature, T_{set} = standard effective temperature, T_m = modified temperature

Some of the reviewed studies explored the difference between the neutral and the preferred temperatures. For instance, a thermal survey was conducted for a whole year in a naturally ventilated classroom in a hot humid region in India. The preferred temperature, around 26.8 °C, was lower than the neutral temperature that was 29 °C approximately. Moreover, it was found that operative temperatures between 22.1 °C and 31.5 °C roughly were satisfying for 80% of the students (Mishra & Ramgopal, 2015). In another study conducted in a hot humid region in Indonesia, 20 students participated in a survey that was carried out in two naturally ventilated classrooms besides a lecture room that was prepared to be similar to a thermal chamber. A total of 200 thermal votes were collected and the neutral temperature was around 24.7 °C, 25.7 °C, 25.4 °C, and 26.1 °C in terms of air, globe, operative, and standard effective temperatures respectively (Karyono, 2008). Another survey was carried out in 25 naturally ventilated Chinese classrooms revealed that around 22.7% and 26.5% of the students with (neutral) thermal sensation preferred cooler and warmer conditions respectively. In total, 78% and 63% approximately of the participants voted (neutral) for thermal and humidity sensations respectively. Besides, the neutral and preferred operative temperatures were roughly 21.5 °C and 22.3 °C respectively (Zhang et al., 2007).

The comfortable conditions in different climates were compared in the reviewed studies. For instance, the thermal comfort zone of young Chinese in Hong Kong was compared with that of Europeans and North Americans. Performing sedentary activities for around 3 hours, 134 university students participated in the study wearing an insulation level of 0.6 clo. Compared with female students, male students preferred lower temperature by 1 °C approximately. The neutral temperature was computed based on a simple linear regression as around 24.9 °C and the comfort zone was determined based on a probit analysis as almost 22.2-25.2 °C. The neutral temperature difference between the Chinese students and the European and American students was insignificant (Chung & Tong, 1990). Another research investigated the adaptation difference between university students from different climate zones. The neutral operative temperature was computed as 26.8 °C roughly in summer and 20.7 °C approximately in winter. It was concluded that the effect of the climatic zone on adaptability was limited (Cao et al., 2011). In another study, the thermal comfort conditions during winter were compared in university classrooms located in three Chinese cities that differ in their climatic conditions. The cities were Harbin, Beijing, and Shanghai that represent sever cold climate, cold climate, and hot summer and cold winter climate respectively. In Harbin and Beijing, the classrooms were equipped with a central heating system, whereas no

heating system was available in Shanghai classrooms. Despite the relatively high mean outdoor air temperature in Shanghai, the mean indoor temperature was the lowest due to heating systems absence. The subjects in Shanghai exhibited better adaptation to the ambience as 80% approximately of the students accepted the indoor air temperatures between 16 °C and 22 °C. A similar percentage was found in Harbin but with indoor air temperatures from 20 °C to 26 °C. Moreover, comparing the actual sensation votes with the PMV revealed that the latter underestimated students' sensations (Cao et al., 2016). Additionally, the response of university students to their thermal ambience in naturally ventilated classrooms was investigated in Poland and Spain. The corresponding optimum air temperature ranges were 21.7-22.3 °C and 23.3-24.8 °C approximately (Krawczyk et al., 2017).

Achieving thermal comfort in educational buildings is positively reflected in students' health and performance. Therefore, the relations between sick building syndromes and thermal conditions were explored in many studies. For instance, a study conducted in three engineering laboratories in Malaysia revealed that students suffered from different sick building syndrome symptoms like dry skin, runny noses, dry eyes, and tiredness. The mean sensation votes were -1.53, -2.44, and -2.68 approximately, which indicated unacceptable indoor conditions. The study highlighted the importance of adequate design of air conditioning systems (Amin et al., 2015). Another study evaluated the influence of a mixing ventilation system and a passive displacement ventilation system on comfort and sick building syndromes in two classrooms. In general, there was no variation in air temperatures in both rooms. Yet, thermal acceptability increased in the room that integrated the passive displacement ventilation system mainly owing to the relatively high draft presence in the room combined with a mixing ventilation system (Shan et al., 2016). Besides, direct evaporative cooling strategies are advised to improve the thermal conditions of large university halls in Egypt. In these halls, around 83% of the students were thermally uncomfortable and preferred cooler conditions. This was the case because of the solar gain, low air velocity, and high surface temperature (Abdallah, 2015). Additionally, the correlation between students' performance and IEQ, including thermal comfort, was explored in Hong Kong. It was revealed that 84% approximately of the students were thermally satisfied. In addition, around 47% of the thermal sensation votes were (neutral) and almost 36.5% were on the cold side. It was concluded that learning performance is strongly related to IEQ complaints (Lee et al., 2012).

Some studies investigated the impact of utilising cooling systems and strategies on the energy consumption of buildings. Among these, a

project was conducted on two stages in Taiwanese universities. In the first stage, the thermal conditions of 26 air-conditioned classrooms and 10 naturally ventilated classrooms were explored. The results indicated that thermal acceptance was not limited to the three central sensations of ASHRAE scale. Regardless of the relatively cool ambience in the air-conditioned classrooms, more students wanted to be cooler compared with those in the naturally ventilated classrooms (Hwang et al., 2006). The project's second stage was carried out in summer in two university dormitories. The first dormitory depended on natural ventilation and electric fans and the other depended on central air conditioning system. The neutral operative temperature was 25.4 °C approximately and the preferred operative temperature was 24.8 °C roughly. Moreover, the upper acceptable operative temperature was estimated at 28.2 °C and 27.2 °C applying direct and indirect methods respectively. The former method was based on a direct question about thermal acceptance. In the latter method, any thermal sensation vote different from the three central votes was considered unacceptable (Cheng et al., 2008).

The adaptive approach of thermal comfort was followed in some of the reviewed studies. One of these investigated the impact of altitude difference on comfort. The study was carried out in two university campuses that were separated by around 1800 m in altitude and 50 km in distance. For the higher and lower altitude campuses, the annual Griffiths' neutral temperature was estimated at 20.8 °C and 28.7 °C respectively (Thapa et al., 2016). In this regard, exploring the adaptive behaviour of university students in naturally ventilated classrooms in China identified changing clothing level as the main adaptive action for a range of indoor air temperatures estimated between 14 °C and 28 °C. Moreover, the investigated students exhibited less sensitivity to warm conditions and preferred slightly cool environments (Yao et al., 2010). Recently, the impact of operating ceiling fans in achieving comfort was explored in two lecture theatres in Nigeria. Almost 56% and 37% of the students in the first and second theatres respectively felt (hot) as operative temperatures were beyond the maximum limit specified by the international standards. However, the respective overall acceptability was around 75% and 81%. According to the researchers, this was mainly due to the positive effect of air velocity that raised the maximum operative temperature by around 2 °C. It is noteworthy that around 96% and 80% of the students in the first and second theatres were satisfied with air velocities of 0.63 m/s and 0.65 m/s respectively (Ali et al., 2018).

It was noticed that some of the reviewed studies explored different aspects related to thermal comfort in universities. For instance, a survey

carried out in free running classrooms in Italy confirmed the seasonal effect on thermal preference (Corgnati et al., 2009). In another study, the relationship between predicted and actual mean votes besides the influence of relative humidity and air velocity perceptions on overall thermal acceptability and sensations were explored. The study revealed a strong correlation between the predicted and the actual mean votes with an estimated coefficient of 0.832. Yet, applying a parametric t-test revealed a statistically significant difference between the arithmetic means of the predicted and the actual mean votes. Besides, the study indicated that sensation and acceptability were significantly influenced by the perceptions of relative humidity and air velocity (Kuru & Calis, 2017).

3.3.4 Mixed studying level

Some reviewed studies considered more than one studying level. In these studies, the thermal conditions of high schools' students were explored perhaps because of their intermediate age between lower and higher studying levels. These studies form 18% of the reviewed papers and they are summarised in

Table 3.4. As demonstrated, the studies were mainly performed in naturally ventilated buildings in the temperate climate.

Table 3.4: A summary of the reviewed studies in mixed studying level

Study	Sample size	Age	Season	Ventilation mode	Location	Climate	Neutral temperature, [°C]
(Kim & de Dear, 2018)	4866	10-18	Summer	NV + AC	Australia	Temperate	-
(Liu et al., 2017)	763	10-15	Winter	NV	China, Weinan + Wuwei	Temperate	T_o: 15.1
(Wang et al., 2017)	1126	9-16	Winter	Different heating systems	China	-	Shaanxi, T_o: 14.2 Gansu, T_o: 14.3 Qinghai, T_o: 13.4
(de Dear et al., 2015)	2850	-	Summer	NV + AC + EC*	Australia	Temperate	T_o: 22.5
(d'Ambrosio Alfano et al., 2013b)	4416	11-18	Whole year	NV	Italy, Campania	Temperate	-
(Liang et al., 2012)	3754	12-17	Whole year	NV	Taiwan	Tropical	Summer, T_o: 29.2 Winter, T_o: 22.4
(Al-Rashidi et al., 2009)	336	11-17	Winter	NV + AC	Kuwait	Hot arid	T_o: 22 (Girls) T_o: 21 (Boys) T_o: 21.5 (All)
(Hwang et al., 2009)	3754	11-17	Whole year	NV	Taiwan, Taichung	Tropical	T_o: 22.7-29.1
(Corgnati et al., 2007)	440	12-17	winter	NV	Italy, Turin	Temperate	-

*EC = evaporative cooling

A thermal comfort survey was carried out in primary and high schools in Australia in summer to measure the neutral, acceptable, and preferred temperatures for the students. Around 70.6% of the thermal votes fell in the three central categories with more votes in the warm side possibly reflecting a seasonal influence. Comparing actual mean votes and PMV revealed their equality in a narrow range of operative temperatures, namely 25-27 °C roughly. Below and above this range, PMV underestimated and overestimated the actual votes respectively. Besides, the neutral and preferred operative temperatures were around 22.5 °C and the acceptable temperatures were between almost 19.5 °C and 26.6 °C (de Dear et al., 2015). The second stage of this research was performed to compare the students' thermal demands and expectations and to investigate their adaptive behaviour. The study revealed that the actual neutral temperatures of all students were lower than the predicted temperatures based on the recommendations of the adaptive comfort approach of ASHRAE 55 standard. The corresponding difference was estimated at 2 K and 3K. Furthermore, a noticeable preference for air conditioning units to modify thermal ambience was reported. This preference was interestingly higher in air-conditioned classrooms compared with the naturally ventilated ones. Besides, the discrepancy between the students' thermal comfort demands and the international standards' recommendation was emphasised as cool conditions were preferred especially by high school students (Kim & de Dear, 2018). This preference is positively related to the performance of the students as indicated in another study conducted in rural primary and high schools in China. The neutral temperature was computed at 15 °C approximately for a mean clothing level of 1.6 clo. However, the highest learning performance was recorded at 14 °C (Liu et al., 2017).

The applicability of the adaptive model of thermal comfort in the tropical climate was explored in Taiwan. A thermal survey was carried out in 48 naturally ventilated classrooms distributed in primary and high schools. A consistency of almost 35% with ASHRAE adaptive comfort range was revealed. Moreover, around 87% of the thermal sensation votes fell in the central categories; however, only 26% of the explored students preferred (no change) in the thermal ambience. Around 54% of them wanted cooler conditions. Besides, the students exhibited more sensitivity to warm conditions as the temperature step required to change the sensation vote on the warm side was 2.9 °C compared with 5.9 °C for the cool side. As for the adaptive behaviour, the students depended mainly on changing clothing level (Hwang et al., 2009).

One of the few published studies conducted in the Arabic region was from Kuwait. The study was performed in primary and high schools

to compare the predictions of various thermal comfort models with the students' actual responses. The compared models were the PMV, extended predicted mean vote ($_e$PMV), predicted mean vote with modified metabolic rate (PMV_{10}), and adaptive model equations. It was revealed that female students were marginally more satisfied than male students. Around 65% of 169 female students, compared with almost 64% of 167 male students, fell in the central categories. Additionally, the predictions underestimated the actual warm sensations and overestimated the actual cool sensations. The neutral operative temperatures for female and male students were estimated at 22 °C and 21 °C respectively (Al-Rashidi et al., 2009). In this regard, the expectancy factor value required to determine the $_e$PMV was investigated in a whole year thermal study carried out in 200 primary and high schools in Italy. This factor accounts for the psychological adaptation influence in non-air conditioned buildings in warm climates. A higher percentage of unsatisfied students resulted from the direct question compared with the votes outside the three central categories of ASHRAE scale. The study concluded that applying the $_e$PMV leads to better predictions in naturally ventilated buildings provided that a correct expectancy factor is used. With reference to the investigated conditions, an expectancy factor of 0.9 resulted in the lowest variations between the predicted and the actual thermal responses in summer and winter (d'Ambrosio Alfano et al., 2013b).

Besides, a study of the thermal, visual, acoustical, and air quality conditions was carried out in four high schools' classrooms and four university classrooms in Italy during winter. The findings indicated that the percentage of unsatisfied people (PPD) model underestimated the actual number of unsatisfied people considered as those with (cool), (cold), (warm), and (hot) votes on ASHRAE sensation scale. However, a better agreement was found when considering the unsatisfied people as those with (cool), (cold), and (hot) votes. The acceptable thermal conditions were those corresponding to sensation votes of (neutral) or (warm) and the preferred thermal conditions were those corresponding to (slightly warm) sensation (Corgnati et al., 2007).

Furthermore, two of the reviewed studies investigated the thermal performance of schools' buildings. In the first, the influence of building envelope, in specific windows, on thermal comfort was investigated in primary and high schools in Taiwan. The investigated schools were characterised by single-pane clear glass windows that have a negative influence on the indoor thermal comfort. Based on this study, the neural temperatures in summer and winter were around 29.2 °C and 22.4 °C respectively. Besides, a combination of classrooms' proper orientation

and windows' external shading was suggested to modify indoor thermal conditions (Liang et al., 2012). The other study was conducted with the aim of identifying design variables for heating systems in rural primary and high schools in Northwest China. Students' thermal sensitivity was overestimated by the predicted votes. The neutral temperatures were computed as around 14.2 °C, 14.3 °C, and 13.4 °C and the preferred temperatures were computed as almost 15.3 °C, 15.6 °C, and 16.2 °C. The students were adapted to cold conditions and considered higher indoor temperatures as uncomfortable (Wang et al., 2017).

3.3.5 Unspecified studying level

Studying level was not specified in two studies from the reviewed literature. The first study evaluated the influence of a new ventilation system on IEQ, including thermal comfort, in a Portuguese school. Air temperature, relative humidity, and CO_2 levels were monitored in four classrooms and a questionnaire was distributed to 104 students. The study reported that 70% and 50% approximately of the students in the refurbished and non-refurbished classrooms respectively were (neutral). Considering the former classrooms, indoor air quality was good for almost 70% of the students compared with around 45% in the latter classrooms (Almeida & de Freitas, 2015). The second study was conducted with the purpose of investigating the applicability of ASHRAE Standard 55-92 in Japan. A thermal survey was performed in naturally ventilated and air-conditioned classrooms during summer. Indoor air temperature, globe temperature, relative humidity, and air velocity were measured and 74 students answered a subjective questionnaire. The results revealed that the thermal conditions in the naturally ventilated classrooms were outside the comfort zone as specified by ASHRAE 55-92. Interestingly, the students found those conditions satisfying (Kwok & Chun, 2003).

3.3.6 Thermal comfort in Omani educational buildings

To the researcher's level of knowledge, no typical thermal comfort studies were conducted in the educational buildings in Oman. However, two studies investigated the thermal conditions as part of exploring sick building syndrome (Abdul-Wahab et al., 2015c) and as part of exploring energy efficient strategies for school buildings (Zurigat et al., 2003). In the first study, the thermal and indoor air quality conditions were investigated in a library building at Sultan Qaboos University. Indoor air temperature, air velocity, relative humidity, CO_2 concentration levels, ammonia levels, and the levels of other chemical components were measured at five different locations in the library. Compared with ASHRAE recommendations, the measured air temperature was low and the relative humidity was high. Some sick building syndrome symptoms

were reported by occupants like fatigue, headache, and dizziness (Abdul-Wahab et al., 2015c). No information was available about the study season. Considering the other study, hourly simulations of certain passive techniques to reduce cooling loads were carried out in a school building considering the climatic conditions of Muscat city. Investigated techniques included envelope insulation, shading, evaporative cooling of the structure, and glazing. The optimum case was a combination of 50 mm polystyrene roof insulation, 25 mm polystyrene wall insulation, double glazing, 0.8 internal shading factor, and 80% external shading of the whole building. As a result, the cooling load was reduced by 43% roughly (Zurigat et al., 2003). It is noteworthy that none of these studies questioned the subjects about their thermal perception of thermal sensation scales.

3.4 Discussion

3.4.1 Climatic distribution, samples' size, and age ranges

The reviewed papers extended from 1969 to 2018 with around 48% of the studies conducted in the last five years and almost 82% in the last ten years. The studies performed in Italy formed 16% roughly of the reviewed papers followed by around 12% and 10% from the UK and China respectively. The interest in thermal comfort in Italian educational buildings may be linked to the sensitivity of this issue as around 9000 of these buildings were constructed before 1940 and, hence, are protected by the cultural heritage regulations (Repubblica Italiana, 1999 in d'Ambrosio Alfano et al., 2013b). Based on this, 54% approximately of the studies were performed in the temperate climate followed by around 24% in the tropical climate. It is noted that few studies from those considered in this review were conducted in the hot arid climate.

The size of the investigated samples ranged from 20 responses (Karyono, 2008) to 4866 (Kim & de Dear, 2018). Figure 3.1 presents the distribution of the samples' size. As noted, most studies analysed 100 to 500 thermal votes. These studies were distributed on all studying levels with the majority from high schools and universities. Based on this, it seems that a sample size of around 250 to 350 participants is acceptable in thermal comfort studies in educational buildings.

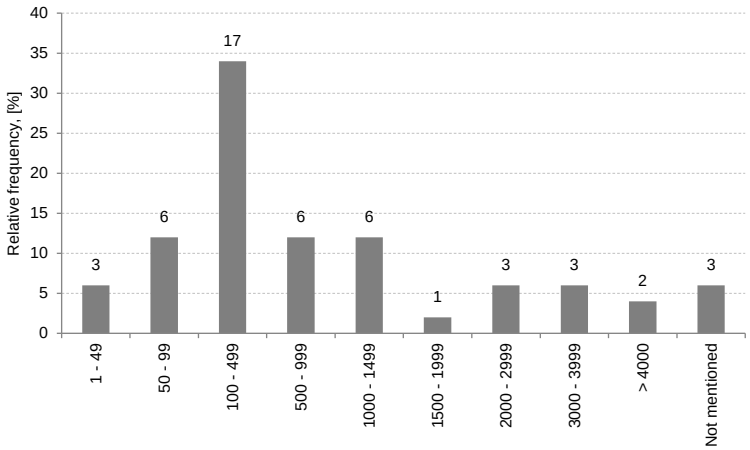


Figure 3.1: Relative frequency of samples' size (Labels are studies' numbers)

Considering students' ages, there were some variations within the one studying level. For instance, students' age in the high schools' level extends between 11 and 19 years old with the highest variations in the universities' level as expected. Considering the primary schools' level, four studies (Korsavi & Montazami, 2018; De Giuli et al., 2014; De Giuli et al., 2012; Mors et al., 2011) explored one age range that extended between 9 and 11 years old. Interestingly, the neutral temperature was not computed in any of these studies. It is noteworthy that some studies requested the participants to report their ages (Hwang et al., 2006; Chung & Tong, 1990); however, these data were not reported in the published papers.

3.4.2 Methodology

Depending on their objectives, the reviewed studies measured several indoor, and sometimes outdoor, climatic variables such as air temperature, globe temperature, relative humidity, and air velocity. Yet, few studies reported the accuracies of the implemented sensors like (Kim & de Dear, 2018; Liu et al., 2017; Cao et al., 2016; Mishra & Ramgopal, 2015). Considering the subjective questionnaires, Figure 3.2 presents the distribution of the implemented thermal scales. As noted, more than 62% of the reviewed studies integrated ASHRAE sensation scale. The popularity of this scale may be linked to the reliance of the PMV model on it as many studies compared the actual and predicted thermal votes. The overestimation behaviour of PMV was reported in many studies including (Hamzah et al., 2018; Wang et al., 2017; de Dear et al., 2015; Teli et al., 2012; Zeiler & Boxem, 2009; Wong & Khoo, 2003) and the underestimation behaviour was reported in other studies like (Cao et al., 2016; de Dear et al., 2015; Loreti et al., 2015). It is noteworthy that no obvious pattern regarding the climatic conditions,

ventilation mode, or studying level can be linked to the behaviour of the PMV owing to the limited number of the reviewed studies.

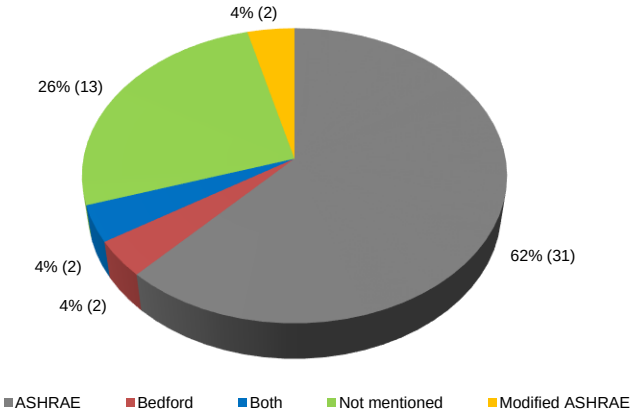


Figure 3.2: The distribution of the integrated thermal sensation scales

3.4.3 Thermal votes and neutral temperature

The reviewed studies reported the students' thermal sensations differently. For instance, around 18% of the studies calculated the percentages of votes that fell within the central sensation categories. These votes extended from slightly above 60% (Al-Rashidi et al., 2009) to around 97% (Zhang et al., 2007) with most votes higher than 85% (Hamzah et al., 2018; Liu et al., 2017; Hwang et al., 2009; Corgnati et al., 2007). Some studies reported general discomfort such as (Abdallah, 2015; Pistore et al., 2015; Katafygiotou & Serghides, 2014a; De Giuli et al., 2012). Some related between discomfort and cool conditions like (Amin et al., 2015; Loreti et al., 2015; Katafygiotou & Serghides, 2014b) and warm conditions like (Katafygiotou & Serghides, 2014b; Puteh et al., 2012).

Besides, it is noted that there is no obvious tendency of thermal sensations among the students possibly due to the varying climatic conditions they were subjected to as well as the effect of their cultural and social backgrounds. Despite that, a general thermal preference of cool conditions was reported in different studying levels and climates like (Hamzah et al., 2018; Kim & de Dear, 2018; Abdallah, 2015; Mishra & Ramgopal, 2015; Nam et al., 2015; Yun et al., 2014; Fabbri, 2013; Teli et al., 2012; Yao et al., 2010; Hwang et al., 2009). In specific, 28% of the reviewed papers reported this preference considering that the thermal preference was not reported in 58% of the studies. Besides, it was noted that the majority of the studies that reported the cool conditions preference were conducted in summer in naturally ventilated buildings. However, the natural ventilation mode should not be linked to this preference because this mode of ventilation was dominant in the

reviewed studies and, accordingly, this sample of literature may not be representative to generate such conclusion. Moreover, it may worth mentioning that (no change) in the thermal environments was preferred in (Thapa et al., 2016; de Dear et al., 2015; Cheng et al., 2008; Corgnati et al., 2007; Zhang et al., 2007) and warmer conditions were preferred in (Thapa et al., 2016; Corgnati et al., 2009; Corgnati et al., 2007).

Furthermore, the optimum temperatures were reported in 50% of the reviewed papers and were expressed differently as demonstrated in Figure 3.3. Obviously, this prevents results' comparison. For instance, several studies expressed the neutral temperature as an indoor operative temperature like (Hamzah et al., 2018; Krawczyk et al., 2017; Liu et al., 2017; Cao et al., 2016; de Dear et al., 2015; Mishra & Ramgopal, 2015). Other studies reported the optimum temperature as an indoor air temperature (Yao et al., 2010; Karyono, 2008; Auliciems, 1969), an indoor globe temperature (Karyono, 2008; Auliciems, 1969), a standard effective temperature (Hwang et al., 2006; Karyono, 2008), or Griffiths' comfort temperature (Thapa et al., 2016).

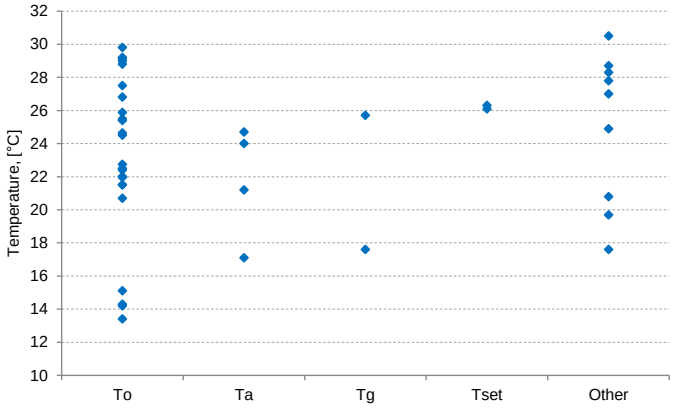


Figure 3.3: The distribution of optimum temperatures

Additionally, an agreement in the neutral operative temperature in the tropical climate for the naturally ventilated buildings was noted. In particular, the temperature extended in a narrow range from around 28.3 °C (Thapa et al., 2016) to almost 29.8 °C (Mishra & Ramgopal, 2015). The former was annual temperature and the latter was reported for both spring and autumn seasons. Similar figures were reported in summer (Hamzah et al., 2018; Liang et al., 2012; Wong & Khoo, 2003). It is worth mentioning that a neutral operative temperature for naturally ventilated building in the hot arid climate in summer was calculated as almost 29.1 °C (Abdallah, 2015).

Further, eight studies reported neutral temperatures within a very narrow range of around 21.2-22.74 °C. Most of these studies were performed in naturally ventilated buildings in the temperate climate.

Interestingly, they were based on all year data (Yao et al., 2010), winter data (Cao et al., 2016; Liang et al., 2012; Cao et al., 2011; Al-Rashidi et al., 2009), spring data (Zhang et al., 2007), autumn data (Krawczyk et al., 2017), and summer data (de Dear et al., 2015). This may indicate the absence of seasonal influence on neutral temperature in naturally ventilated buildings in the temperate climate. However, a possible reason may be related to the adaptive actions taken by the occupants to adapt to the seasonal variations in the climatic conditions. Further investigations are highly recommended. It should be mentioned that the limited number of reported neutral operative temperatures from primary schools restricted the comparison based on studying level.

3.4.4 Students' adaptive behaviour

The adaptive behaviour of the students was investigated in around 24% of the reviewed studies. It was revealed that adjusting clothing was the most used technique among students (Mishra & Ramgopal, 2015; Yao et al., 2010; Hwang et al., 2009; Kwok & Chun, 2003; Humphreys, 1976). Other favourable actions include opening windows and switching on fans (Abdallah, 2015; Mishra & Ramgopal, 2015; De Giuli et al., 2014; De Giuli et al., 2012; Kwok & Chun, 2003). It is worth mentioning that these studies were performed in naturally ventilated classrooms except (Kwok & Chun, 2003) study that was conducted in both air-conditioned and naturally ventilated classrooms. Moreover, most of these studies were from the temperate climate, which may justify the dependence on these adaptive actions. However, the availability of air conditioning units encourages their use as was the case in (Kim & de Dear, 2018; Cheng et al., 2008) that were performed in temperate and tropical climates respectively.

Furthermore, the influence of students' sitting locations on their adaptive behaviour inside classrooms was not discussed in any of the reviewed studies. Nevertheless, it should be mentioned that two studies commented on the link between students' thermal discomfort and their sitting near windows (Mishra & Ramgopal, 2015; Puteh et al., 2012). In general, this group of students reported less satisfaction with their classrooms' environments.

3.4.5 Thermal scales' behaviour

Considering the behaviour of thermal scales, only two studies from Indonesia and Singapore integrated ASHRAE and Bedford sensation scales (Hamzah et al., 2018; Wong & Khoo, 2003). These studies were performed in summer in naturally ventilated high schools. In both studies, ASHRAE scale was used to evaluate the students' thermal sensation and Bedford scale was used to evaluate their thermal

comfort. In the first study, 87% and 85% approximately of students' votes fell within the central categories of the former and latter scales respectively. A similar agreement in the scales' behaviour was not reported in the second study where the thermal votes clustered on the cool side of ASHRAE scale and in the central categories of Bedford scale. Considering that both studies were conducted in similar contexts, the change in scales' behaviour may be attributed to the influence of translation. Although not mentioned in both papers, it is thought that the questionnaires were translated into the local languages to suit the participants' level of knowledge. Additionally, some of the reviewed studies mentioned translating thermal scales to the local languages; however, none discussed the translation influence on scales' behaviour.

3.5 Conclusion

Several researchers around the world studied thermal comfort in educational buildings due to its influence on students' performance and health. Managing ventilation rates and students' number inside each classroom contribute to improving the thermal conditions. However, some challenges related to students and schools' buildings can restrict achieving thermal comfort. This reveals the importance of increasing students' awareness of passive adaptive actions and implementing passive design techniques in educational buildings.

This chapter discussed the findings of a narrative review in which 54 published papers were reviewed. The objective was to investigate the topic of thermal comfort in educational buildings in the literature. The reviewed papers were published in databases like Science Direct, Scopus, and Abstracts in New Technology and Engineering and they extended on 49 years with the majority from the temperate and tropical climates. They investigated a noticeably wide range of sample sizes extending from 20 to almost 4900 participants with a clear cluster in the range 100-500. Therefore, a sample size of around 250 to 350 subjects seems acceptable. Likewise, the investigated ranges of age differ even within the one studying level with the widest variations among university students.

The measured physical variables and applied subjective scales differ between the reviewed studies and were determined based on their objectives. Yet, most studies reported indoor air temperature, air velocity, relative humidity, and globe temperature. Besides, ASHRAE thermal scale was widely integrated in the distributed questionnaires. This was the case because the comparisons between actual mean votes and PMV were widely reported despite the general disagreement between the votes. This emphasises previous reviews' conclusions that

discussed the inappropriateness of the current international standards to determine thermal comfort demands in educational buildings (Singh et al., 2018; Zomorodian et al., 2016; Fabbri, 2013). Moreover, it may reflect the need to establish regional reference models, or at least reference equations, to which the results of the regional studies can be compared.

It was noted from the reviewed papers that the thermal sensation and optimum temperatures were reported differently. Besides, the lack of general tendency of thermal sensations was noted in the reviewed papers, unlike thermal preferences. It was not possible to attribute the tendency of preferring cool conditions to a ventilation mode or a climate type due to the limited number of reviewed papers.

Moreover, few studies explored the students' adaptive behaviour. Most of these studies were conducted in naturally ventilated buildings, which illustrates the sequence of the most widely used techniques that were changing clothing level, opening windows, and switching on fans. None of the reviewed studies explored the effect of sitting locations on students' thermal comfort or translation influence on thermal scales. Likewise, comparing the behaviour of the integrated scales was not explored except in two studies.

It should be mentioned that the narrative review approach has its limitations that are necessarily applicable to the discussion of this chapter. Therefore, it is possible that the reviewed papers lack a proper representation of the literature due to the relative selection randomness and unclear inclusion and exclusion criteria (Bryman, 2012). Taking the performed review into account, clustering in certain studying levels like university level was obvious.

Although the reviewed papers exhibited clustering of climate type and ventilation mode, there was an obvious disagreement in the format of reporting the findings. This, consequently, restricts the possibility of comparing the results, which is required for better understanding of thermal comfort. Accordingly, it is recommended to report sufficient data regarding the context, participants, methodology, and results in the published papers. In specific, it is recommended to report the season, city, mean climatic conditions, buildings' function, and ventilation mode besides subjects' age, gender, and the number of analysed thermal responses. For the methodology, the physical variables should be specified with the sensors' accuracy. Moreover, the integrated thermal scales should be specified as well as the translated thermal phrases if any. Considering the results, the distribution of the thermal sensation

and preference votes should be reported besides specifying the type of the optimum temperature, if calculated, and the calculation method.

Chapter (4):

Local Context and Climatic Analysis

Chapter 4 Local context and climatic analysis

Exploring the local context in thermal comfort surveys is useful as it assists in understanding the participants' thermal behaviour. This is due to the influence of the climatic, cultural, and social background on interpreting thermal phrases and selecting thermal preferences. Thus, the first part of this chapter presents an overview of the Sultanate of Oman and Muscat city. In specific, it presents the geographical location of Oman, its climatic conditions, and its social and cultural features. In addition, the development of the educational system is briefly explained with a special focus on the academic year and the school uniform of female students in high schools. The climatic conditions of Muscat are discussed in detail presenting the data of air temperature, relative humidity, wind, precipitation, and solar radiation. In the second part of the chapter, the explored schools are presented and their architectural designs are discussed. The features of the investigated classrooms are briefly presented and the selection of the survey period was justified.

4.1 Introduction to the Sultanate of Oman

The Sultanate of Oman is located at the farthest eastern edge of the Arabian Peninsula with an estimated area of 309,500 km^2. It extends between 16°40' N and 26°20' N latitudes and 51°50' E and 59°40' E longitudes. Oman has common boundaries with the United Arab Emirates, Saudi Arabia Kingdom, and the Republic of Yemen as demonstrated in Figure 4.1. The latest statistics estimate the population at 4,559,963 people with almost 1,459,249 people live in Muscat, the capital city (NCSI, 2018).



Figure 4.1: Oman geographical location
[Reproduced from (On The World Map, 2018)**]**

4.1.1 Topography

The topography of Oman is classified into three distinctive regions, which are the coastal plain, the mountainous regions, and the desert regions as presented in Figure 4.2. Forming around 3% of the total area of Oman, the coastal plain region is represented by Al-Batinah plain in the north and Salalah plain in the south. The coastal line extends for more than 3000 m overlooking the Arabian Gulf (also known as the Persian Gulf), Oman Gulf, and the Arabian Sea (NCSI, 2018; Frenken, 2009; Indurti et al., 2009). Consequently, the monsoon season that occurs in the southern part of Oman is a result of the cyclones that occur in the Indian Ocean.

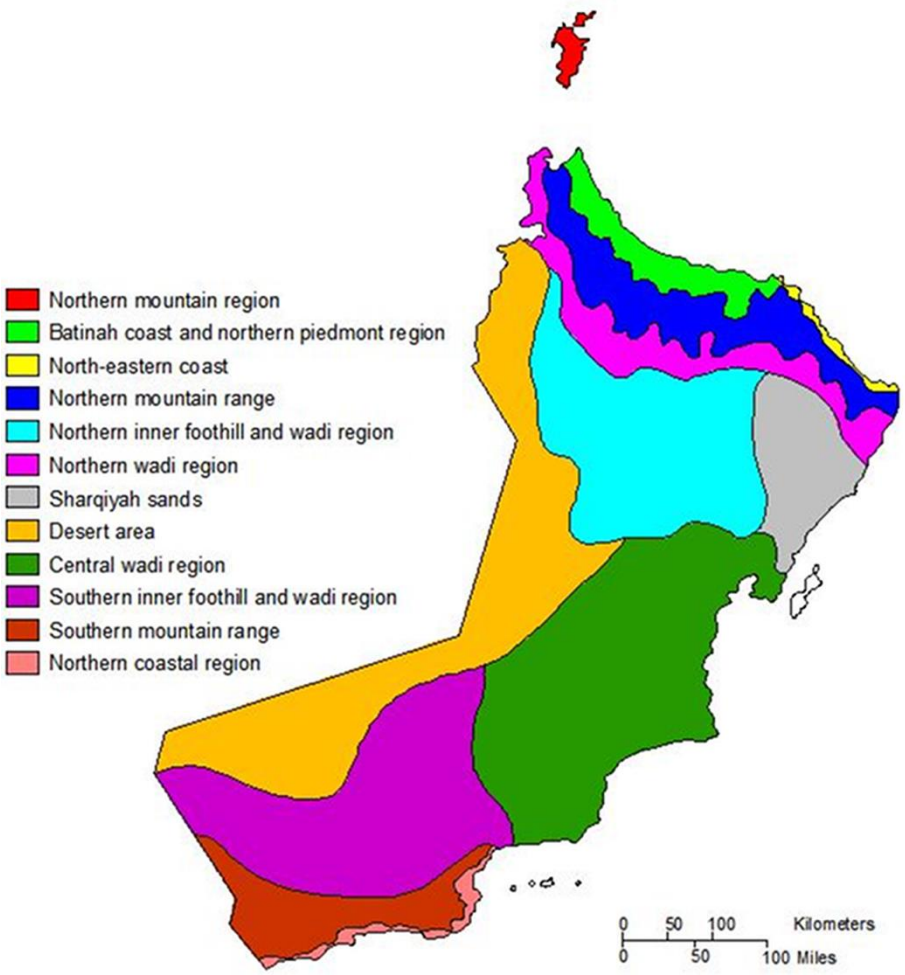


Figure 4.2: Diverse topography of Oman
[Reproduced from (Costa, 2001)]

The mountainous region forms almost 15% of the total area and it extends in two ranges of mountains along an east-west direction in the northern and southern parts of Oman as demonstrated in Figure 4.2. The northern range is Al-Hajar Mountains and its highest point is Jabal Shams (Sun Mountain) of almost 3000 m above sea level, whereas Al-Qamar (Moon) range extends in the southern part with the highest apex

of Samhan Mountain at an estimated height of 2100 m (NCSI, 2018; Ministry of Tourism, 2013; Indurti et al., 2009). Regarding the desert region, Ar'Rub Al-Khali (The Empty Quarter) desert forms the majority of this region (NCSI, 2018; Frenken, 2009; Indurti et al., 2009).

4.1.2 Climatic conditions

Following the three distinctive geophysical regions, it is possible to differentiate three climatic types in Oman. These are the hot humid in the coastal Plaines, the milder climate in the mountainous regions, and the hot dry in the interior desert regions. Considering the hot humid climate of the coastal regions, daily maximum temperature extends from 25 °C to 35 °C in the relatively cooler season, whereas it reaches up to 40 °C during the hot season. Occasional snowfall and freezing temperatures are sometimes witnessed in the milder mountainous regions. Oppositely, the maximum temperature can exceed 50 °C in the considerably hotter interiors (Weather Online, 2015; Indurti et al., 2009). The annual maximum and minimum air temperature and relative humidity in Oman computed for 10 years are plotted in Figure 4.3. As observed, the annual maximum and minimum air temperatures were centred around 32 °C and 22 °C respectively with corresponding ranges of 1.4 °C and 1.8 °C. Besides, the maximum relative humidity extended between 67% and 80% and the minimum relative humidity was around 30% except that of 2014 as it was almost 10%.

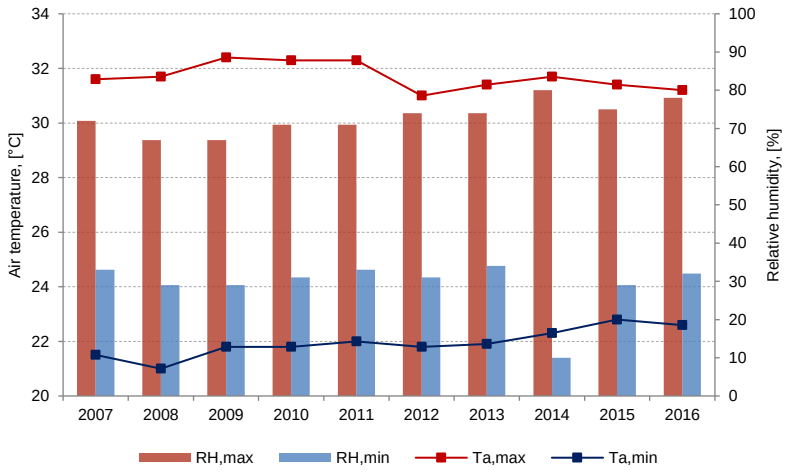


Figure 4.3: Annual maximum and minimum air temperature and relative humidity [Reproduced from (NCSI, 2017)]

4.1.3 Social and cultural background

The Omani society is characterised by the divergent origins of its tribes with the majority from Arabs. The Islamic values and traditions are clearly present in all aspects of life as most Omanis are Muslims; however, very few families, mostly from non-Arabic origins, practice

other religions. Generally, Omani people from coastal regions, including Muscat city, are known to be more tolerant and open towards others compared with those from the inner side of the country. A possible reason for this nice nature is the influence of the historical maritime trade (Jones & Ridout, 2015; Ragette, 2012; Indurti et al., 2009).

The official language in Oman is the Arabic language, which is the native tongue for a wide geographical area extending from Oman to Morocco. Linguists differentiate between two levels of Arabic, namely the Colloquial Arabic on one level and Classical or Literary Arabic and Modern Standard Arabic on another (Alsmearat et al., 2017). Modern Standard Arabic is taught in schools and has no native speakers. The Colloquial Arabic is defined as 'a collective term that refers to the whole range of Arabic vernaculars in numerous local dialects' (Saiegh-Haddad, 2018, p. 2) and it is generally classified into Eastern and Western Arabic (Saiegh-Haddad, 2018). It is noteworthy that the former is spoken in Oman. Moreover, dialects' variations are positively related to geographical distances, which perhaps form a barrier against understanding between people from different regions. In such cases, people tend to speak Modern Standard Arabic that is understood by all Arabs despite that the used vocabulary differs based on the speaker's region (Holes, 2004).

4.1.4 The educational system

The educational system in Oman went through different phases of development as presented in Figure 4.4. Quranic schools were widely distributed in which the Holy Quran is taught in addition to the basics of Islamic sciences, Arabic language, and mathematics. The early formal schools started in the 1930s although formal infrastructure was not available except in three governmental schools (Al-Najar, 2016). Six grades were taught in these three schools with a total capacity of 909 male students in the academic year 1969/1970. In the same academic year, almost 50 female students were registered in an American missionary school. Besides, few students were registered in three small private schools managed by the Hyderabadi community and one technical trade school managed by the Petroleum Development Company (Unesco, 1972).



Key:
GES = General Education System, BEC = Basic Education Curriculum, PBEC = Post Basic Education Curriculum

Figure 4.4: Education development in Oman
[Reproduced from (Al-Najar, 2016)]

In 1970, His Majesty Sultan Qaboos took power in the country and started its modern development. As a result, the systematic education started in Oman represented by the general education system (GES). This system consisted of three stages, namely elementary, preparatory, and secondary. The first stage extended for six years and the others extended for three years each (Al-Najar, 2016; Ja'abub, 2010). Further, the educational system passed through 9 development phases until 2015; each consisted of 5 years and focused on certain aspects. For instance, the first phase (1970-1975) focused on the fast spread of schools besides educating adults and handicapped children. The number of schools increased from 16 to 107. The interest in schools' buildings started in the second phase (1975-1980). The majority of tents and traditional wooden schools were upgraded into durable buildings. In addition, libraries, laboratories, and workshops were constructed in all new schools and were added as annexes to the existing ones (Ministry of Education, 2013).

Following these development phases, the quality of the general education system was evaluated by several studies. Some weaknesses were emphasised specifically in areas like communication, personal skills, study skills, and English language. Consequently, the graduates were not effectively prepared for involvement in higher education or work market (Al-Najar, 2016). The ministry of education responded by introducing the basic education curriculum (BEC) system in 1998. The system is centred on the learner and aims to develop the skills required to meet the demands of higher education and work market. It has two cycles; the first lasts for four years in which both genders study in schools managed by female staff. The students are separated based on their gender in the second cycle that extends for six years. As noted in Figure 4.4, the application of the post-basic education curriculum system (PBEC) started in 2007. In this system, the graduates of the BEC system study for two years. Besides, the students are allowed to select the courses they study based on their interests (Al-Najar, 2016; Ministry of Education, 2013; Ja'abub, 2010).

It should be mentioned that the research reported in this thesis was applied to governmental female high schools. According to the school type, the participated students were enrolled in the 10^{th}, 11^{th}, and 12^{th} grades. The former grade belongs to the BEC system and the other two belong to the PBEC system.

4.1.4.1 The academic year and the typical school day

The academic year consists of around 160 days distributed over two semesters. Figure 4.5 presents the 2015/2016 academic year that

consisted of 88 and 75 studying days in the first and second semesters respectively. It is worth mentioning that the academic year covers the relatively cooler period in Muscat city, which extends from November to March. However, most of the hot and humid months, i.e. April to October, are outside the academic year. Hence, convenient days were selected to conduct the survey considering the teaching activities in each school.

The students in Oman attend schools 5 days a week. The typical day extends for almost seven hours divided into 8 classes each lasts for around 45 minutes. Generally, students spend around 45 minutes in the school plaza distributed as 15 minutes before the first class for the national flag salute and a 30 minutes break after the fourth class. In addition, most classes of physical education are taken in the plaza. It is noteworthy that there are minor variations in the duration and the start time of the school day between schools as well as in the number of breaks and their duration. For instance, there is a minor break of almost 10 minutes towards the end of the day in some schools specified for practising Muslims' second prayer.

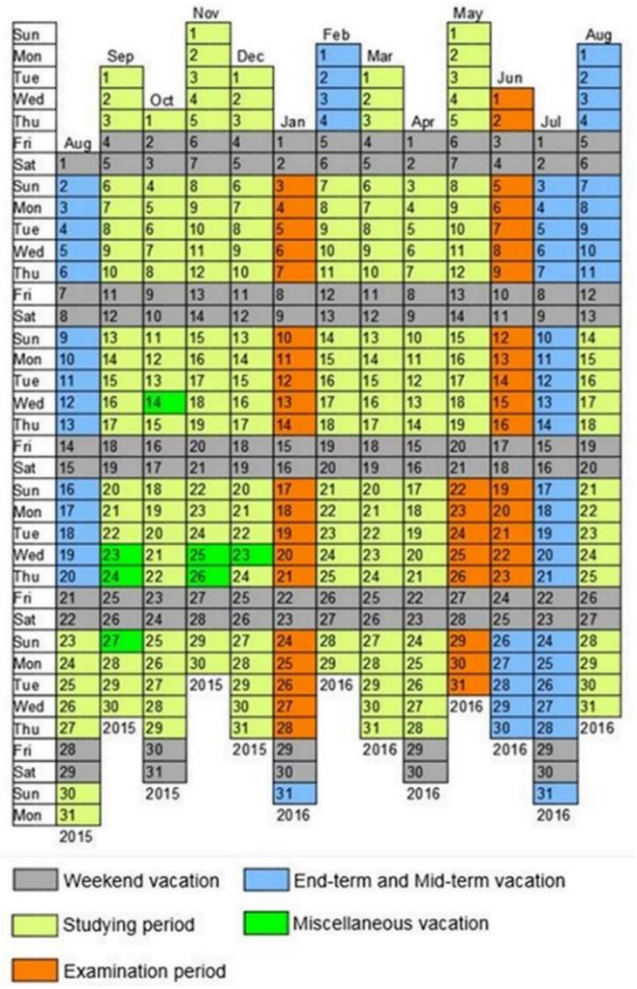


Figure 4.5: The schedule of 2015/2016 academic year

4.1.4.2 The school uniform

In governmental high schools, female students wear a uniform that consists of a white scarf, a white long sleeves blouse, a navy sleeveless dress, white trousers, white socks, and black shoes as presented in Figure 4.6. The overall insulation value is around 1.07 clo (ASHRAE, 2017; Al-ajmi et al., 2008). Generally, students modify their thermal conditions by adding jackets or taking off their headscarves. Besides, another uniform should be worn in physical education classes.



Figure 4.6: Female students' uniform in Omani governmental high schools

4.2 Muscat climatic conditions

Muscat is the capital city of the Sultanate of Oman and it is located at 23.61 °N latitude and 58.54 °E longitude. Based on Koppen-Geiger climate classification, the city is located in a desert hot arid region. Yet, its mountainous nature and proximity to the Indian Ocean changed its climatic conditions to hot and humid (Al-Azri et al., 2013b; Ragette, 2012; Konya & Vandenberg, 2011). In general, there are two distinctive climatic periods; the first starts in April and extends to October and it forms the hot humid period. The rest of the year forms the relatively cooler period.

The climatic data of Muscat city were officially requested from the General Directorate of Meteorology and the obtained data were from Muscat International Airport weather station. Additionally, the average number of wet days and the average daily sunshine hours were obtained from Weather Base website. Details follow below.

4.2.1 Air temperature

The monthly mean, minimum, and maximum air temperatures of 14 years are presented in Figure 4.7. In the hot humid period, the mean temperature extended from around 29.5 °C in April and October to

almost 34.7 °C in June. The maximum air temperature extended between 39.0-45.3 °C approximately in October and May respectively. The range of minimum air temperature was almost 20.9-27.7 °C. Considering the cooler period, the mean temperature roughly extended from 20.8 °C to 25.8 °C in January and November respectively. The maximum and minimum temperatures were around 28.2-35.8 °C and 13.2-17.8 °C respectively.

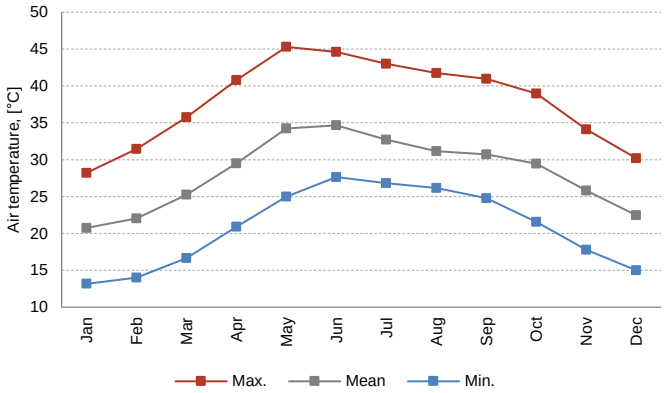


Figure 4.7: Monthly mean, maximum, and minimum air temperature for 2001-2014 [Reproduced from the Omani General Directorate of Meteorology data]

4.2.2 Relative humidity

Figure 4.8 presents the monthly mean, maximum, and minimum relative humidity for 14 years. Considering the hot humid period, the mean relative humidity roughly fluctuated between 41.5% and 74.3% in May and August respectively. The maximum records roughly extended from 93.9% in October to 96.1% in August, whereas the minimum records approximately extended from 6.6% in May to 19% in August. The ranges were smaller in the cooler period. For instance, the mean relative humidity ranged from almost 57.5% to around 65.6% in March and December respectively. The maximum and minimum ranges were around 91.8%-96.0% and 10.9%-27.1% respectively.

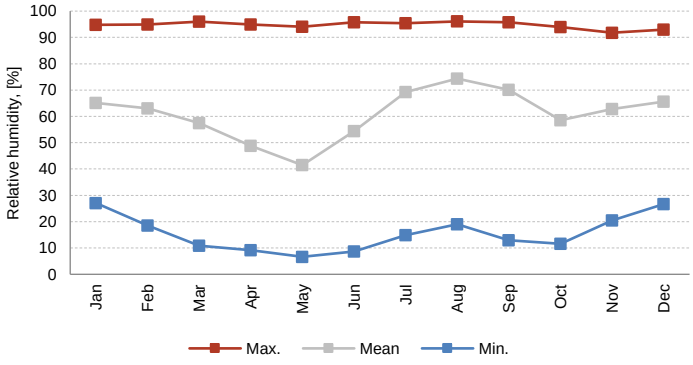


Figure 4.8: Monthly mean, maximum, and minimum relative humidity for 2001-2014 [Reproduced from the Omani General Directorate of Meteorology data]

4.2.3 Wind

The hourly wind data obtained from the General Directorate of Meteorology covered a period of four years. The data were measured at a height of 10 m and were used to plot the wind rose of mean velocity as demonstrated in Figure 4.9. The wind rose was generated using a template excel file from Enviroware web page.

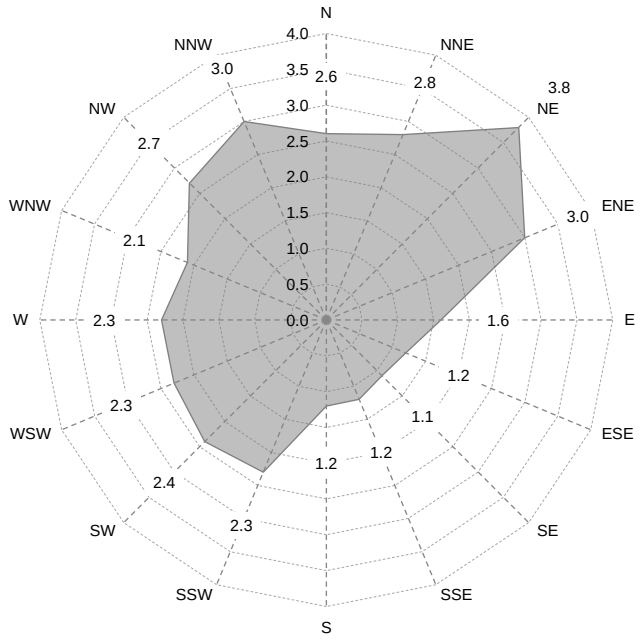


Figure 4.9: Wind rose of mean air velocity [m/s] for 2006-2010
[Reproduced from the Omani General Directorate of Meteorology data]

As noted from the figure, the mean wind velocity ranged between 1.1 m/s and 3.8 m/s. The corresponding directions were south-east and north-east. In general, it is possible to classify the mean wind velocity into three categories, namely:

- 0 ≤ mean wind velocity < 2 from east, east-south-east, south-east, south-south-east, and south directions;
- 2 ≤ mean wind velocity < 3 from north, north-north-east, south-south-west, south-west, west-south-west, west, west-north-west, and north-west directions; and
- 3 ≤ mean wind velocity from north-east, east-north-east, and north-north-west directions

Moreover, the distribution of the wind direction is plotted in Figure 4.10. The dominant direction for the wind is north-east as it blew from this direction for around 15% of the measured period. The frequencies of the other directions were below 10% and can be categorised into:

- Relative frequency < 5% for the directions between east and south including both besides to west-north-west and north-west directions; and

- 5% ≤ relative frequency < 10% for the remaining directions

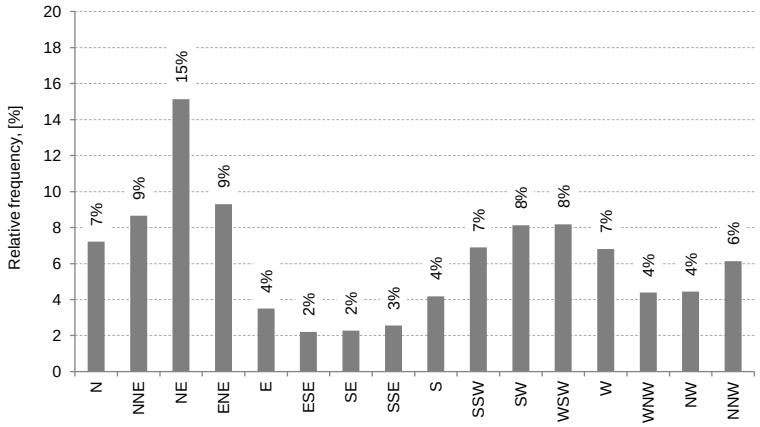


Figure 4.10: Distribution of wind direction for 2006-2010
[Reproduced from the Omani General Directorate of Meteorology data]

4.2.4 Precipitation

The monthly mean and maximum precipitation were computed for 14 years starting from 2001 as presented in Figure 4.11. It is possible to distinguish a rainy period from November to April with monthly means of around 10 mm or slightly higher. January was an exception with a mean of 6.6 mm roughly. In the remaining period, the monthly means were below 3 mm except June that had a mean of almost 6 mm. In addition, September was the driest month with a mean of around 0 mm.

As expected, the pattern of the maximum amount of precipitation was similar to that of the monthly means. The maximum precipitation in June was noticeably higher because of Gonu and Phet cyclones' effect as discussed in Chapter 1. The recorded amounts of precipitation in Muscat International Airport weather station during these cyclones were around 257 mm and 81.6 mm respectively.

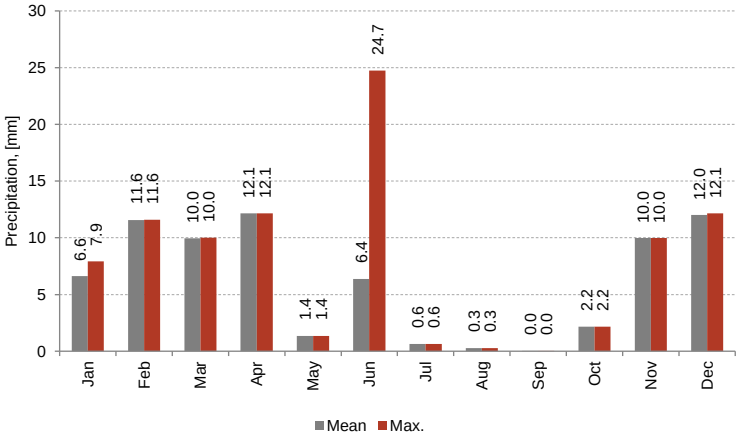


Figure 4.11: Monthly mean and maximum precipitation for 2001-2014
[Reproduced from the Omani General Directorate of Meteorology data]

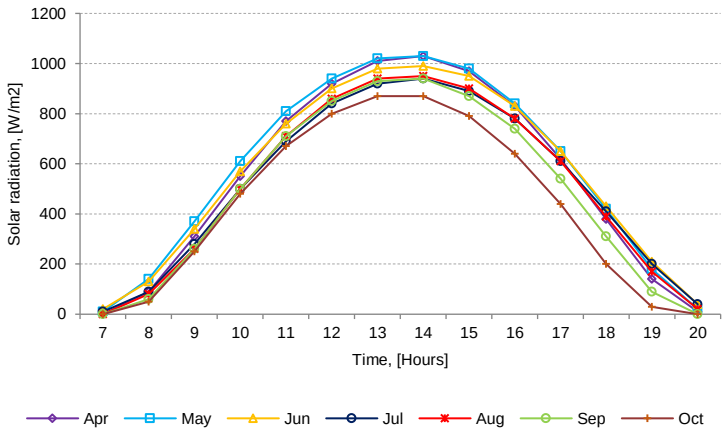
Furthermore, the average number of wet days was obtained from Weather Base website as presented in Table 4.1. As expected, the data followed a similar pattern to that of the mean amounts presented in Figure 4.11. It should be mentioned that the considered period when computing the average number of wet days was not mentioned by the website.

Table 4.1: Average number of rainy days
[Reproduced from (Weatherbase, 2018)]

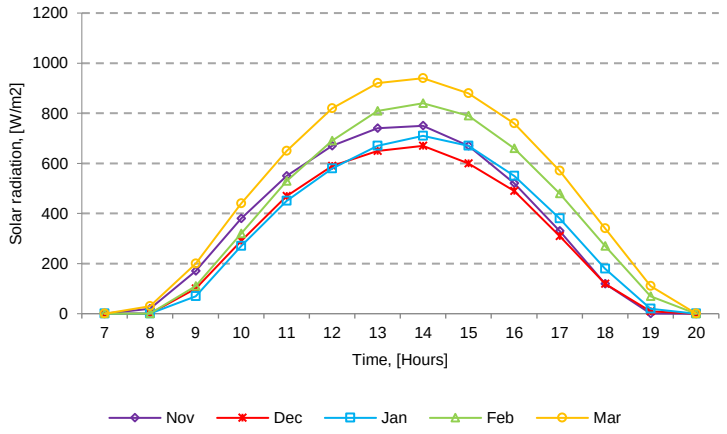
Jan.	Feb.	Mar.	Apr.	May	Jun.	Jul.	Aug.	Sep.	Oct.	Nov.	Dec.
3	5	4	2	1	1	1	1	0	1	1	3

4.2.5 Solar radiation

The hourly mean of solar radiation for each month is plotted in Figure 4.12 for seven years starting from 2001. As noted, the maximum mean extended between 800 W/m^2 and 1000 W/m^2 roughly in summer compared with 600 W/m^2 and 900 W/m^2 approximately in winter.



(a)



(b)

Figure 4.12: Hourly mean of solar radiation for 2001-2007 in: (a) summer, and (b) winter
[Reproduced from the Omani General Directorate of Meteorology data]

Moreover, the sunshine hours were almost constant for all months. The maximum was around 13 hours in summer and the minimum was

around 11 hours in winter. This is generally consistent with the data obtained from Weather Base website as presented in Table 4.2. Yet, both January and December were exceptions as they have a mean of 9 and 10 hours respectively according to the website. The corresponding differences from Figure 4.12 were two and one hours.

Table 4.2: Average daily sunshine hours
[Reproduced from (Weatherbase, 2018)]

Jan.	Feb.	Mar.	Apr.	May	Jun.	Jul.	Aug.	Sep.	Oct.	Nov.	Dec.
9	11	11	11	13	13	12	12	12	11	11	10

4.3 The investigated schools

There are 10 governmental high schools for female students in Muscat. Two of these schools are located in rural areas, which made their participation in the survey inconvenient. Therefore, the primary list of schools consisted of a convenient sample that included eight governmental schools. They are Shatti Al-Qurum (SQ), Ummamah bint Abi Al-Aas (UA), Al-Mubailaa Al-Janubia (MJ), Dohat Al-Adab (DA), Nusiba bint Kaab (NK), Al-Wadi Al-Kabeer (WK), Zubaida Um Al-Ameen (ZA), and Hil Al-Awamer (HA) Schools. It is noteworthy that private schools were excluded because of the generally small number of students in each classroom. In Figure 4.13, the selected schools' locations are presented with reference to Muscat International Airport.



Figure 4.13: The geographical distribution of the selected schools with reference to Muscat International Airport
[Reproduced from Google Maps]

The architectural designs and construction dates of the selected schools are different. As presented in Figure 4.14, the schools were classified into four groups, which are courtyards, clustered courtyards, linear form, and a combination of courtyards and wings. One school was selected from each group to participate in the survey, namely (SQ), (NK), (DA), and (ZA) Schools. Moreover, (WK) School was selected as it has three floors, unlike the other schools that have two floors only. More details about the schools and the investigated classrooms are presented in the following sections.

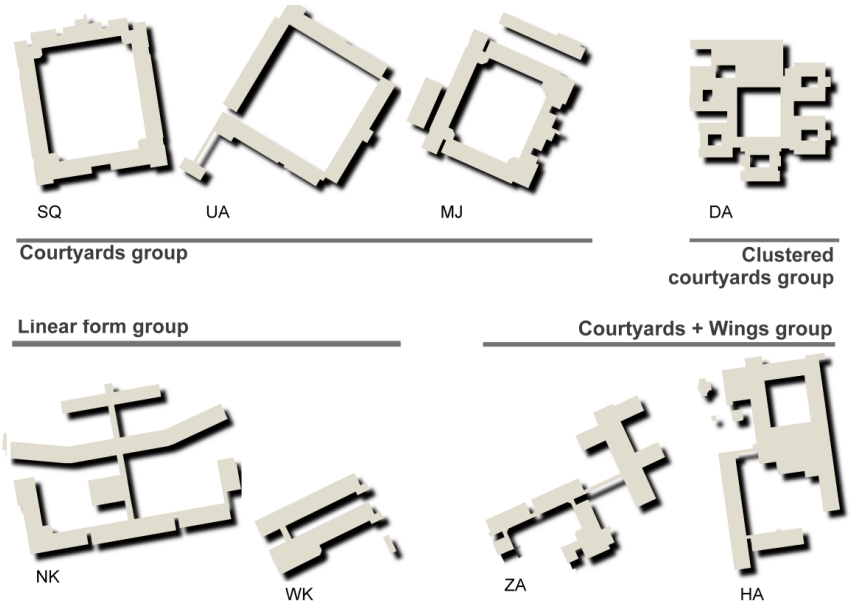


Figure 4.14: The groups of the investigated schools

4.3.1 Shatti Al-Qurum (SQ) School

Shatti Al-Qurum (SQ) School is around 0.5 km from the Gulf of Oman and almost 1.2 km from the main street in Muscat. It was chosen to participate in the survey owing to the frequent complaints of the students and teachers from the humidity level in the survey's early visits. The school was opened in 1993. The internal courtyard has an area of around 3250 m^2 and it forms the school's plaza as presented in Figure 4.15. Almost half of the plaza area is shaded with a steel structure shade. The classrooms are located on the southern side of the ground floor and the eastern, western, and southern sides of the first floor. The northern side of the building is mainly equipped with administrative spaces on both floors. Other educational spaces equip the eastern and western sides of the ground floor.

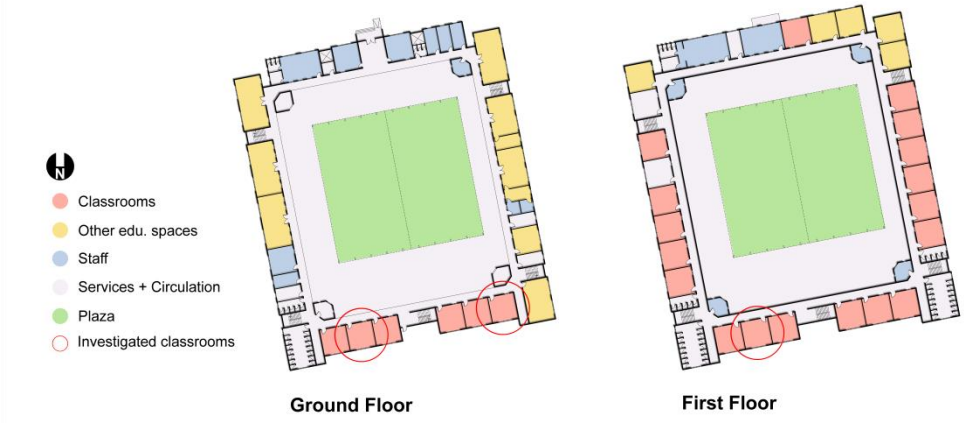


Figure 4.15: Schematic plans of Shatti Al-Qurum (SQ) School

There are 24 identical classrooms in the school. Each classroom has an estimated area of 49 m^2 each and an average number of

students of 32. As presented in Figure 4.15, the explored classrooms are located on the southern side of the building and are surrounded from the north by open corridors. In the ground floor, one of the explored classrooms is adjacent to another classroom from the west. The other investigated classroom is adjacent to two classrooms from the east and the west. Above this classroom was the third investigated classroom that shares its eastern and western walls with other two classrooms. It is worth mentioning that all the explored classrooms have two split air conditioning units and two ceiling fans. Windows are single glazed and are located on the northern and southern walls. Besides curtains, the northern windows are shaded by open corridors and the southern windows are shaded by short external shading shelves. Some photos from the school are displayed in Figure 4.16.

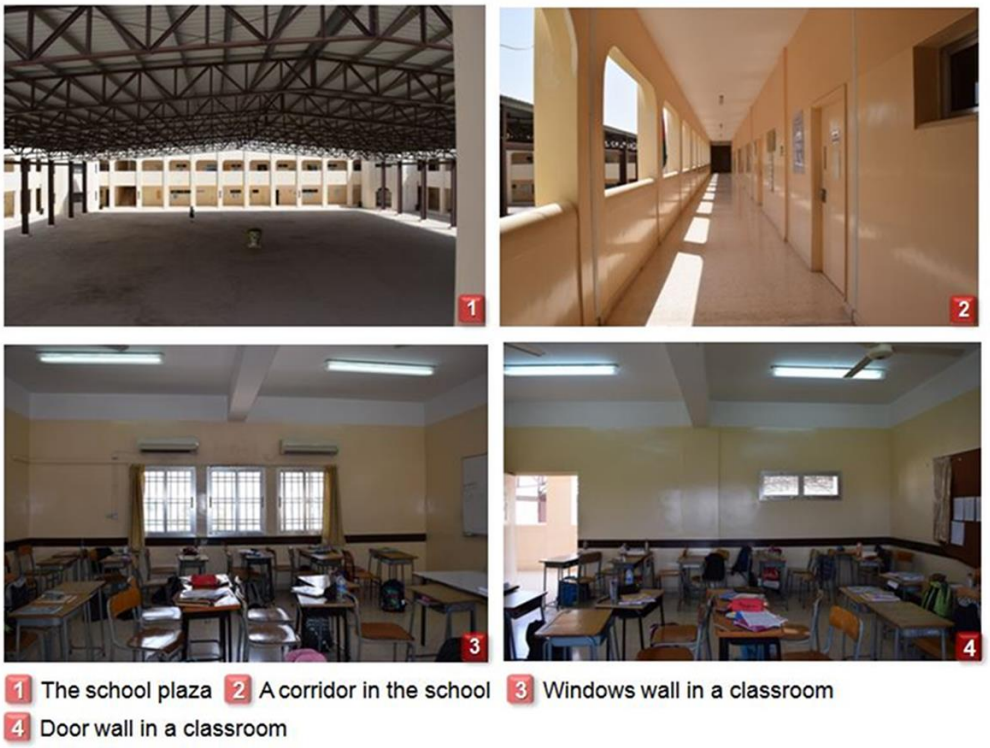


Figure 4.16: Selected photos from Shatti al-Qurum (SQ) School

4.3.2 Dohat Al-Adab (DA) School

Dohat Al-Adab (DA) School is located within an active commercial area that is close to a relatively dense residential region. Besides, the main highway in Muscat is around 100 m far. The school was opened in 1983 and it is the only one in the clustered courtyards group. Currently, it has an area of 4250 m^2 approximately with a western main façade. The school consists of seven courtyards as presented in Figure 4.17. The main shaded courtyard has an estimated area of 105 m^2 and it forms the school plaza where the flag salute and most physical education classes take place. The school contains 25 classrooms that

mainly extend on an east-west axis and are distributed in two floors around two small courtyards. Other educational spaces surround another two courtyards.

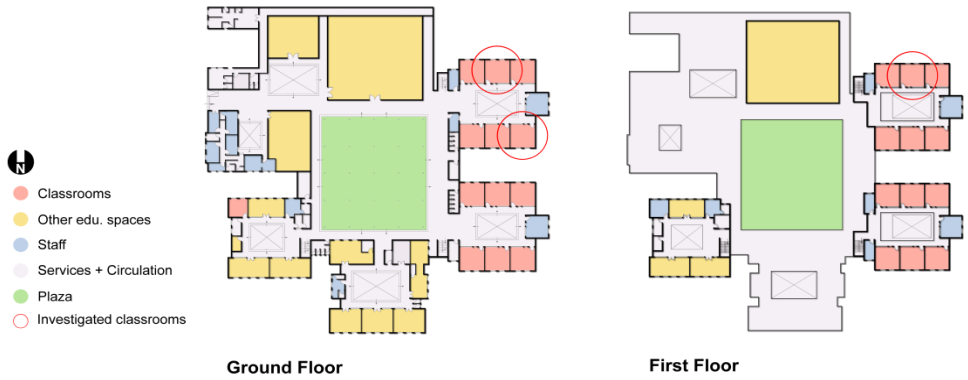


Figure 4.17: Schematic plans of Dohat Al-Adab (DA) School

The investigated classrooms were selected from one courtyard, as observed in Figure 4.17, owing to some restrictions from the school administration. One of the investigated classrooms in the ground floor has a main northern façade shaded by an open corridor with its western side adjacent to another classroom. The other investigated classrooms are above each other and they share their eastern and western sides with other classrooms. All classrooms have an area of around 33 m^2. Besides, they have three split air conditioning units and two ceiling fans. They have two large windows opposite to the door and a strip of short high windows, on the door side, used mainly to enhance natural lighting levels. Some photos of the school are displayed in Figure 4.18.



Figure 4.18: Selected photos from Dohat Al-Adab (DA) School

4.3.3 Nusiba bint Kaab (NK) School

Nusiba bint Kaab (NK) School is located within a dense residential area at an estimated distance of 1 km from the Gulf of Oman. It was opened in 1996 and it has a north-south central corridor that connects

the three linear masses of the school that extend on an east-west axis. The plaza is shaded and has an estimated area of 518 m^2. As noted in Figure 4.19, the administrative spaces are located in the northern mass. The classrooms and other educational spaces equip the two floors of the other masses. Most spaces in the school are connected to the central corridor from the north via narrower open corridors. However, reaching a few spaces require crossing the plaza or outdoor areas mainly due to constructing additional spaces in the school and, thus, breaking the circulation continuity. As a result, students and teachers frequently walk under the sun for one or two minutes. It is noteworthy that the school has two small water fountains; one is in front of the administration mass and the other is between this mass and the classrooms. A photo of the latter fountain is presented in Figure 4.20.



Figure 4.19: Schematic plans of Nusiba bint Kaab (NK) School

Although the school has 37 classrooms, only 26 are used with an average number of students of around 26 per classroom. The explored classrooms have an area of around 50 m^2 each. They extend in an east-west axis and are shaded from the north by corridors. One of the explored classrooms on the ground floor shares its western side with another classroom, which leaves its southern and eastern sides without shading. The other classroom shares the eastern and western sides with other classrooms. Above this classroom is the third explored classroom. It should be mention that all classrooms have two split air conditioning units and two ceiling fans. Located on the northern and southern walls, the windows are single glazing and are often covered by curtains. Figure 4.20 displays some photos from the school.

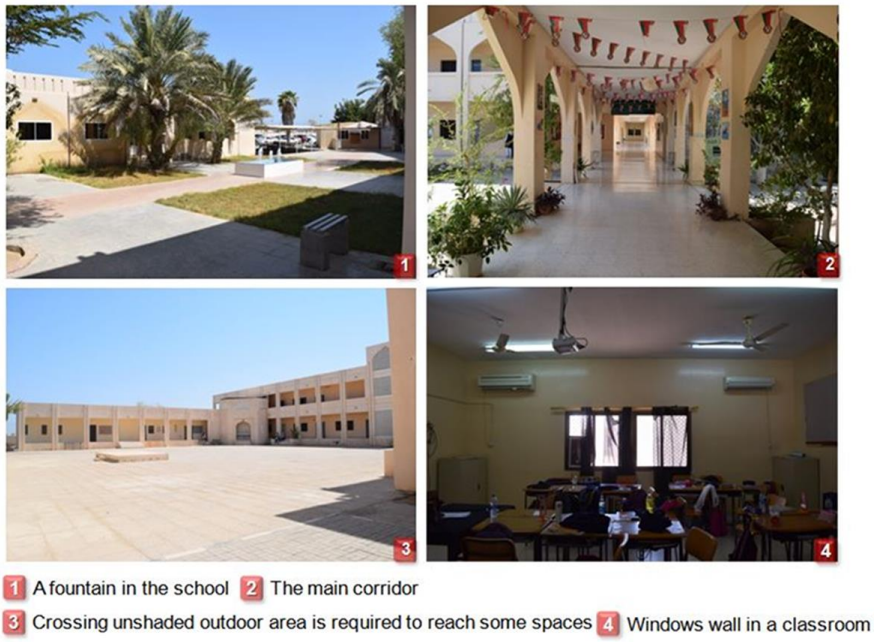


Figure 4.20: Selected photos from Nusiba bint Kaab (NK) School

4.3.4 Al-Wadi Al-Kabeer (WK) School

Al-Wadi Al-Kabeer (WK) School is located in a narrow valley area that represents one of the densest regions in Muscat city. The valley, called Al-Wadi Al-Kabeer, is characterised by hot air temperatures due to the urban heat island effect (Charabi & Bakhit, 2011). As presented in Figure 4.21, the school consists of two linear masses connected by a corridor. The area between them is shaded by fabric as displayed in Figure 4.22. The school was constructed at two stages. The northern mass was added in the second stage and the school was opened in 1989 with a total area of around 1400 m^2. It was selected to participate in the research because it is the only school that has three floors. The administrative spaces and some educational spaces are located on the ground floor. Besides, there are 14 classrooms and they equip most of the area in the first and second floors. Despite that the plaza, where the flag salute and physical education classes take place, is shaded, the students and teachers often complain from glare. Sunrays penetrate the plaza due to a difference in the height of the plaza's shade and the school outer wall.

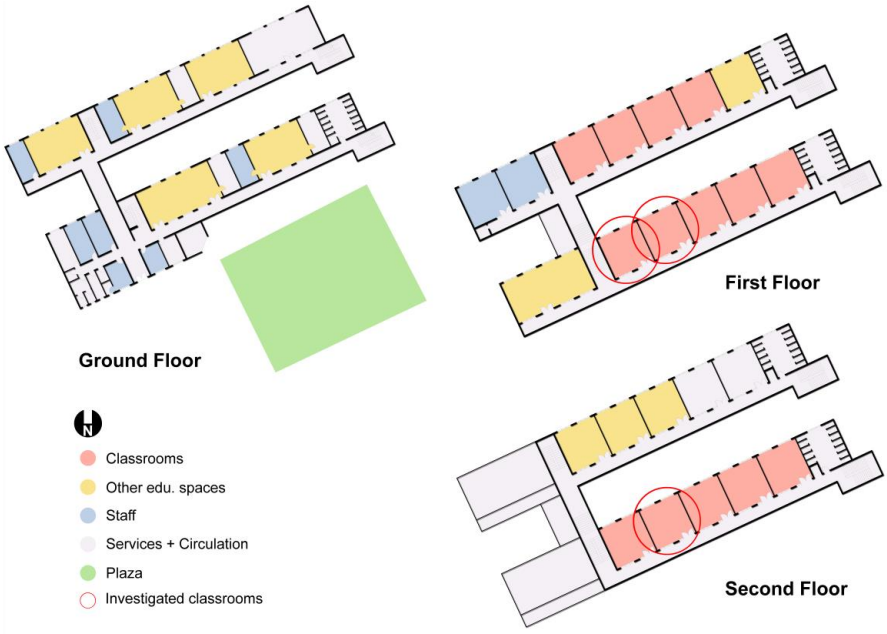


Figure 4.21: Schematic plans of Al-Wadi Al-Kabeer (WK) School

The investigated classrooms are located in the southern mass as observed in Figure 4.21. They are shaded from the south by the open corridors and from the north by the fabric shade between the school masses. The investigated classrooms share their eastern and western sides with other classrooms and have an estimated area of 51 m^2 each. Each classroom has two split air conditioning units and four ceiling fans. The windows are single glazes and are located in the northern and southern walls. Additionally, curtains were available in the investigated classrooms.

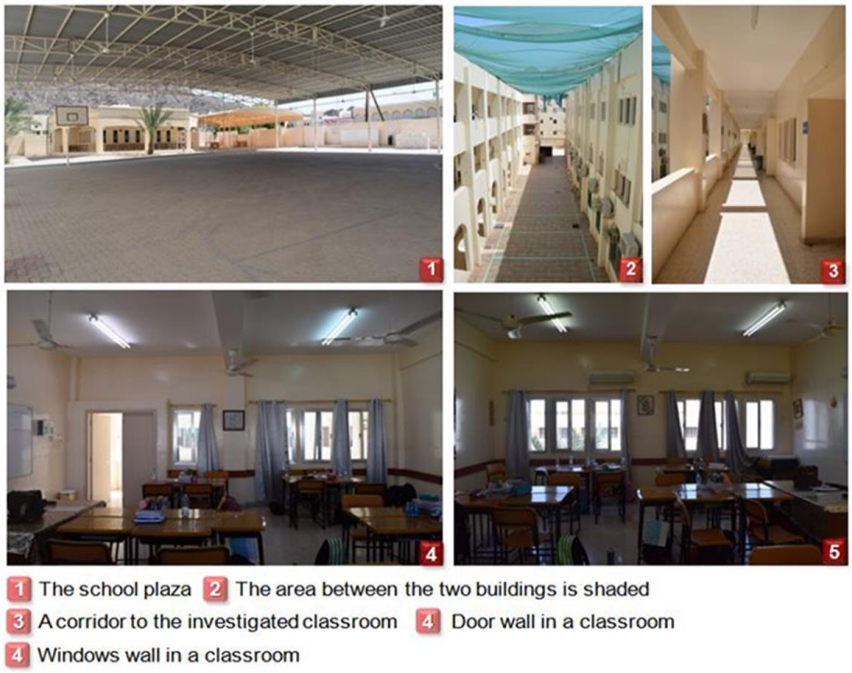


Figure 4.22: Selected photos from Al-Wadi Al-Kabeer (WK) School

4.3.5 Zubaida Um Al-Ameen (ZA) School

Zubaida Um Al-Ameen (ZA) School was selected to participate in the research because of its urban context. Located within a residential area that is surrounded by mountains, the school is on the side of the main road in the region and it is less than 1 km from the Gulf of Oman. It was opened in 1980 with a built-up area of around 2260 m^2. As presented in Figure 4.23, the school consists of two buildings. The first has an unshaded courtyard with an area of around 770 m^2. In the ground floor, the courtyard is surrounded by classrooms and other educational spaces except for the south-west corner. Considering the first floor, only the south-east corner is constructed and it contains an administrative space and other educational spaces. The other building has a linear form from which three short wings extend. The wings are equipped with classrooms except two on the ground floor where administrative spaces are located. Besides, the plaza has an area of around 205 m^2 and it is located between the eastern wings. It has fabric shading and some fans as presented in Figure 4.24. The two buildings are connected by stairs owing to a difference in the height of their ground levels. The difference is estimated, from the stairs, at 3 m.

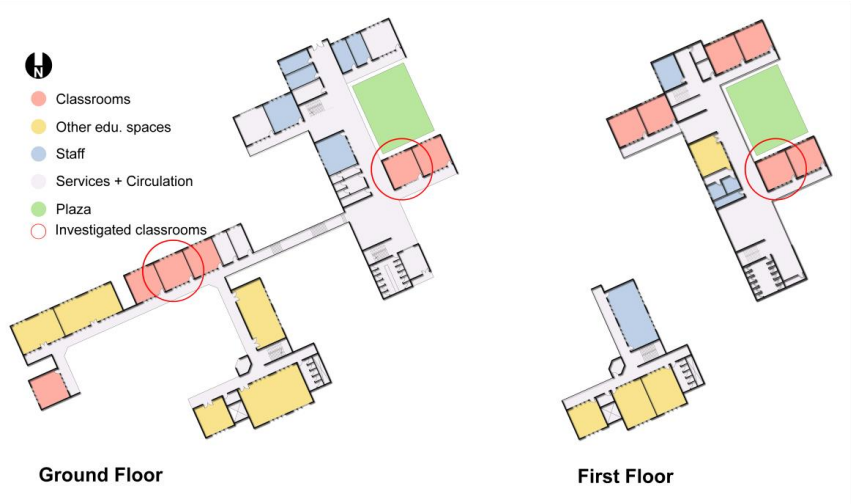


Figure 4.23: Schematic plans of Zubaida Um Al-Ameen (ZA) School

There are 12 classrooms in the school; however, only 10 are in operation. The classrooms have an identical area of almost 48 m^2 and an average number of students of around 27. As noted in Figure 4.23, one of the investigated classrooms is located in the first building, i.e. the courtyard, and it shares its eastern and western sides with adjacent classrooms. Its southern side is shaded by the open corridor. The other two classrooms are above each other in one of the wings of the other building. They share their eastern walls with other classrooms. In this school, all classrooms have two split air conditioning units and two ceiling fans. Often covered by curtains, the windows are single glazed

and are distributed as two on the southern wall and two on the northern wall. Some photos for the classrooms and other spaces in the school are displayed in Figure 4.24.

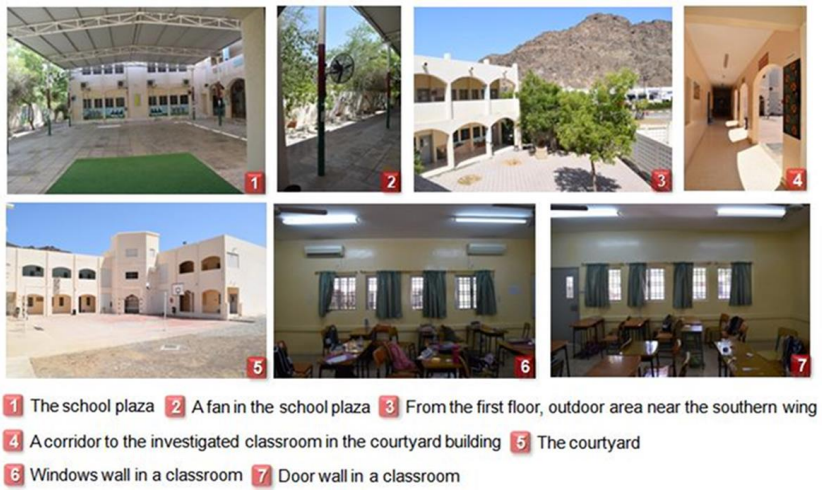


Figure 4.24: Selected photos from Zubaida Um Al-Ameen (ZA) School

4.4 Survey selected periods

Considering the climatic conditions of Muscat city as discussed in Section 4.2, it is possible to select February, or December, to represent the cooler period and select July to represent the warmer period. Yet, the survey was conducted in September and March. This is explained in Figure 4.25 that represents the academic year with reference to the two climatic periods of Muscat. For the cooler period, December was not selected as it represents a busy studying period as the examination period follows this month. Similarly, February was not selected because most schools' administrations preferred to conduct the survey after two weeks from the start of each term in order to allow students to settle in their classrooms and studies. In addition, it should be mentioned that schools mostly celebrate the Teachers' day that coincides on the 24th of February. Yet, the celebration itself may be on another date according to the circumstances in each school. Moreover, November was not selected to avoid students' boredom as the warmer period survey was conducted in September. The latter was selected mainly due to its closeness to July, which is the representative month of the hot humid period.

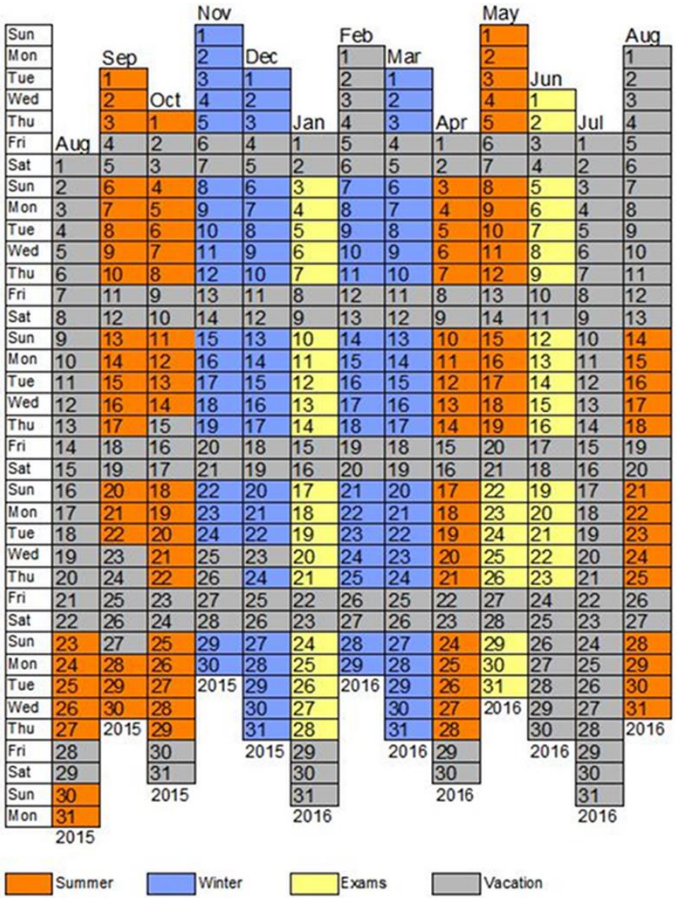


Figure 4.25: Climatic classification of 2015/2016 academic year

4.5 Conclusion

Located at the eastern edge of the Arabian Peninsula, Sultanate of Oman is characterised by three different topographical regions with different climatic zones. The majority of Omani people are Muslims and speak the Eastern Colloquial Arabic. Besides, the educational system went through several development phases since the 1930s. With reference to the 12 grades of the educational system, the explored students were from the last three grades with a clothing level of 1.07 clo approximately. It is possible to consider the survey period as a convenient period because the academic year is not representative from a climatic point of view.

The survey was performed in Muscat, the capital city of Oman. In general, Muscat is characterised by two climatic periods. The first is hot humid and it extends from April to October including both. The other period is relatively cooler and it includes the remaining months. The mean air temperature fluctuates from 29.5 °C to 34.7 °C approximately in the warmer period, whereas it ranges from 20.8 °C to 25.8 °C roughly in the cooler period. The corresponding ranges of relative humidity are around 41.5%-74.3% and 57.5%-65.6% respectively.

There are ten governmental high schools for female students in Muscat from which eight schools formed the primary list of the selected schools of the thermal survey. Based on their architectural design, five schools formed the final list of the investigated schools. These are Shatti Al-Qurum (SQ) School from the courtyards group, Dohat Al-Adab (DA) School from the clustered courtyards group, Nusiba bint Kaab (NK) School and Al-Wadi Al-Kabeer (WK) School from the linear form group, and Zubida Um Al-Ameen (ZA) School from the combination of courtyards and wings group. Three classrooms were selected in each school to participate in the thermal survey. In addition, the survey was conducted in March and September although they are not representative from a climatic perspective. Both months were convenient as they were free from examinations.

Part (2):
Methodology

Chapter (5):

Methodology and Pilot Studies' Results

Chapter 5 Methodology and pilot studies' results

Thermal comfort studies are generally classified into rational and empirical studies and conducting a fieldwork survey is the core of any empirical study of thermal comfort. Basically, sensors measure the physical variables of the explored environment and the questionnaires record the subjective responses of the involved participants. The aim of this research is exploring the thermal conditions of Omani female students in high schools and investigating their interpretation of thermal scales. To achieve this, the participated schools were visited several times. Two pilot studies were carried out in the first two main visits. The third main visit represented the summer study and the fourth was the winter study. The explorations of the students' interpretation of thermal scales were performed in the second, third, and fourth main visits.

This chapter focuses on the methodology of empirical studies. It starts with a brief presentation of the concepts of the rational and empirical studies followed by a brief presentation of the used sensors in the latter studies and the required levels of accuracy. Besides, it briefly presents some issues related to questionnaires' design and testing, data preparation for analysis, and methods for extracting information from questionnaires. In the second part of the chapter, the research strategy and the followed experimental protocol are presented with a special focus on the survey preparations, sensors' selection criteria, distributed questionnaires' types, and the methodology limitations. The chapter is concluded by discussing the findings of the first and second pilot studies presenting their objectives in addition to the generated conclusions regarding the selected sensors, questionnaires' design, experimental protocol, and analysis procedure.

5.1 Classification of thermal comfort studies

In their simplest forms, thermal indices integrate the influence of several factors on human thermal environments into a single value that represents thermal sensation (Parsons, 2014). It is possible to classify thermal studies into two major categories according to the approach followed in their formulation. The first is the rational or analytical studies that depend on climate chambers' experiments. They are based on heat balance model and, thus, compute comfort zone considering physical and physiological factors like skin temperature and wettedness. The second category is the empirical studies that depend on field surveys conducted in ordinary environments (Nicol et al., 2012; Singh et al., 2011; Auliciems & Szokolay, 2007). More details are discussed below.

5.1.1 Rational studies

5.1.1.1 Rational studies' concept

Early analytical studies, like those of Gagge and Fanger, rely on heat balance model. This model is widely known as the constancy or static model because it limits people's role in their thermal environments by considering them as passive receivers of thermal stimuli. For this model, the physiological adaptation is the main mechanism by which the human body retains its core temperature in the attempt to respond to the changes in thermal ambience as displayed in Figure 5.1. The reasonably replicable nature of rational studies may be owing to the limited availability of adaptive opportunities in climatic chambers (Singh et al., 2011; Brager & de Dear, 1998).

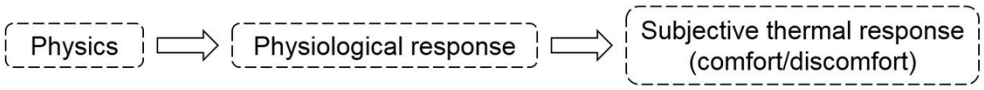


Figure 5.1: The logic of heat balance model
[Reproduced from (Singh et al., 2011; Brager & de Dear, 1998)]

A typical analytical index is the Predicted Mean Vote (PMV) that is based on Fanger's equation that relates thermal sensation to subjects' physiological state. The index associates thermal comfort with climatic conditions, clothing level, and metabolic rate. The latter is estimated considering skin temperature and sweat production (Parsons, 2014; Peeters et al., 2009; Auliciems & Szokolay, 2007). Accordingly, four conditions should be satisfied in order to achieve thermal comfort. These are reaching a heat balance of the human body, keeping both sweat rate and mean skin temperature within a comfortable range, and achieving an absence of local thermal discomfort (Parsons, 2014).

5.1.1.2 Rational studies' criticism

The rational approach is often criticised owing to its focus on the physiological conditions and ignorance of the psychological and social aspects of thermal comfort (Nicol & Roaf, 2017). For most rational indices, reaching optimum thermal conditions involves reaching thermal balance. Yet, this does not guarantee thermal comfort. For instance, producing sweat in hot conditions may achieve thermal equilibrium but not necessarily comfort (Parsons, 2014; Nicol et al., 2012) as the latter does not relate to physiology only. Besides, rational indices tend to ignore the dynamic interaction between people and their ambience. This is partially owing to the nature of climate chambers where subjects lack familiarity with space, which affects the results negatively (Nicol et al., 2012; Wang, 2006a).

Although Fanger's model accounts for the effect of solar radiation on thermal comfort, through computing the mean radiant temperature, it may not do so accurately. This may be due to the contradiction between the model's assumption of acclimatization and the dynamic nature of solar radiation as well as the possibility to avoid the latter via changing location for instance (La Gennusa et al., 2007). Moreover, it should be mentioned that PMV is highly sensitive to the minor variations in mean radiant temperature. In general, applying different calculation methods or utilising various sensors can result in such variations. This sensitivity adds to the model's complexity especially in moderate environments where calculating a reliable value of mean radiant temperature is generally difficult (Hasan et al., 2016; d'Ambrosio Alfano et al., 2013a).

Besides, rational models may add some complexity to the process of architectural design as their equations request clothing and activity levels. Usually, the values are not precisely known (Jazizadeh et al., 2013; Nicol et al., 2012; Singh et al., 2011; Brager & de Dear, 1998). In these situations, most designers make a simple, though unrealistic, assumption of static indoor design temperature (Hasan et al., 2016; Nicol et al., 2012). Consequently, excessive energy consumption and health problems result from potential overheating and overcooling (Mendell & Heath, 2005). Additionally, the dependence on tabulated metabolic and clothing levels may contribute to the prediction errors. This is because tables generally ignore the climate influence on clothing like looseness (Nicol et al., 2012).

5.1.2 Empirical studies

5.1.2.1 Empirical studies' concept

Empirical studies rely on fieldwork and emphasis on behavioural adaptation (Djongyang et al., 2010). This emphasis evolves from the adaptive principle that is identified as 'If a change occurs such as to produce discomfort, people react in ways which tend to restore their comfort' (Nicol, et al., 2012, p. 8; Nicol & Humphreys, 2002, p. 564). Therefore, people are involved in active interaction with their thermal surroundings to avoid discomfort (Parsons, 2014). In general, adaptive actions are classified into those taken to regulate the rates of body heat generation or loss, actions to regulate or change thermal ambience, and actions to modify the body's physiological conditions (Nicol et al., 2012; Roaf et al., 2005).

5.1.2.2 Empirical studies' criticism

To some extent, the accuracy of empirical studies' findings is related to the size of the collected data. Thus, achieving high accuracy

may involve causing subjects' disturbance or increasing fieldwork size. In addition, the empirical studies are restricted by tight time schedules as they measure realistic climatic conditions. Normal fluctuations in these conditions are a potential source of error. Thus, checks should be performed to ensure that the survey time is climatically representative for the investigated region. However, performing such checks is not possible before conducting the survey.

Furthermore, the adaptive approach equations do not explicitly reflect all the major factors that influence thermal comfort such as air velocity and mean radiant temperature (Nicol & Roaf, 2017; Halawa et al., 2014; Halawa & van Hoof, 2012; Singh et al., 2011; La Gennusa et al., 2007). Yet, indoor comfort temperature calculated by the adaptive approach is often expressed as operative temperature, which implies its consideration of mean radiant temperature. Additionally, the equations' ignorance of clothing level may seem contradictive considering the importance of this mechanism in achieving thermal adaptation from the model point of view (Halawa & van Hoof, 2012).

Finally, it is noteworthy that measurements' errors are unavoidable for both rational and empirical studies as this type of error is associated with measuring environmental factors that are required in all thermal comfort studies (Nicol et al., 2012).

5.2 Empirical studies' methodology

The empirical studies of thermal comfort involve conducting field surveys that require good planning because of the associated financial and logistical requirements in addition to the complexities resulted from subjects' involvement (Nicol et al., 2012). These surveys are classified based on their duration and measurements as illustrated in Figure 5.2. Considering the timeframe, the surveys are categorised into transverse and longitudinal. In the former, questionnaires are distributed within a short period, mostly one day, on a large sample of subjects. Oppositely, longitudinal questionnaires depend on a small sample of participants reporting their votes repetitively for a longer period. In the transverse surveys, subjects' annoyance and sampling bias are minimised; yet, the results' limitations are increased due to the narrow climatic differences. The inverse is valid for longitudinal surveys. An intermediate approach is the repeated transverse that combines the advantages of large samples and repetitive reporting of sensation votes (Nicol et al., 2012).

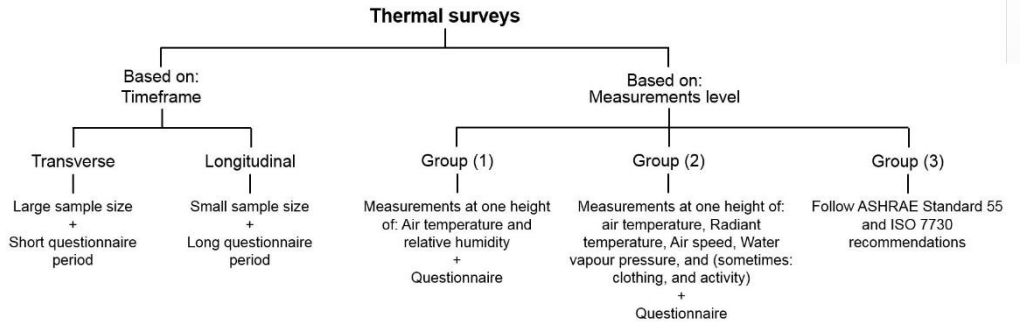


Figure 5.2: Classifications of thermal comfort surveys [Reproduced from (Nicol et al., 2012; Brager & de Dear, 1998)]

Considering the measurements' level, thermal surveys are classed into three groups as illustrated in Figure 5.2. Most early work of the adaptive approach falls within the first group. Usually, an average daily temperature is recorded due to its correlation with comfort temperature. Sometimes, mean operative temperature is used as it accounts for the effect of both air and mean radiant temperatures. The comprehensive arrangements of the third group facilitate comparing the findings with those of the analytical models (Nicol et al., 2012; Brager & de Dear, 1998).

5.2.1 Objective measurements

Despite the accuracy of the instrument's display, which is known as the sensor's precision or resolution, it is always advised to compare the measurement accuracy of concerned instruments with others that have well-known accuracy. The required and desired levels of accuracy differ based on the study purpose. Generally, the accuracy levels recommended for most thermal comfort studies are displayed in Table 5.1. For the calculations of mean radiant temperature, it is advised to maintain an identical accuracy of the air and globe temperatures' sensors. In addition, some references suggest accuracy level of 10% and 5% for air velocity and relative humidity respectively (Burt, 2012; Nicol et al., 2012; BS EN ISO 7726, 2001).

Table 5.1: Required and desired accuracy levels of sensors for thermal comfort studies [Reproduced from (Parsons, 2014; BS EN ISO 7726, 2001)]

	Air temperature	Mean radiant temperature	Air velocity	Water vapour pressure
Required	±0.5	±2	± (0.05 + 0.05 v)	±0.15
Desired	±0.2	±0.2	± (0.02 + 0.07 v)	±0.15

Ideally, physical measurements should accurately record the subjects' thermal environment. Thus, besides the careful considerations of instruments' accuracy, it is advised to maintain a horizontal distance of 1 m between the subjects and the sensors to overcome the subjects' effect on air temperature and velocity. Considering seated people, an optimum vertical height of sensors is 0.6 m from the floor level. This

height represents the breathing height of seated people. Additionally, it is recommended to consider the representative points of the space like its centre. Under all circumstances, sensors should not be subjected to unnecessary air draughts or direct sunrays unless similar conditions are experienced by the participants (Dias Pereira et al., 2014b; Nicol & Humphreys, 2002; BS EN ISO 7726, 2001).

5.2.1.1 Air temperature

Traditionally, measuring air temperature involves using a whirling or sling hygrometer. The hygrometer composes of two thermometers surrounded by a frame as demonstrated in Figure 5.3. Before reading the temperature, the device should be rotated for at least four minutes. Consequently, the convective heat exchange between the surrounding air and the thermometer increases and, therefore, it becomes possible to read the dry bulb temperature. The radiant exchange can be ignored compared with the increase in convective heat exchange. The other thermometer is covered by gauze immersed in distilled water from a small container. The whirling movement increases water evaporation and, thus, allows for the wet bulb temperature reading (Szokolay, 2014; Nicol et al., 2012).

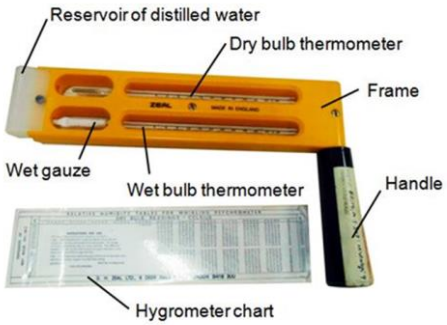


Figure 5.3: Whirling or sling hygrometer
[Reproduced from (Parsons, 2014; Mollyee, 2013)]

Regardless of its type, the air temperature sensor should maintain good contact with the ambient air to record accurate readings. Yet, care should be taken to ensure its protection from the influence of radiant heat reflected from surrounding objects. Several procedures have been equipped to ensure this isolation (BS EN ISO 7726, 2001). Typically, outdoor variables are measured by positioning thermometers inside a Stevenson screen, which is a white louvred box with an enclosed top and a north-facing door in the northern hemisphere. It is usually mounted at a height of around 1.2 m to 2 m. Home-made versions are allowed due to the expensive cost of Stevenson screens, especially if there is no need to compare measurements with other stations records (Burt, 2012; Brown, 2010). For indoor measurements, small sensors are

widely used as their size correlates inversely with convection and radiation heat exchange. Alternatively, sensors are covered by a metallic shield that has limited radiant heat exchange owing to the low emissivity of metals (Nicol et al., 2012).

5.2.1.2 Globe temperature

As mentioned earlier, it is acceptable to approximate the radiant temperature by the globe temperature in order to reduce its measuring errors. The latter is measured by a thermometer located inside the centre of a black sphere. Typically, the sphere has a 150 mm diameter. However, several studies revealed that smaller diameters, particularly 40 mm, resembles the human response to the combined influence of radiation and convection heat exchange better (Szokolay, 2014; Nicol et al., 2012). It is noteworthy that spherical sensors are usually used for the measurements of seated subjects, whereas ellipsoid sensors are used for standing subjects (BS EN ISO 7726, 2001).

The sensor's response time is affected by the sphere's thermal properties, material, and thickness. Precautions should be taken to ensure airtightness as air presence in the sphere may lead to wrong readings. One reading of globe temperature for the whole space is often sufficient for most internal spaces. In the case of inhomogeneous environments, measurements should be recorded for each subspace (Szokolay, 2014; Nicol et al., 2012).

5.2.1.3 Air velocity

Traditionally, Kata thermometer is used to measure air velocity. As presented in Figure 5.4, it consists of a bulb located inside a glass tube that has two graduations. Air velocity is estimated from the time required for heated alcohol inside the glass tube to return to its position between the two graduations. Despite that the measured temperature accounts for turbulence influence and average velocity in a certain period, Kata thermometers are demanding and time-consuming (Nicol et al., 2012; Chadderton, 2007).

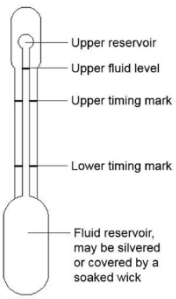


Figure 5.4: Kata thermometer
[Reproduced from (Chadderton, 2007)]

Currently, air velocity is measured by hot-wire or heated-sphere anemometers. In the former, an electrical current is passed to heat a fine wire. Either the current or the temperature should be kept constant. Despite its rapid measurement, this anemometer is direction-dependent as it was originally designed for use in air ducts in which flow direction is known. In general, hot-wire anemometers with constant temperature are preferred due to their results' reproducibility. The heated-sphere anemometer has a sphere that contains a heated object. The difference in temperature between this object and air determines the velocity. In addition, the sphere's diameter affects the anemometer's reaction time and interaction with the thermal surroundings (Nicol et al., 2012; BS EN ISO 7726, 2001).

It is worth mentioning that the cooling effect of air velocity depends on its mean value and the fluctuations caused by turbulence. Besides, air velocities below 0.1 m/s can be ignored as they are due to natural convection resulted from human body heat. It is advised to explore air movement pattern in the investigated spaces as rapid variation in its magnitude and direction complicates measurements. Among several methods, using thistledown, a smoke puffer, a helium-filled balloon that remains constant in still air, or even moving in the space with careful observation are simple, yet effective, procedures to understand the air pattern (Parsons, 2014; Nicol et al., 2012).

5.2.1.4 Water vapour pressure

Water vapour pressure is normally constant in most spaces; thus, one measurement is often sufficient. Traditionally, it is measured using whirling hygrometer, Assman psychrometer, or dew-point hygrometer. Using whirling hygrometer, it is directly obtained from the hygrometer chart by computing the difference between the air temperature and the wet bulb temperature. Despite its high accuracy, Assman psychrometer is not widely used owing to its big size as it requires a fan to move air towards the thermometer. When measuring water vapour pressure using a dew-point hygrometer, air temperature is replaced by dew point. The latter is the condensation temperature of air vapour. Although some wet and dry thermocouples are accompanied with dataloggers, they are not recommended due to possible wrong results in cases of fan absent, gauze dryness, or water pollution (Nicol et al., 2012; BS EN ISO 7726, 2001).

5.2.2 Subjective measurements

In thermal surveys, subjective data are recorded by questionnaires and interviews. Usually, self-completion questionnaires, widely known as self-administrated, are used because of their rapid and economic

distribution. There are several forms like postal, e-mail, and supervised. In all types, the subjects are requested to answer a couple of questions without intervention from the researcher. Although this minimises social desirability bias, it reduces the opportunities to gain further details for the answers of the open questions (Bryman, 2012). However, this type of questions is rarely used in self-completion questionnaires because of the associated difficulties in categorising answers and coding (Krosnick & Presser, 2010). In general, using questionnaires involves a relatively high risk of missing data and a low rate of response (Bryman, 2012).

5.2.2.1 Questionnaires' design

Good designing of questionnaires prevents several potential errors (Bryman, 2012; Krosnick & Presser, 2010). For instance, it is possible to minimise missing data by keeping the questionnaires short and by using interesting cover letters, attractive layouts, and clear directions to assist participants in answering questions (Bryman, 2012). Besides, questionnaires' good design involves wording and questions' order. Avoiding negation, leading, and double questions are advised besides replacing technical phrases with words with precise meanings that consider the subjects' educational and cultural levels. Considering the questions' order, the first few questions should present the research topic and capture subjects' attention. In addition, questions' progress should start with the broad to the more detailed, leaving any private topics to the end and grouping similar questions when possible. It is noteworthy that filter questions are useful in organising questionnaires (Krosnick & Presser, 2010) although their use should be restricted to the electronic versions (Bryman, 2012).

Often, answering closed questions involves choosing from a rating scale that contains a certain number of points. It is possible to decrease potential errors by increasing rating points. However, the fine variations between the points, if exceeding 7, make them unclear for most subjects. Hence, the 7-points scale may be the best, especially when supported by verbal labels. Most importantly is to ensure that selection points cover all possible answers in an accurate order recognised by the subjects (Krosnick & Presser, 2010).

5.2.2.2 Questionnaires' pre-test

Testing questionnaires before applying them is important to reveal any questions that may cause errors. Questionnaires are usually tested by mathematical models, computer programmes, or experts' reviews. Reviewers can be from the same research field or other fields if questionnaires are their main research tool. Moreover, it is possible to distribute the questionnaire on a small sample of the targeted subjects

in a similar setting to the real survey. It is, additionally, acceptable that the researchers answer their questionnaires to discover any potential sources of errors. Indeed, it is recommended to use mixed methods and to repeat the process each time errors are discovered and fixed. In addition, repeating questions from previous questionnaires, as far as they serve the purpose, benefits from other researchers' experience and facilitates results' comparisons (Krosnick & Presser, 2010).

5.2.2.3 Preparing data for analysis

As part of preparing collected data for analysis, it is recommended to explore the behaviour of the translated scales. This is accomplished by the successive categories method that defines the categories' actual widths as perceived by the participants. Consequently, it is possible to compare the categories' widths and their relative positions. Besides, the method converts the ordinal thermal scales into interval scales and, thus, allows for regression analysis application. Although the method does not compute extreme categories' widths, the formed conclusions are generally not affected as these categories usually have very few votes. It should be mentioned that the compared scales should be derived from the same survey (Humphreys et al., 2016).

5.2.2.4 Extracting information from thermal surveys

Several results are extracted from thermal comfort surveys like the neutral temperature, preferred temperature, and unsatisfied subjects' percentage. However, there is no agreement on the methodology of extracting such information. For instance, some researchers consider the temperature at which the maximum number of 'no change' votes occurs as the preferred temperature. Others take it as the intersection point between the curves of warm and cold dissatisfaction percentages. Similarly, the percentage of unsatisfied subjects can be considered as 10% if the average thermal vote is ±0.5 and 20% if the average vote is ±0.85. Sometimes, it is that percentage of all subjects voting outside comfort range. In this regard, some studies revealed that subjects accepted their ambience although their votes fall outside the comfort range. Thus, it is advised to use a direct question to investigate thermal acceptability (Mishra & Ramgopal, 2013).

5.3 Research strategy

A research strategy can be defined as "a general orientation to the conduct of social research" (Bryman, 2012, p.35) and, in general, it can be either quantitative, qualitative, or mixed methods. It is determined by the research's epistemological approach, ontological position, and its relation to theory. Considering the research at hand, it has a mixed

methods strategy based on the mode of research followed to achieve the first and second parts of the aim. The first part of the aim explores the students' thermal conditions following a qualitative research strategy that is derived by an obvious positivist approach. Additionally, it applies qualitative research tactics, i.e. instrumentation measurements and self-completion questionnaires. However, the ontological position tends to be a mixture of objectivism and constructivism as the general characteristics of the classrooms' thermal conditions are defined by factors that are isolated from the students like the climatic conditions of the city. Yet, the students' interaction with these conditions is obvious as indicated by the adaptive approach to thermal comfort. It may worth mentioning that the emphasise on the natural settings of the objects of inquiry, i.e. the classrooms' thermal conditions, implied by the adaptive approach of thermal comfort is a key component of the qualitative research (Groat & Wang, 2013). The second part of the aim explores the students' understanding of the thermal scales adopting a qualitative research strategy with an interpretive approach of epistemology and a constructivist position of ontology. Yet, this part of research borrowed a quantitative tool represented in the self-completion questionnaire.

5.4 The experimental protocol

Figure 5.5 presents the experimental protocol of this research. Four major visits were arranged in which the objective and subjective variables of the students' thermal experience were recorded. In specific, air temperature, globe temperature, air velocity, and relative humidity were measured in the plaza and three classrooms in each school simultaneously. Indoor sensors were roughly located at the middle of the classrooms at a height of around 0.6 m from the ground level and the outdoor sensors were positioned at roughly 1.2 m height from ground level for accurate measurements of air temperature (Burt, 2012; Brown, 2010). Moreover, the subjective variables included the votes of thermal, humidity, and air velocity sensations and preferences. It is noteworthy that no restrictions on students' adaptive behaviour were applied. With reference to Figure 5.2, the survey performed in this research can be considered as a repeated transverse survey with a measurement level like group (2).

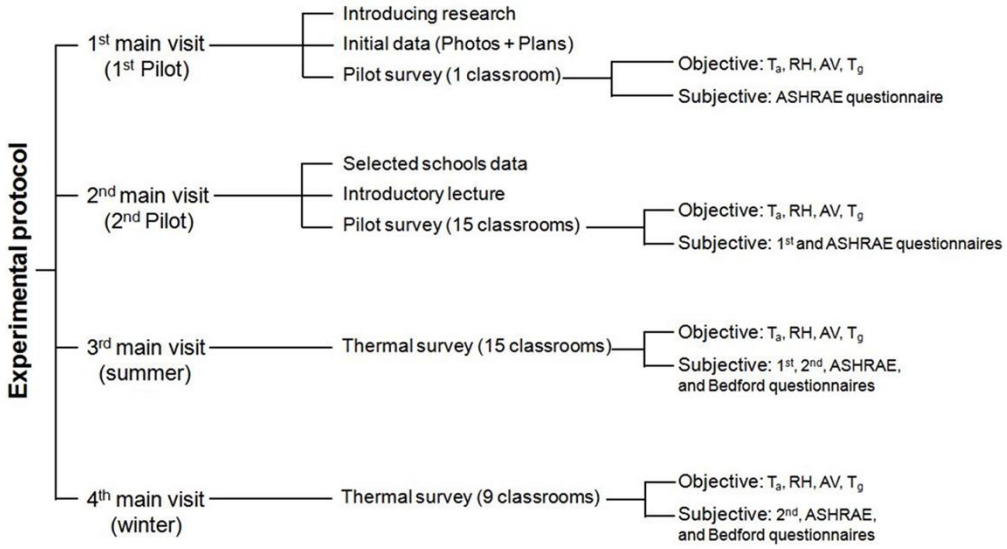


Figure 5.5: Experimental protocol followed in this research

As illustrated in Figure 5.5, the aim and scope of the research were introduced to the administrations of eight schools during the first visit that was conducted in September 2015. Additionally, the schools' architectural schematic plans and photos were collected and a pilot survey was conducted in one classroom in (DA) School to test the questionnaire and the sensors. At that time, only one sensor of each type was purchased. Outdoor measurements were for air temperature and relative humidity. For indoor measurements, air temperature, globe temperature, air velocity, and relative humidity were recorded besides distributing 25 copies of the questionnaire. The findings are discussed in Section 5.5.1.

Each school was visited three times in the second pilot study that was conducted in March 2016. In the first visit, schools' principals were informed about selecting their schools to participate in the research. A data collection sheet was used to gather initial data about the schools and the selected classrooms as attached in Appendix 5.1. The results are presented in Section 4.3. Additionally, the research importance and experimental protocol were introduced to the students in an introductory lecture during the second visit. In the third visit, a thermal survey was conducted in three classrooms from each school in which indoor and outdoor variables were simultaneously logged at intervals of 5 minutes. Subjective data were collected once during the fifth, sixth, or seventh classes and the first questionnaire was distributed before break time. This pilot study was conducted over two weeks due to unexpected study suspension because of a deep climatic depression. In Oman, it is usual to have days off due to heavy rains as riverbeds and strong water streams impede traffic. The findings are presented in Section 5.5.2.

Summer and winter studies were conducted in September 2016 and March 2017 respectively. Excluding preparations visits, each participated school was visited twice over a period of three weeks. In the first and third weeks, ASHRAE and Bedford questionnaires were distributed following the sequence illustrated in Figure 5.6. Students' boredom was expected to increase as the survey progresses. Hence, it was thought that inverting the sequence of questionnaires' distribution may decrease the negative effect of students' boredom. Additionally, a break of seven days was thought to be useful in order to avoid students' boredom without experiencing a considerable change in the climatic conditions. Accordingly, no visits were carried out in the second week. It is noteworthy that the first and second questionnaires were distributed in summer, whereas only the second questionnaire was distributed in winter. Besides, the number of participated classrooms decreased to 9 in winter because of unforeseen difficulties.

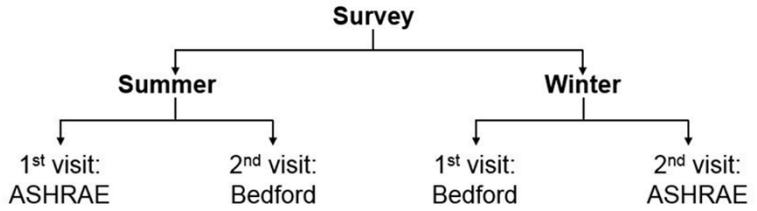


Figure 5.6: Questionnaires' distribution sequence in summer and winter studies

5.4.1 Introductory lecture

A general introductory lecture about thermal comfort was delivered in the second main visit (i.e. 2nd pilot study) to familiarise the students with the research aiming to increase their participation rate. The lecture introduced some thermal concepts like comfort definitions, adaptation, saturation, and the factors that affect thermal comfort. In addition, it presented the importance of achieving thermal comfort and conducting its research as well as an overview of the current research and its methodology. It should be mentioned that delivering this lecture was initially not planned in order to avoid affecting students' answers. However, conducting the first pilot study revealed a lack of confidence in students' answers possibly because it was the first participation in scientific research for almost all of them.

5.4.2 Selected devices

The British market was surveyed in order to generate a list of the companies that sell suitable instruments for the research as displayed in Appendix 5.2. The surveyed instruments were compared and a selected sample is presented in Appendix 5.3. A rating system was applied to evaluate the compared devices based on their technical, physical, logistical, and general features as displayed in Appendix 5.4.

The evaluation ensures that the selected sensors fulfil the required levels of accuracy and reduce disturbance in classrooms. Additionally, indoor weather stations were explored considering their advantages. However, it was not possible to reach an acceptable level of accuracy, size, and cost. For instance, affordable weather stations with adequate sizes were below the required level of accuracy, whereas advanced stations with high accuracies were costly and have bulky sizes.

Based on the evaluation system, the scores of Tinytag Plus 2 Dual Channel Temperature/Relative Humidity (TGP-4500) and Tinytag View 2 Temperature/Relative Humidity Logger (TV-4500) were the highest among the investigated devices that measure air temperature and relative humidity. Both are suitable for indoor measurements and the former is, further, used outdoors. Additionally, their compactness and metallic shields ensure decreasing radiation effect largely (Nicol et al., 2012) and their weight provides flexibility in performing the measurements at different heights.

None of the evaluated sensors of globe temperature integrated a datalogger except the selected one, namely Data Logger PCE-WB 02SD. With reference to Appendix 5.4, device no.9 is the most accurate; yet, it was excluded due to its bulk size. Considering air velocity, device no.14 measures air temperature and relative humidity with high accuracy. Yet, it was not selected because of its high cost and need for external datalogger that, in turn, costs at least £400 according to the company estimations. Hence, HHF2005HW Hot wire anemometer with real-time datalogger was selected as it combines acceptable accuracy and affordable cost.

Considering the sensors' positions, indoor sensors were placed at a height of 0.6 m in the middle of classrooms. This is in agreement with the standard specifications regarding the locations of equipment (ASHRAE, 2010; BS EN ISO 7726, 2001) and the need to decrease disturbance in the classrooms. The outdoor sensors were located at a height of 1.2 m following the recommendations of (Burt, 2012).

5.4.3 Research questionnaires

As indicated in Figure 5.5, four questionnaires were distributed in this study. The first and second questionnaires were used to explore the students' understanding of thermal phrases. The second questionnaire was based on the answers of the first as noted in Figure 5.7. The latter, attached in Appendix 5.5, was distributed in the first and second main visits and it was similar to (Pitts, 2006) questionnaire. Specifically, the students were requested to translate the phrases of ASHRAE sensation scale to the Arabic language, order them on a linear scale, and identify

comfort. The linear scale is assumed to resemble the thermal continuum. To assist the students, they were requested to determine the possibility of considering any phrase of ASHRAE sensation scale as an equivalent to comfort. If their answer was (yes), they were requested to specify that phrase. If their answer was (no), they were asked to determine comfort on the given linear scale.

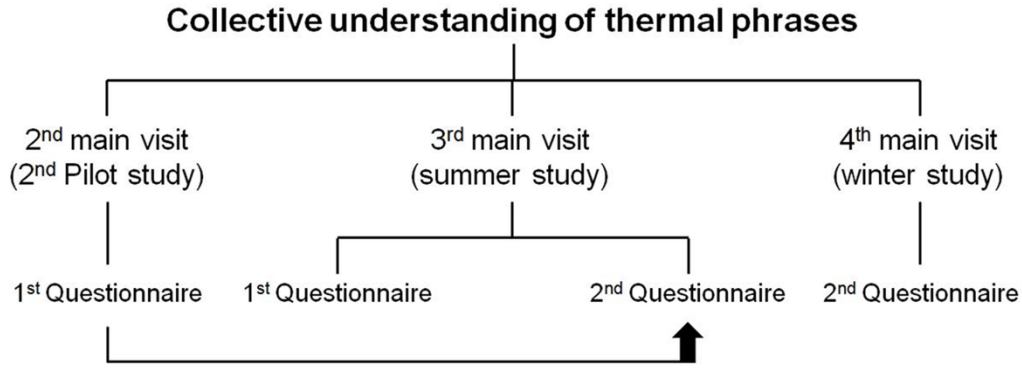


Figure 5.7: Distribution sequence of the first and second questionnaires

Moreover, the translated phrases provided by 5% of the students or more were used to construct the second questionnaire as attached in Appendix 5.6. This multiple-choice questionnaire was distributed in the third and fourth main visits. The students were asked to select the most accurate Arabic equivalent to each sensation and were encouraged to provide new phrases if they felt the need to. It is noteworthy that the questions' order was different from that of ASHRAE sensation scale.

A pilot questionnaire integrating ASHRAE sensation and Nicol preference scales was prepared in the English and Arabic languages. The Arabic version considered the translated scales of (Sufeljen, 2014; Saleh, 2011). The researcher's colleagues, who are native speakers of Arabic and their research field depend on questionnaires, reviewed this version. Additionally, the questionnaire was tested and modified in the first and second pilot studies. A final version was distributed in summer and winter studies as attached in Appendix 5.7. An identical version integrating Bedford questionnaire was prepared. It should be mentioned that questions (D.5), (D.6), and (D.7) were added to the questionnaire in winter study.

Table 5.2 displays the translated introductory questions and Table 5.3 presents the translated thermal phrases. As noted, the translated phrases of ASHRAE scale in the second pilot study were different from those in summer and winter studies. The effect of the used semantics is discussed in Chapter 8.

Table 5.2: Arabic translation of introductory questions as used in the distributed questionnaires

Scale	English	Arabic

ASHRAE, Bedford	Currently, I feel:	حاليا، أشعر بـــ:
Nicol	Currently, I would prefer to be:	حاليا، أريد أن أكون:

Table 5.3: Arabic translations of scales' categories as used in the distributed questionnaires

	ASHRAE[1]	ASHRAE[2]	Bedford	Nicol
-3	باردة جدا	باردة جدا	باردة جدا	
-2	باردة	باردة	باردة	أسخن كثيرا
-1	باردة قليلا	باردة قليلا	باردة لكن مرتاحة	أسخن قليلا
0	معتدلة	معتدلة	مرتاحة لا باردة ولا ساخنة	لا تغيير
+1	ساخنة قليلا	ساخنة قليلا	ساخنة لكن مرتاحة	أبرد قليلا
+2	ساخنة	ساخنة	ساخنة	أبرد كثيرا
+3	ساخنة جدا	ساخنة جدا	ساخنة جدا	

[1]Second pilot questionnaire, [2]Summer and Winter questionnaires

5.4.4 Methodology limitations

The experimental protocol followed in this research is associated with some limitations including those regarding instruments' accuracy, instruments' locations in classrooms, and the selected classrooms. The accuracy of the used instruments as presented in Appendix 5.3 is lower than the standards' recommendations as displayed in Table 5.1 due to the lack of financial resources that prevented purchasing sophisticated instruments with higher accuracy. Additionally, this lack of resources prevented purchasing more sensors for accurate measurements of the physical variables inside classrooms. To account for this, the sensors were placed at the centre of each classroom. Yet, this compromise resulted in neglecting the cooling influence of increasing air velocity as the ceiling fans were distributed at different points. Furthermore, the fluctuations in air temperatures are narrow due to the presence of air conditioning units in each of the investigated classrooms as indicated in Section 4.3. Consequently, the regression model widely applied to analyse the relationship between thermal votes and environmental variables is negatively affected.

5.5 Pilot studies' results

A pilot study is defined as 'a small-scale test of the methods and procedures to be used on a larger scale if the pilot study demonstrates that these methods and procedures can work' (Porta et al., 2014, p. 215). The priority is on the methodological aspects (Leon et al., 2011). Therefore, the statistical results of any pilot study should be interpreted with caution as the main focus is the methods' feasibility (Billé, 2010; Thabane et al., 2010). Although conducting pilot studies may be essential owing to their role in exposing potential errors in full-scale studies, they may be considered demanding (Thabane et al., 2010). Considering the current research, two pilot studies were performed as mentioned earlier. The first pilot study was conducted in (DA) School with the objective of testing the prepared questionnaire and the selected

sensors. The second pilot study was mainly conducted to test the suggested experimental protocol at full scale and to test the applied modifications on ASHRAE questionnaire.

5.5.1 First pilot study

As illustrated in Figure 5.8, the surveyed classroom has an area of around 33 m^2 and it is adjacent to two classrooms from the east and the west. The door opens onto a southern inner courtyard with two large windows on the opposite wall viewing an empty space. There are smaller high windows beside the door and they are mainly used to enhance natural lighting levels. It is noteworthy that all windows had no curtains.

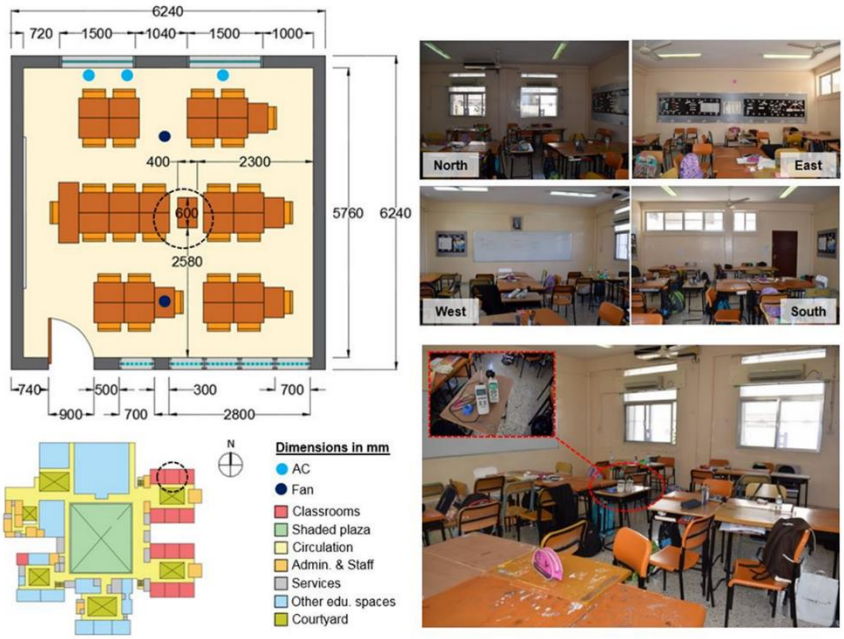


Figure 5.8: Investigated classroom's layout and sensors' location

5.5.1.1 Objective measurements

The indoor sensors were positioned at a height of 0.6 m roughly in the centre of the classroom as presented in Figure 5.8. The physical variables were recorded at a sampling interval of 5 minutes for an hour as presented in Figure 5.9. As expected, the variables' change was marginal due to operating air conditioning units besides the shortness of the measuring period. The ranges of indoor air and globe temperatures were around 0.2 °C and 0.6 °C respectively. Oppositely, the range of outdoor air temperature was higher, 4 °C approximately, despite the recording period shortness possibly owing to approaching midday. Similarly, indoor and outdoor relative humidity ranges were around 4% and 13% respectively. In addition, mean indoor air temperature was almost 27.9 °C and mean indoor relative humidity was around 42%. Corresponding outdoor measurements were almost 32.6 °C and 66%

respectively. In general, indoor air was still and the highest velocity was 0.2 m/s approximately.

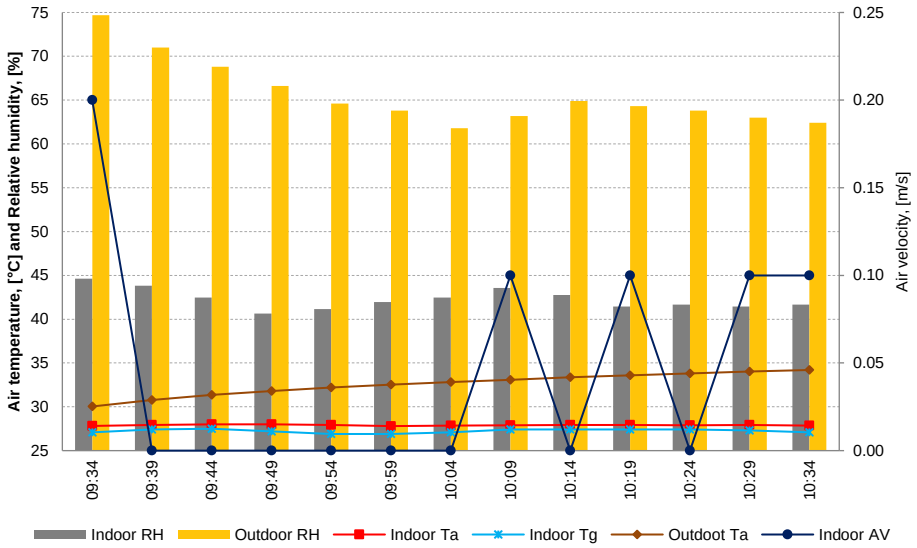


Figure 5.9: The physical variables during 1st pilot study

5.5.1.2 Subjective measurements

Given the freedom to choose the language, all students answered the questionnaire in Arabic except three students. One of them chose English and the other two answered in both languages. Table 5.4 summarises the students' response pattern of the first questionnaire. As noted, all students missed question (3) perhaps owing to its location and order. It was located at the end of the page and was preceded by a relatively difficult question.

Table 5.4: Summary of the first questionnaire answers

	Fully answered	Partially answered	Not answered	Total
Question (1)	17	8	0	25
Question (2)	16	5	4	25
Question (3)	0	0	25	25
Total	33 (44%)	13 (17.3%)	29 (38.7%)	75 (100%)

The copies of ASHRAE questionnaire were fully answered except two. One of the missed questions was located at the end of the page, which indicated the importance of the questionnaires' good layout. In addition, the students' enquiries revealed the need to introduce them to the questionnaire; consequently, the introductory lecture was prepared and delivered in the second pilot study.

As noticed in Figure 5.10, the majority of the students clustered in the middle categories of sensation scales. No votes were on the warm side of humidity sensation, unlike air velocity sensation where no votes were on the cool side. The preference votes of both variables were relatively skewed to the cool side. In addition, all the students were

seated, reading, or writing just before distributing the questionnaire that was at the end of the third class. It was interestingly noted that one student reported opening curtains to modify the thermal conditions despite that no curtains were available in the classroom. The question misinterpretation indicated the importance of giving clear directions and clarifying some questions to the students. This support was provided during the second pilot study as well as the summer and winter studies.

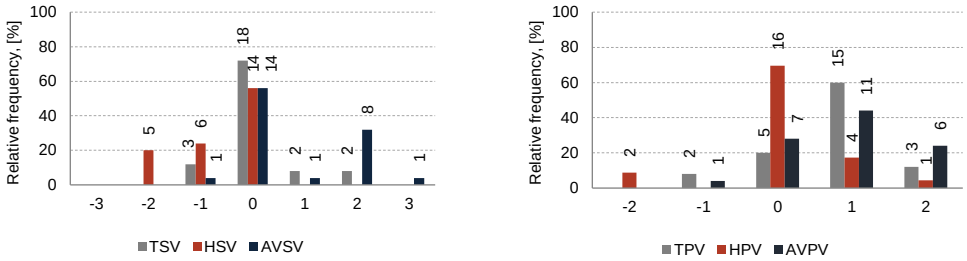


Figure 5.10: Relative frequency of thermal, humidity, and air velocity: (a) sensation votes and (b) preference vote
(Labels are students' numbers)

It is noteworthy that both questionnaires, i.e. the first and ASHRAE questionnaires, were distributed simultaneously. This allowed some students to modify their answers in the first questionnaire based on the questions of ASHRAE questionnaires although they were requested to answer the questionnaires in sequence. Therefore, the questionnaires' distribution sequence was modified in the second pilot study as well as summer and winter studies.

5.5.2 Second pilot study

From the 383 ASHRAE questionnaires distributed in the second pilot study, 117 were excluded from the analysis due to incomplete or inconsistent answers. For instance, some students preferred (no change) on the thermal, humidity, or air velocity conditions despite being uncomfortable. Likewise, incomplete sets of the physical records of (NK-G2) and (DA-F1) classrooms were excluded. As a result, the subjective votes obtained from these classrooms were not included in the analysis. It should be mentioned that the impact of some activities on the thermal condition of the person can extend for some time after finishing the activity (Nicol et al., 2012). Therefore, three questionnaires were excluded as the students attended physical education class just before participation in the survey. It is noteworthy that the second pilot study formed an opportunity to explore the procedure of data analysis.

5.5.2.1 Objective measurements

To appreciate the students' thermal experience, the hourly profiles of a selected sample of the indoor physical variables from the explored

classrooms are presented in Figure 5.11. The measurements of the other classrooms fell within the dominant ranges that are depicted in the figure. The plotted hourly profiles examine the similarity of classrooms' thermal conditions, which is required to enhance the accuracy of the study results.

Generally, the classrooms had similar thermal conditions as noted in Figure 5.11. The dominant ranges of both air and globe temperatures extended for 4 °C and 5 °C starting from 23 °C and 22 °C respectively. For both variables, some measurements from (WK-F1), (WK-S1), and (DA-G2) classrooms were outside the dominant ranges. However, they lasted for almost 30 minutes or less except air and globe temperatures of (WK-F1) and (DA-G2) classrooms respectively. For air velocity and relative humidity ranges, most records extended roughly from 0.0 m/s to 0.6 m/s and from 35% to 60% respectively. Exceptions were some air velocity measurements from (WK-F1) classroom and relative humidity measurements from (NK-G1) and (NK-F1) classrooms. It is noteworthy that comparatively high relative humidity levels were noticed in (NK) School perhaps due to its closeness from the sea.

Besides, Figure 5.12 compares the indoor and outdoor mean and instantaneous measurements to determine if the questionnaires were distributed at representative times. The instantaneous measurements were recorded at the beginning of questionnaires' distribution. As noted, low instantaneous temperatures were measured in (ZA-G2), (WK-S1), and (DA-G1) classrooms. However, the departures from the means of air and globe temperatures were relatively not important and estimated at 1.6 °C and 2.4 °C respectively.

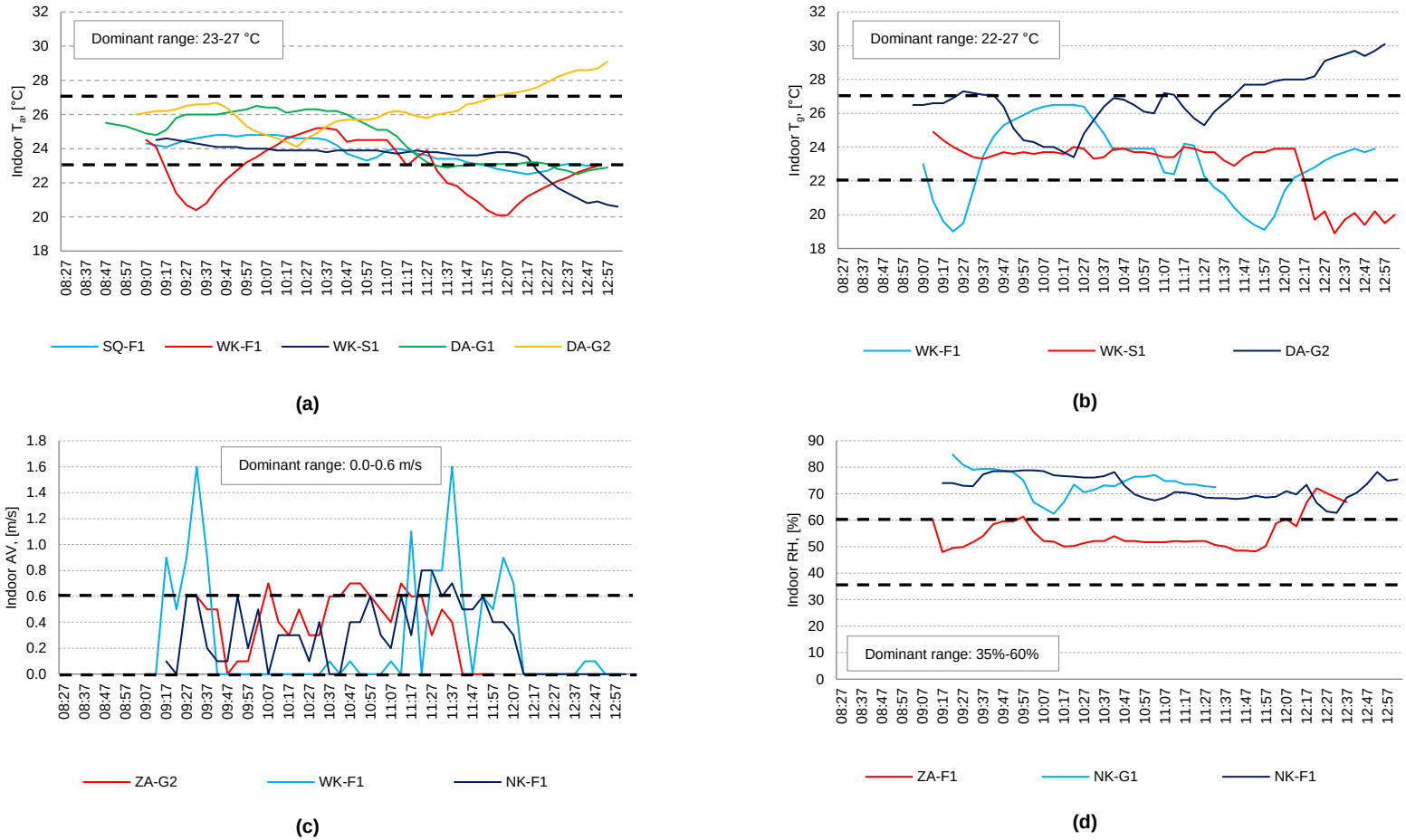


Figure 5.11: Hourly profiles of indoor: (a) air temperature, (b) globe temperature, (c) air velocity, and (d) relative humidity

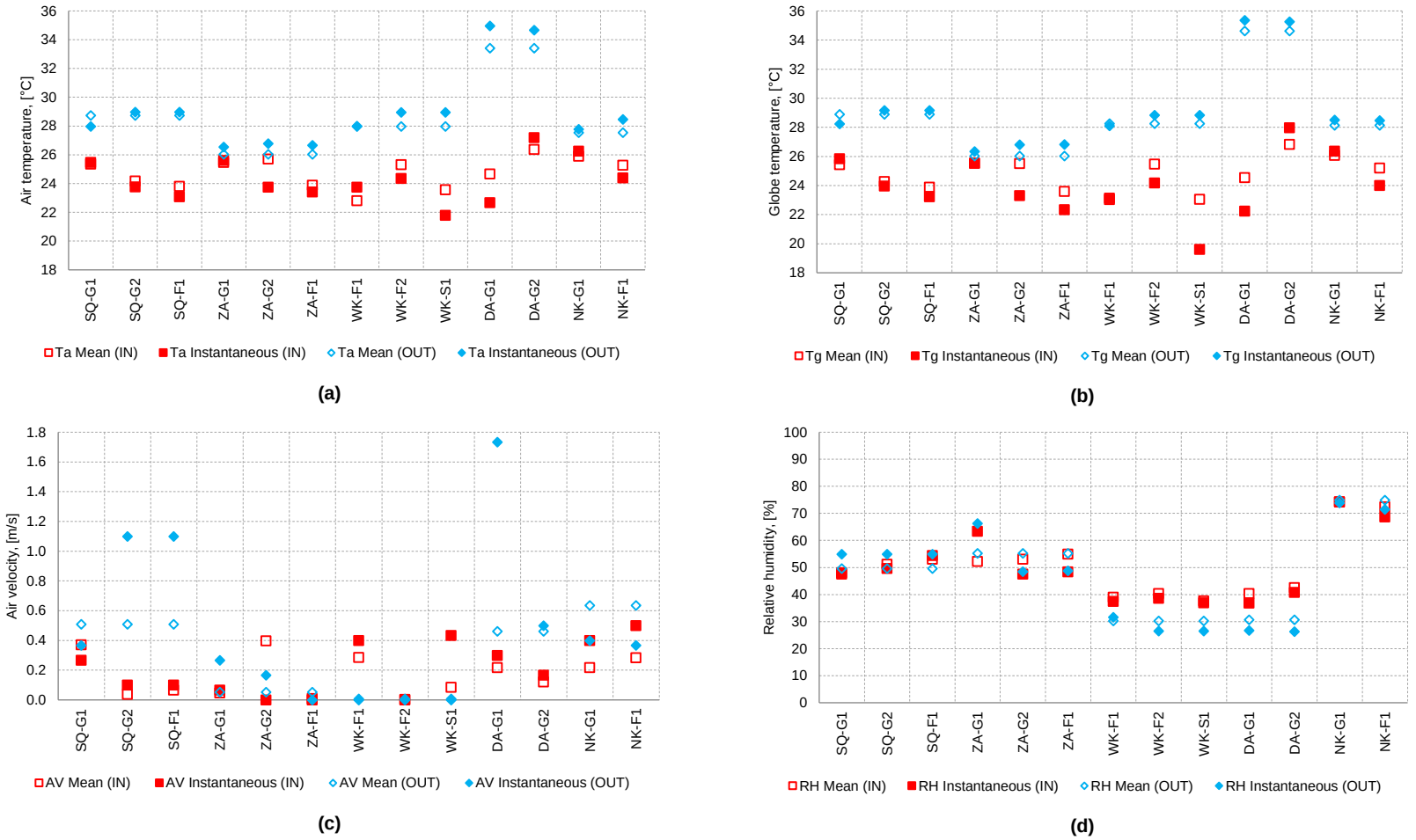


Figure 5.12: Indoor and outdoor mean and instantaneous: (a) air temperature, (b) globe temperature, (c) air velocity, and (d) relative humidity

5.5.2.2 Subjects

The students were 15 to 19 years old with two students at the age of 14 and 20 years old. The majority were 16 and 17 years old forming around 41% and 32% respectively. Regarding familiarity with schools' buildings, almost 56% of the students attended their schools for less than a year and 42% approximately for one to two years. Besides, 70% roughly were healthy and around 10% reported having the menstrual cycle. The remaining students suffered from eczema, diabetes, asthma, anaemia, cold, and cough. It should be mentioned that cool thermal conditions have a negative effect on asthmatics (Tham & Fadeyi, 2015).

Additionally, around 96% of the students wore school uniform and almost 98% were seated, reading, or writing before distributing the questionnaire. Around 72% of the students had similar activities 30 minutes earlier. Besides, 15% and 11% approximately were walking and eating respectively.

5.5.2.3 Sensation and preference

The direct evaluation of comfort and acceptance revealed that around 71% and 83% of the students found the classrooms' conditions comfortable and acceptable respectively. This difference in comfort and acceptance levels may indicate the effect of other factors on students' comfort besides the thermal ambience. However, it is possible that the variation was because of a random fluctuation. Thus, it is advised to explore comfort and acceptance levels further. Moreover, considering that around 86% of the thermal votes were within comfort range (i.e. slightly cool, neutral, and slightly warm), it may be concluded that the classrooms' thermal environments were satisfactory.

The relative frequency of subjective votes is displayed in Figure 5.13. Considering thermal votes, around 56% of the students were neutral; however, only 38% roughly preferred (no change). Indeed, 20% approximately of those with thermal votes within comfort range were thermally uncomfortable and around 81% of them preferred cooler conditions. Similarly, 4.5% of the comfortable students had thermal sensations outside comfort range. These observations may indicate the necessity of reviewing the widely accepted range of comfort perhaps by taking the climatic background influence into consideration.

Moreover, it is noted that humidity sensation and preference votes were centred on (neutral) and (no change) categories with percentages of around 57% and 64% respectively. The measured levels of relative humidity were within Muscat's comfortable limits, which may justify the students' votes. Yet, there is a possibility that the votes reflect some

doubts in understanding the humidity scale as uncertain people often exhibit clustering in the central categories of rating scales (Humphreys et al., 2016).

Similarly, almost 71% of the air velocity sensation votes clustered in the central categories. Although only around 26% of the students reported that the air velocity was (slow) and (very slow), almost 60% preferred (a bit faster) and (much faster) conditions indicating a general preference towards cool conditions. Indeed, this figure is consistent with the 50% of the thermal votes that preferred cooler conditions taking into account the cooling effect of air movement.

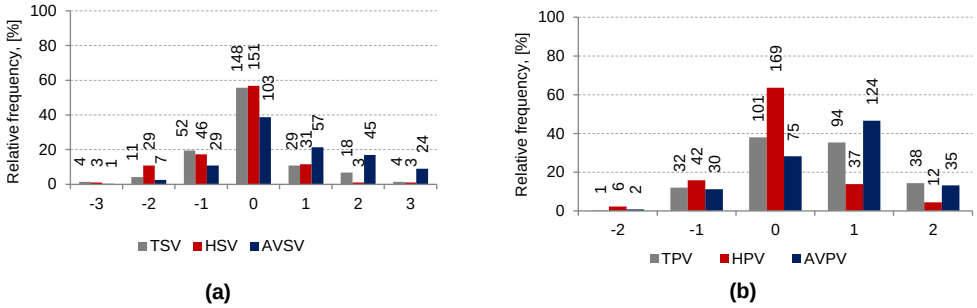


Figure 5.13: Relative frequency of thermal, humidity, and air velocity: (a) sensation votes and (b) preference votes
(Labels are students' numbers)

Moreover, Table 5.5 displays the means, standard deviations, and ranges of the subjective votes. As noted, the means of thermal and humidity sensation and preference votes fell in the central categories of the scales. The means of air velocity sensation and preference were in the (slightly slow) and (a bit faster) categories. It is noteworthy that humidity statistics may not be reliable as the students questioned the scale meaning frequently, which may reflect a lack of confidence in the provided answers.

Table 5.5: Mean, standard deviation, and range of sensation and preference votes (N = 266).

	Thermal sensation	Humidity sensation	Air velocity sensation	Thermal preference	Humidity preference	Air velocity preference
Mean	-0.01	-0.24	0.60	0.46	0.01	0.62
SD	1.01	0.96	1.24	0.90	0.76	0.88
Range	-2.64 to 2.42	-2.72 to 2.20	-3.02 to 2.79	-2.08 to 1.82	-1.63 to 1.84	-1.77 to 2.00

5.5.2.4 Available adaptive opportunities

The students' adaptive behaviour was explored in Figure 5.14. As noted, the majority of the students relied on increasing thermostat followed by opening windows to modify their thermal conditions. Based on how Omani people use this phrase, increasing thermostat means increasing its cooling effectiveness, which results in decreasing room temperature. The heavy dependence on this active energy behaviour reflects the efficiency of air conditioning units in achieving thermal

comfort regardless of the outer conditions, which are, generally, far from comfortable conditions. Besides, it may reflect the cultural background influence; air conditioning units are widely distributed in Omani houses with installation rates of almost 100% for sleeping rooms and around 60% for living rooms, guest rooms, and kitchens (Majid et al., 2014). These units are often operated for 20-24 hours daily during summer, especially in Muscat (Al-Gharibi, 2016). Besides, few students relied on changing the clothing level possibly due to the restrictions on school uniform. In general, students change their clothing by adding on jackets or taking off headscarves.

Figure 5.14 presents the usage time distribution of three adaptive actions. As observed, windows were mostly opened in the morning when outdoor conditions are relatively acceptable. As expected, air conditioning units were operated throughout the school day. This continuous use may be illustrated by their availability, the influence of cultural background, and the absence of economic responsibility. Yet, it should be mentioned that few students reported switching on air conditioning units in the morning or the afternoon only. Considering fans usage, it seems that there was no clear pattern as around 36% of the students reported no use of fans and almost 27% reported using fans in the afternoon.

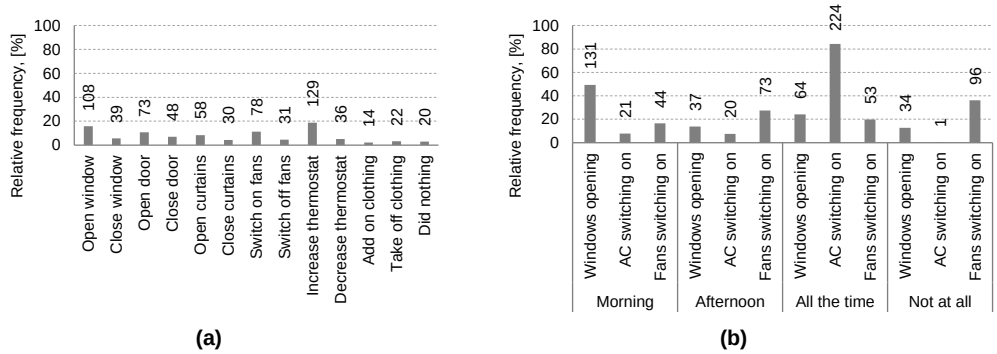


Figure 5.14: Students' adaptive behaviour: (a) available opportunities and (b) usage time (Labels are students' numbers)

5.5.2.5 Subjective categories' widths

Applying successive categories method, the categories' widths of the translated scales are plotted in Figure 5.15. It is noteworthy that end categories have no defined width (Humphreys et al., 2016). As noted, the categories' widths of ASHRAE scale were irregular. The median sensation (i.e. 0 on the thermal continuum) and the centre of (neutral) category were roughly identical. Although the width of (neutral) category may indicate adaptation to wide conditions, it possibly reveals a need for finer central categories. This may support the new scale proposed by (Buratti et al., 2016). Besides, negligibly higher sensitivity to the

warm conditions was noticed as warm side categories were marginally narrower. This may reflect a climatic background influence. Regarding Nicol scale, the categories had almost regular widths and the median preference coincided with the edge between (no change) and (a bit cooler) categories.

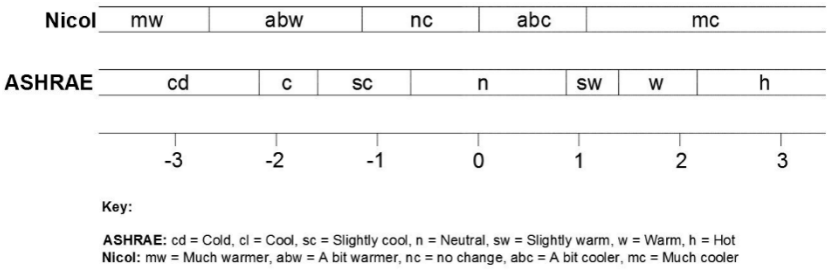


Figure 5.15: Translated scales' categories on the thermal continuum

5.5.2.6 Sensation votes against physical variables

To investigate the relationship between the objective variables and the subjective votes, Pearson's correlation coefficients were computed. The results indicated a roughly moderate association between air and globe temperatures and corresponding sensations as the coefficients were around r = 0.291 and r = 0.275 respectively. Oppositely, humidity sensation votes were weakly related to water vapour pressure with an estimated coefficient of r = -0.091. Similarly, a positive weak coefficient of r = 0.039 approximately related air velocity sensation and air velocity. It seems that other factors may affect the students' sensations of their thermal environment.

Additionally, thermal sensation votes were plotted against indoor air and globe temperatures as observed in Figure 5.16. The respective coefficients of determination were 0.085 and 0.076 roughly. In general, low coefficients of determination are expected in simple regression models that attempt to predict human behaviour (Frost, 2013a; Frost, 2013b). Further, they are expected in thermal field surveys as different factors influence thermal sensation besides the physical variables. It should be mentioned that the irregularity in categories' widths had a negative effect on the regression because of the assumption of equal intervals that is required by this analysis (Nicol et al., 2012). Thus, the residuals are plotted in Figure 5.17 to check the model correctness. As observed, they were scattered around (zero) in the explored ranges of indoor air and globe temperatures that roughly extended from 21.8 °C to 27.2 °C and from 19.6 °C to 28.0 °C respectively.

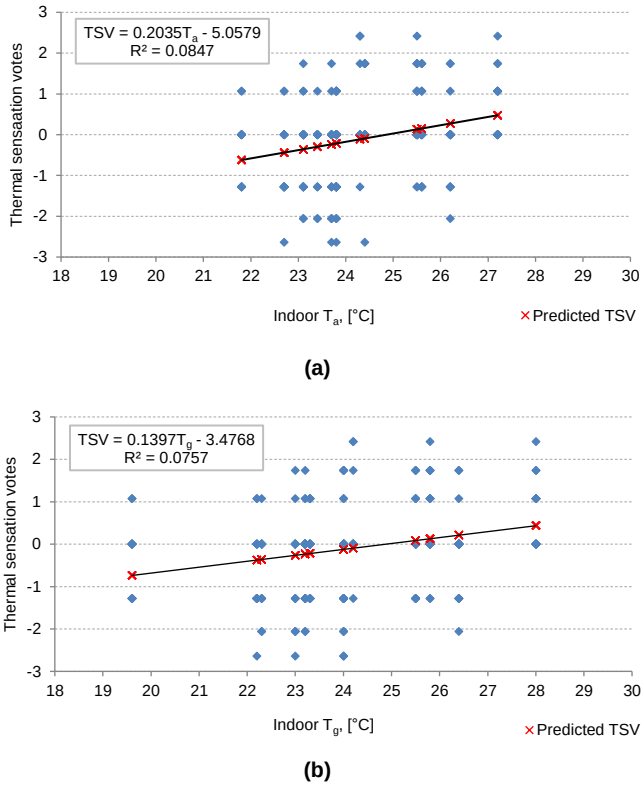


Figure 5.16: Regression between thermal sensation votes and: (a) indoor air temperature and (b) indoor globe temperature

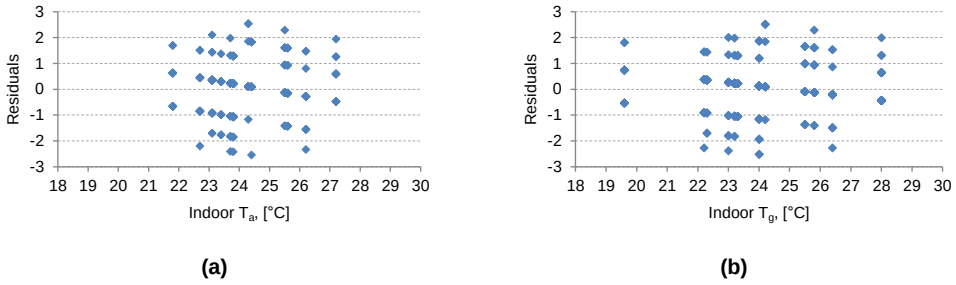


Figure 5.17: Residuals of thermal sensation votes: (a) indoor air temperature and (b) indoor globe temperature

The models are useful based on the p-values that were lower than 0.05 for both air and globe temperatures. The regression coefficients were around 0.203 and 0.140 with standard errors of almost 0.041 and 0.030 for the associations with air and globe temperatures respectively. Based on a confidence interval of 95%, the air temperature coefficient had lower and upper limits of around 0.122 and 0.284 respectively. The corresponding limits for the globe temperature coefficient were around 0.080 and 0.200 respectively.

Furthermore, Table 5.6 presents the categories' widths expressed in air and globe temperature. The steps were not equal because of the irregular widths of categories. The average step of air temperature was 4.1 °C roughly. This is higher than the typical step of almost 3 K (Nicol et al., 2012), which may indicate adaptation to wide thermal conditions.

Further investigations are recommended to explore the possible climatic influence on these steps.

Table 5.6: Steps of air and globe temperatures

	Cold to cool	Cool to slightly cool	Slightly cool to neutral	Neutral to slightly warm	Slightly warm to warm	Warm to hot
T_a, [°C]	2.8	3.8	6.3	5.3	3.3	3.3
T_g, [°C]	4.1	5.6	9.2	7.7	4.8	4.9

5.6 Conclusion

Two approaches to study thermal comfort are distinguished, which are the heat balance approach followed in rational studies and the adaptive approach followed in empirical studies. The former approach is often criticised for its complicated calculations and the noticeable effect of minor measurement errors on the models' predictions. Likewise, the latter approach is criticised for the reliance of its results' accuracy on the sample size and the explicit ignorance of some important factors that affect thermal comfort. Despite the followed approach, thermal comfort results are affected by the measurement accuracy of the physical variables that are required in both approaches.

Measuring the physical variables of the thermal environments and recording the participants' responses towards these environments are the main components of the empirical studies of thermal comfort. Based on the brief discussion of the empirical studies' methodology, it is concluded that selecting sensors should aim to maintain the levels of accuracy recommended by the international standards. This ensures the accuracy of the formed conclusions and enables comparing them with previous research results. Besides, it is concluded that several potential errors are avoidable by the questionnaires' good design and testing.

The mode of this research follows a mixed method of quantitative and qualitative methods. On one hand, the first part of the research aim tends to be quantitative with a mixture of objectivist and constructivist ontological position. On the other hand, the second part of the aim tends to be qualitative borrowing a quantitative research tool. To achieve the aim, four main visits to the investigated schools were conducted. The first two main visits were considered as pilot studies, whereas the other visits formed the summer and winter studies. The two pilot studies were performed in order to enhance the accuracy of the research results. The aim of the first pilot study was to explore the suitability of the selected sensors to satisfy the research requirements and reveal any potential sources of error in the designed questionnaire. The study concluded the sensors' suitability and it recommended some modifications regarding the questionnaires' design and their distribution

sequence. Besides, it revealed the need to assist the students in their attempt to answer the questionnaires. This resulted in the introductory lecture delivered in the second visit besides clarifying some questions to the students during the summer and winter studies.

The second pilot study was essentially carried out to investigate the feasibility of the full-scale studies (i.e. summer and winter studies) through revealing any potential sources of error as well as to test the questionnaire's modifications. The study provided an overview of the analysis procedure despite that its statistical findings should be considered with caution. The records of indoor physical variables had relatively narrow ranges; for instance, the indoor air temperature range was around 4 °C. The collected questionnaires from 266 students revealed that they differentiated between comfort, neutrality, and acceptance, which suggested exploring this differentiation further. Besides, the analysed data indicated the subjective sensations' cluster in the three central categories and the general preference of cooler conditions. Regarding the adaptive behaviour, a high dependence on air conditioning to modify thermal ambience was revealed.

Applying the successive categories method revealed the irregular widths of categories and the relatively wider width of (neutral) category. Therefore, the application of new scales with finer central categories is recommended. Besides, the findings indicated that changing students' thermal sensations required different steps of temperature. The mean step of air temperature was estimated at 4.1 °C. Constructing a linear regression model revealed that each change by one unit in air or globe temperatures was responsible for a change of 0.203 or 0.104 roughly in thermal sensation respectively.

Part (3):

Results and Conclusions

Chapter (6):

The Survey Objective Results

Chapter 6 The survey objective results

In the current study, the measured objective data included outdoor and indoor air temperature, globe temperature, air velocity, and relative humidity. As mentioned earlier, indoor measurements were collected from 15 classrooms in five schools in summer study and from 9 classrooms in three schools in winter study. In specific, the latter study was limited to Zubaida Um Al-Ameen (ZA), Dohat Al-Adab (DA), and Nusiba bint Kaab (NK) Schools. Additionally, due to unforeseen failure in batteries of Tinytag View 2 Temperature/Relative Humidity Logger (TV-4500) and Tinytag Plus 2 Dual Channel Temperature/Relative Humidity (TGP-4500) sensors, air temperature and relative humidity were measured using Data Logger PCE-WB 20 SD sensors in both summer and winter studies.

This chapter presents the objective measurements with the aim of appreciating the thermal conditions in the investigated schools. For instance, the relative frequencies of the indoor variables were plotted to identify their dominant ranges and their proportions were explored to appreciate their distribution in the classrooms. Moreover, the chapter compares the indoor thermal conditions, by plotting the hourly profiles, to ensure their similarity that is required to increase the accuracy of the results by eliminating the outliers. Accordingly, the selected classrooms for further analysis are identified. Besides, the relations between indoor air temperature on one hand and outdoor air temperature, indoor air velocity, and indoor globe temperature on the other hand are explored. The indoor data were compared with the comfort zone obtained from the ASHRAE 55 standard. It is should be mentioned that because of calibrating the used sensors, the measurements' errors were assumed to be marginal (Burt, 2012) and, thus, were not reported. The details are discussed in the following sections.

6.1 Central tendency and variability statistics

The central tendency and variability measures of summer study data are displayed in Table 6.1. In ASHRAE questionnaire, the mean indoor air temperature was measured as 25.7 ± 1.66 °C compared with 26.1 ± 2.29 °C in Bedford questionnaire. In the former, both the median and mode values were identical at 25.9 °C, whereas they were 25.8 °C and 25.9 °C respectively in the latter questionnaire. Besides, it is noted that the indoor data distributions around their means were relatively wider in Bedford questionnaire as indicated by the standard deviations. It is noteworthy that the proximity of the means and medians values indicates the symmetrical distribution of the data around the means. For

outdoor data, the modes of air and globe temperatures were slightly lower than the mean values in both questionnaires.

Table 6.2 summarises the statistics of winter study. The means of indoor air temperature were 23.9 ± 1.61 °C and 24.6 ± 1.41 °C during Bedford and ASHRAE questionnaires respectively. Compared with summer data, the means of indoor variables decreased slightly. Indeed, this is generally expected in air conditioned buildings (Nicol et al., 2012). The symmetrical distribution of the data around the means was revealed by comparing the indoor means and medians. Considering outdoor data, the relative humidity mean of Bedford questionnaire was higher than that of ASHRAE questionnaire by almost 15% and the data had considerably narrower distribution. During ASHRAE questionnaire, the measured outdoor relative humidity in (ZA) and (DA) Schools was between 21% and 43%, whereas that measured in (NK) School was between 44% and 67%.

Table 6.1: Basic statistics of summer study measurements

		Indoor				Outdoor			
		T_a, [°C]	T_g, [°C]	AV, [m/s]	RH, [%]	T_a, [°C]	T_g, [°C]	AV, [m/s]	RH, [%]
ASHRAE	N	1025	1023	950	1025	336	336	333	336
	Mean	25.7	25.7	0.1	49.4	32.6	33.2	0.2	61.8
	SD	1.66	1.55	0.17	7.01	2.31	2.34	0.31	9.70
	Median	25.9	25.9	0.0	49.1	32.5	33.9	0.1	61.7
	Mode	25.9	25.9	0.0[1]	49.1	29.9	29.9	0.0[2]	74.3
	Max.	29.5	29.4	1.1	70.9	36.3	36.9	1.5	83.2
	Min.	19.8	20.6	0.0	32.9	26.0	24.3	0.0	32.5
	Range	9.7	8.8	1.1	38	10.3	12.6	1.5	50.7
Bedford	N	1031	1031	998	1031	349	347	347	347
	Mean	26.1	26.2	0.2	49.8	32.8	33.4	0.4	60.1
	SD	2.29	2.21	0.25	9.12	1.84	2.00	0.60	12.08
	Median	25.8	25.9	0.1	48.4	32.9	33.7	0.1	63.2
	Mode	25.9	25.9	0.0[3]	50.8	32.9	31.4	0.0[4]	64.3
	Max.	33.3	33.3	1.5	80.5	39.9	43.7	3.0	84.4
	Min.	20.7	21.4	0.0	32.9	24.3	25.3	0.0	36.4
	Range	12.6	11.9	1.5	47.6	15.6	18.4	3.0	48

[1]Around 60.3% of measurements, [2]Around 46.2% of measurements, [3]Around 48.4% of measurements, [4]Around 48.1% of measurements

Table 6.2: Basic statistics of winter study measurements

		Indoor				Outdoor			
		T_a, [°C]	T_g, [°C]	AV, [m/s]	RH, [%]	T_a, [°C]	T_g, [°C]	AV, [m/s]	RH, [%]
Bedford	N	580	580	580	580	197	197	197	197
	Mean	23.9	24.0	0.1	49.1	25.4	25.9	0.2	52.7
	SD	1.61	1.52	0.16	4.74	0.96	1.13	0.31	6.13
	Median	24.0	24.0	0.0	48.7	25.4	25.8	0.1	54.2
	Mode	23.6	23.5	0.0[1]	48.9	25.2	25.8	0.0[2]	57.7
	Max.	26.7	26.7	0.9	63.5	27.7	28.1	1.8	63.9
	Min.	17.8	18.5	0.0	39.0	23.4	23.3	0.0	39.1
	Range	8.9	8.2	0.9	24.5	4.3	4.8	1.8	24.8
ASHRAE	N	572	572	572	572	194	194	194	194
	Mean	24.6	24.7	0.1	43.0	28.9	29.3	0.2	38.1
	SD	1.41	1.36	0.17	8.62	2.28	2.50	0.27	15.15
	Median	24.4	24.6	0.0	41.1	29.5	29.8	0.0	32.2
	Mode	23.8	24.3	0.0[3]	36.5	30.9	31.1	0.0[4]	23.0
	Max.	28.1	28.2	1.1	65.8	33.0	33.4	1.3	67.3
	Min.	19.3	20.0	0.0	26.1	24.5	24.3	0.0	21.3
	Range	8.8	8.2	1.1	39.7	8.5	9.1	1.3	46

[1]Around 69.5% of measurements, [3]Around 65.4% of measurements, [2]Around 43.7% of measurements, [4]Around 60.3% of measurements

6.2 Relative frequencies

The relative frequency for each variable was plotted to identify its dominant range and any outliers. In both seasons, the range of the category bin for air and globe temperatures was 1 °C. For air velocity and relative humidity, it was considered as 0.1 m/s and 5% respectively. It should be mentioned that each value in the x-axes of the plotted graphs below represents the middle of the bin range.

6.2.1 Air temperature

Almost 90% of indoor air temperatures in summer questionnaires extended from 23 °C to 28 °C as indicated in Figure 6.1. It is noticed that around 7% of the temperatures in Bedford questionnaire were above 30 °C. These temperatures were mainly recorded in (ZA-G2) classroom where air conditioning units were out of service during the survey day. The winter dominant range extended from 23 °C to 26 °C and contained 84% approximately of Bedford records. In ASHRAE questionnaire, 92% roughly of temperatures were between 23 °C and 27 °C. Similar ranges were reported in air conditioned classrooms in a study conducted in Taiwan (Cheng et al., 2008).

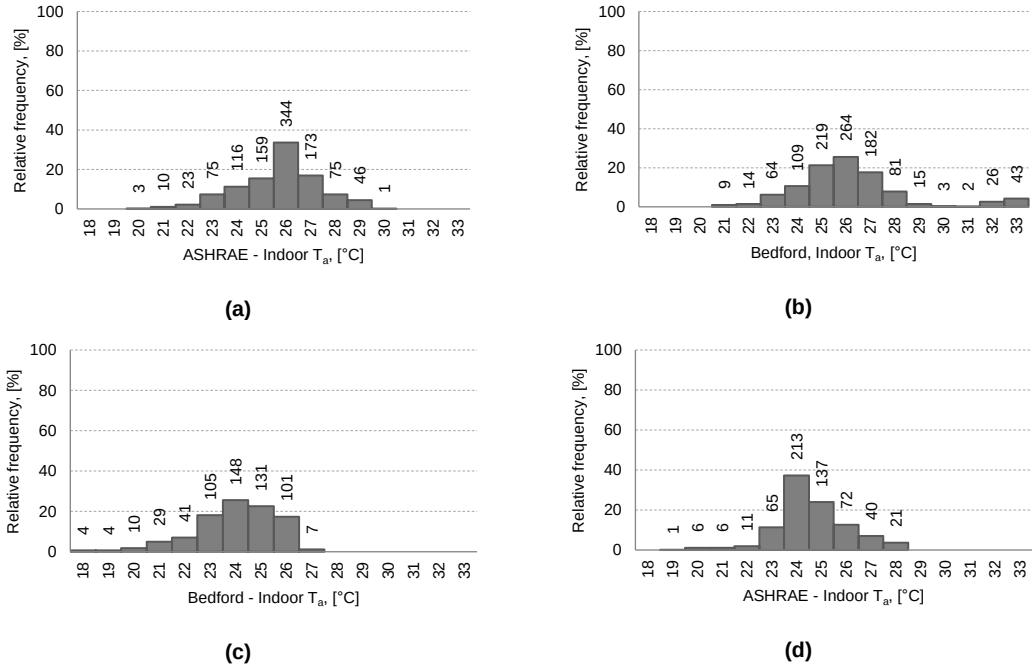


Figure 6.1: Relative frequency of indoor air temperature: (a) summer-ASHRAE (N = 1025), (b) summer-Bedford (N = 1031), (c) winter-Bedford (N = 580), and (d) winter-ASHRAE (N = 572) (Labels are measurements' sizes)

Considering outdoor data presented in Figure 6.2, around 67% of summer temperatures in ASHRAE questionnaire were between 32 °C and 36 °C with 17% approximately fell in 30 °C bin. The temperatures had a relatively wider distribution in Bedford questionnaire. However, only almost 6% of the recorded temperatures were above 36 °C. The

dominant range was 33-35 °C with around 22% of the records fell within 31 °C bin. In winter, almost all Bedford records extended between 24 °C and 27 °C with 69% roughly in the 25 °C and 26 °C bins. Considering ASHRAE questionnaire, almost 19%, 21%, and 20% of records fell in the 27 °C, 30 °C, and 31 °C bins respectively.

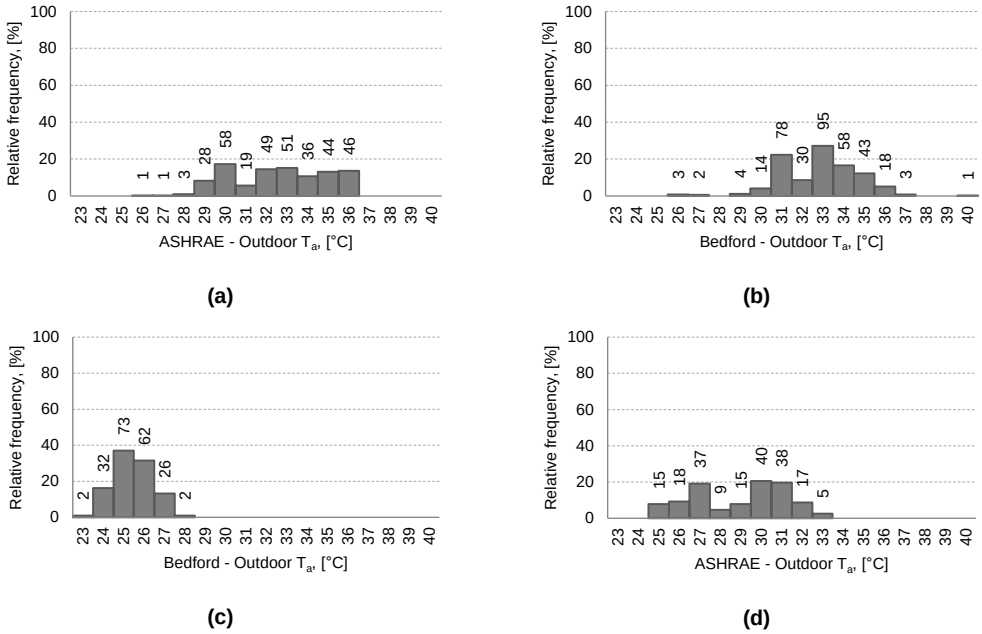


Figure 6.2: Relative frequency of outdoor air temperature: (a) summer-ASHRAE (N = 336), (b) summer-Bedford (N = 349), (c) winter-Bedford (N = 197), and (d) winter-ASHRAE (N = 194) (Labels are measurements' sizes)

6.2.2 Globe temperature

In summer, around 94% of ASHRAE indoor globe temperatures extended from 23 °C to 28 °C as demonstrated in Figure 6.3. In Bedford questionnaire, the dominant range, containing 86% approximately of the measurements, was 24-28 °C. Besides, almost 7% of the temperatures, mainly recorded in (ZA-G2) classroom, were above 30 °C. Considering winter, the dominant range was 23-26 °C and it contains around 85% of the measurements of both questionnaires. It is noteworthy that almost 93% of ASHRAE measurements fell between 23 °C and 27 °C as noted in Figure 6.3.

Figure 6.4 reveals that more than 60% of summer outdoor globe temperatures in ASHRAE questionnaire extended between 33 °C and 36 °C with 19% approximately fell in the 30 °C bin. Moreover, around 95% of Bedford temperatures were between 31 °C and 36 °C with almost 1% fell in 40-44 °C range. Considering winter, approximately all Bedford temperatures extended from 24 °C to 28 °C. It is noteworthy that the 26 °C bin formed almost 37% of measurements. Besides, around 46% of ASHRAE records extended between 30 °C and 32 °C and roughly 20% of the records fell within the 27 °C bin.

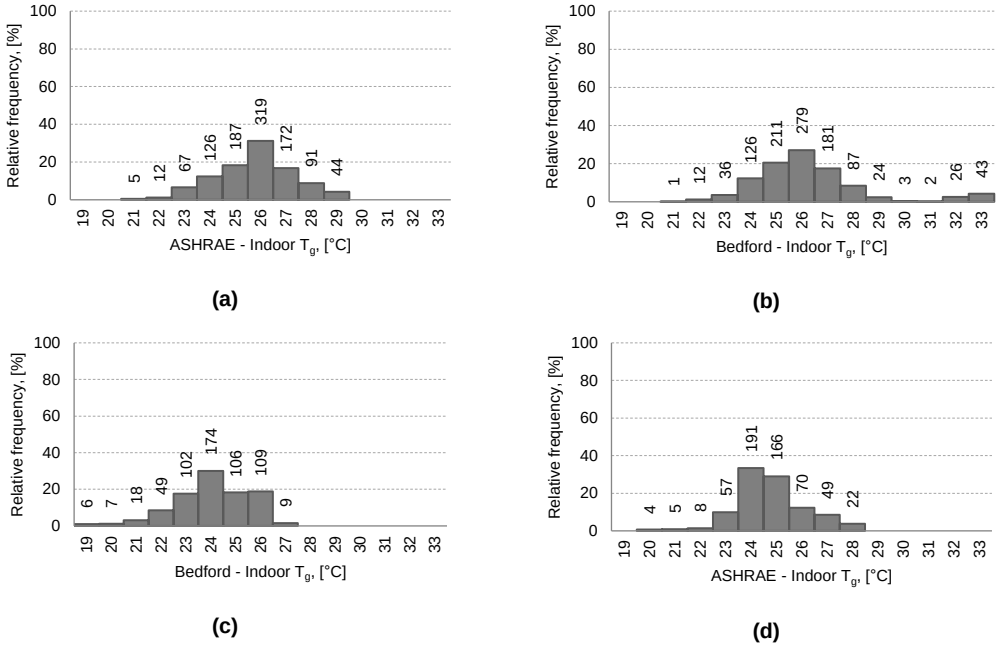


Figure 6.3: Relative frequency of indoor globe temperature: (a) summer-ASHRAE (N = 1023), (b) summer-Bedford (N = 1031), (c) winter-Bedford (N = 580), and (d) winter-ASHRAE (N = 572) (Labels are measurements' sizes)

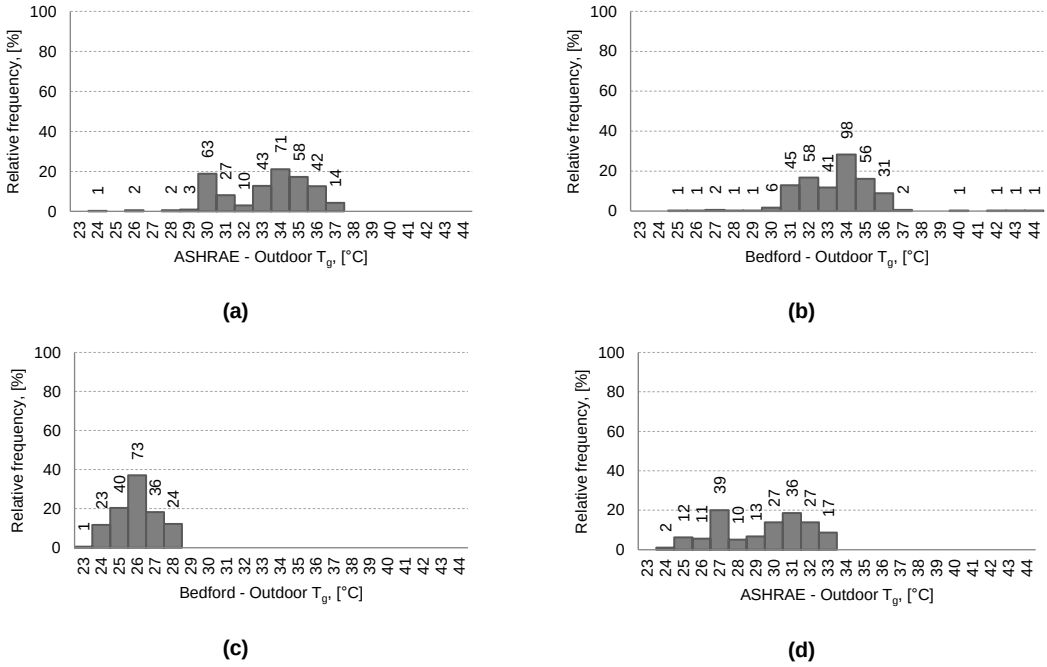


Figure 6.4: Relative frequency of outdoor globe temperature: (a) summer-ASHRAE (N = 336), (b) summer-Bedford (N = 347), (c) winter-Bedford (N = 197), and (d) winter-ASHRAE (N = 194) (Labels are measurements' sizes)

6.2.3 Air velocity

Recalling that the used anemometers have 0.2-20 m/s measuring range, it is noted in Figure 6.5 that no or unreliable indoor air velocities formed 75% and 59% approximately of ASHRAE and Bedford records respectively in summer. Velocities between 0.2 m/s and 0.5 m/s formed almost 23% of ASHRAE records. In Bedford, around 36% of velocities ranged between 0.2 m/s and 0.6 m/s with two records only as 1.5 m/s.

Besides, the figure indicates that no or unreliable velocities formed 79% and 74% roughly of Bedford and ASHRAE winter records respectively. In the former questionnaire, the dominant range extended from 0.2 m/s to 0.6 m/s forming around 19% of the measurements. In the latter, the dominant range contained almost 23% of the velocities and it extended between 0.2 m/s and 0.4 m/s. Considering that the maximum allowable limit of indoor air velocity defined by ASHRAE is 0.8 m/s (Katafygiotou & Serghides, 2014b), it is noted that the measurements were equal to or exceeded this limit in a few occasions that were less than 3.5% of summer and winter records.

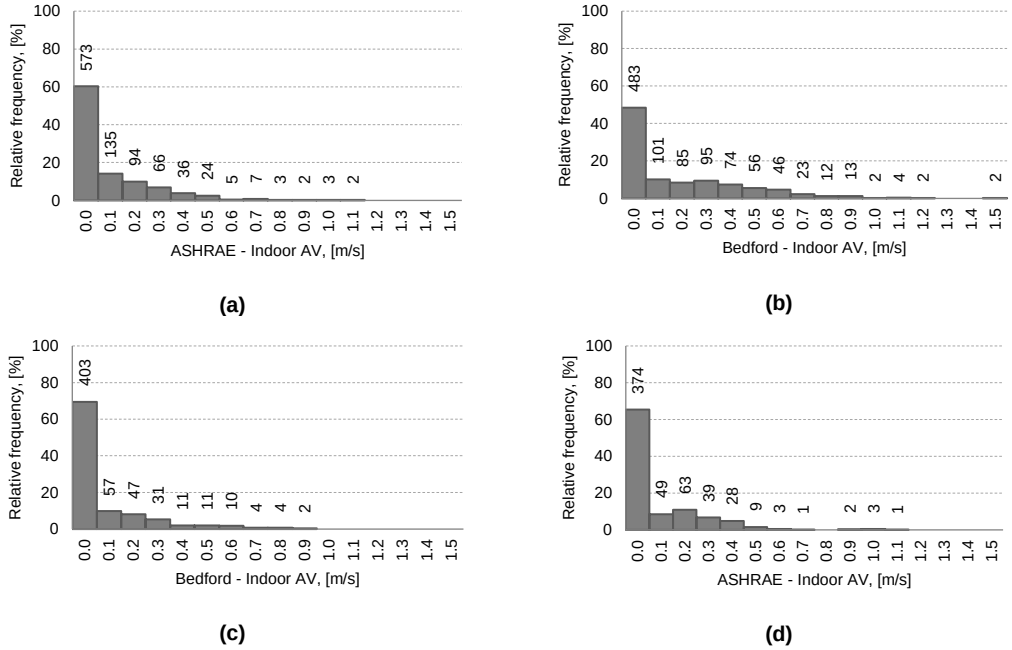


Figure 6.5: Relative frequency of indoor air velocity: (a) summer-ASHRAE (N = 950), (b) summer-Bedford (N = 998), (c) winter-Bedford (N = 580), and (d) winter-ASHRAE (N = 572) (Labels are measurements' sizes)

In summer, the outdoor air velocities during Bedford questionnaire were wider that of ASHRAE velocities as indicated in Figure 6.6. For both questionnaires, the measured velocities were unreliable in almost 56% of the measurements. Besides, around 24% of ASHRAE velocities were from 0.2 m/s to 0.4 m/s and almost 28% of Bedford velocities fell between 0.2 m/s and 1.0 m/s. In winter, the unreliable velocities formed 54% and 67% approximately of Bedford and ASHRAE measurements respectively. Around 34% of the velocities were between 0.2 m/s and 0.5 m/s in the former questionnaire and almost 22% of the velocities extended between 0.3 m/s and 0.6 m/s in the latter questionnaire.

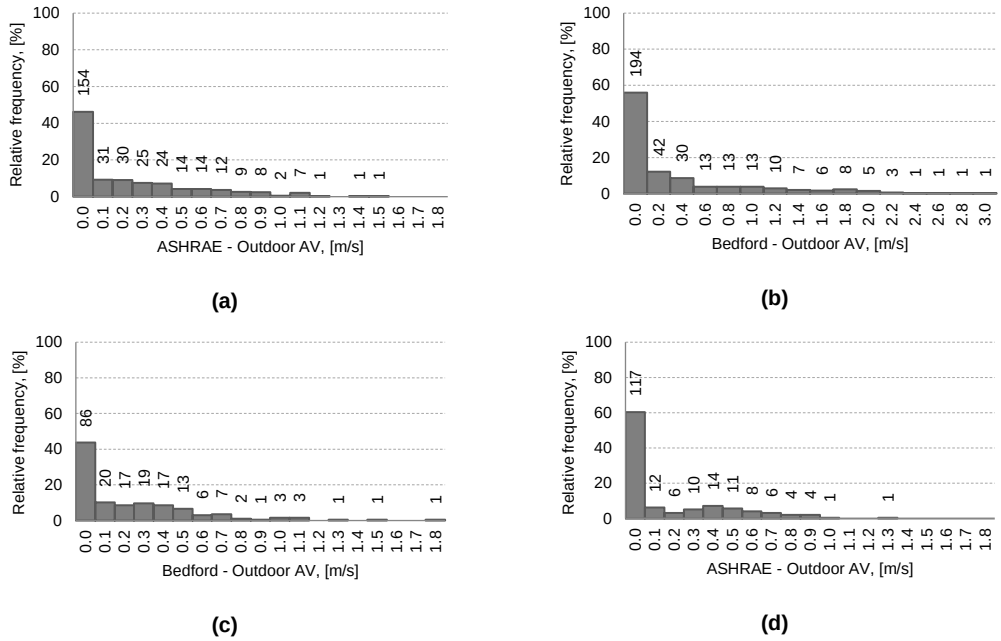


Figure 6.6: Relative frequency of outdoor air velocity: (a) summer-ASHRAE (N = 333), (b) summer-Bedford (N = 347), (c) winter-Bedford (N = 197), and (d) winter-ASHRAE (N = 194) (Labels are measurements' sizes)

6.2.4 Relative humidity

In summer, the dominant range of indoor relative humidity was 38%-58% and it formed almost 93% of ASHRAE records as noted in Figure 6.7. In Bedford questionnaire, the range extended from 38% to 63% and it contained 93% of the measurements. Similarly, almost 97% of Bedford relative humidity in winter fell in 43%-58% range and around 94% of ASHRAE records were from 33% to 58%. Normally, indoor relative humidity are between 30% and 70% (Katafygiotou & Serghides, 2014b), which was generally the case in summer and winter.

Moreover, Figure 6.8 indicates that around 94% of outdoor relative humidity recorded during ASHRAE questionnaire in summer extended between 48% and 73%. Besides, 27% and 65% roughly of Bedford records were in 38%-48% and 58%-73% ranges respectively. In winter, a dominant range extended between 43% and 58% and it formed 90% roughly of Bedford relative humidity. Around 60% of the measurements in ASHRAE questionnaire were from 23% to 33% and 12% roughly fell in the 63% bin. It may worth mentioning that the dominant ranges of outdoor and indoor measurements during Bedford questionnaire in winter study were identical. However, the distribution of the records within the ranges was different.

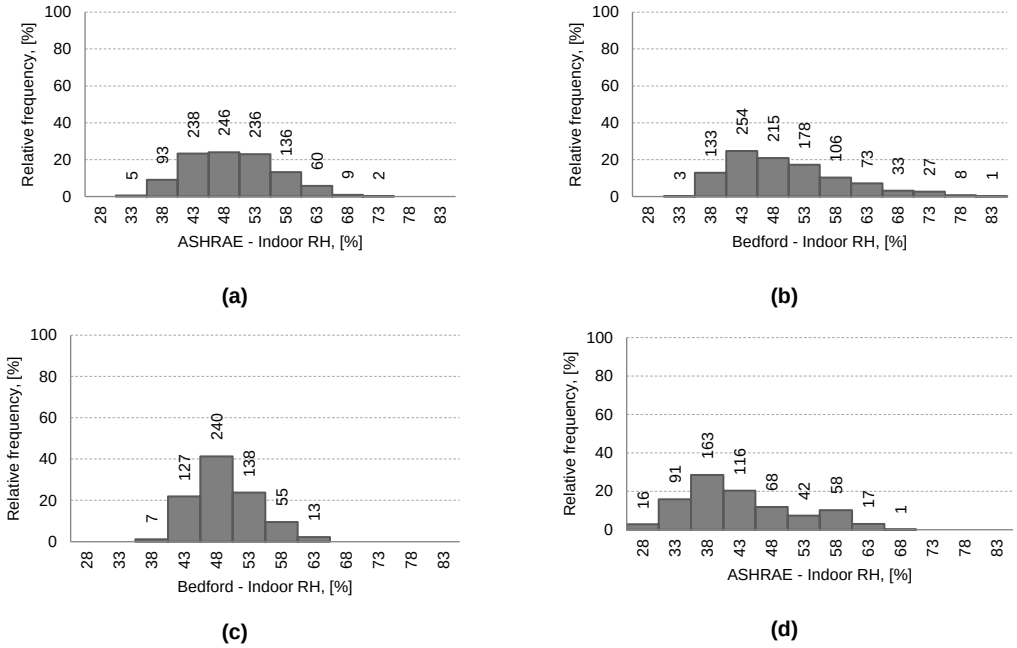


Figure 6.7: Relative frequency of indoor relative humidity: (a) summer-ASHRAE (N = 1025), (b) summer-Bedford (N = 1031), (c) winter-Bedford (N = 580), and (d) winter-ASHRAE (N = 572) (Labels are measurements' sizes)

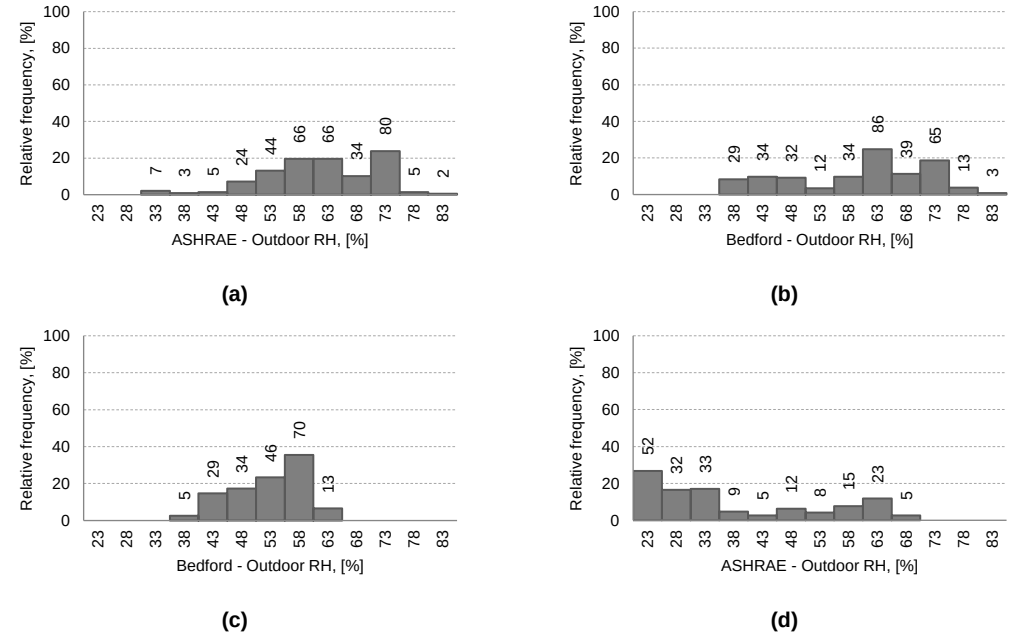


Figure 6.8: Relative frequency of outdoor relative humidity: (a) summer-ASHRAE (N = 336), (b) summer-Bedford (N = 347), (c) winter-Bedford (N = 197), and (d) winter-ASHRAE (N = 194) (Labels are measurements' sizes)

6.3 Proportions

Considering the identified dominant ranges, the proportions of the measured variables are presented in the following sections. This assists in recognising the classrooms and schools that had different thermal conditions.

6.3.1 Air temperature

Figure 6.9 presents the proportions of indoor air temperature of the investigated classrooms. It is obvious that (ZA-G2) classroom had different thermal conditions during ASHRAE questionnaire in summer. Indeed, the dominant range formed less than 50% of its measurements mainly owing to an improper air conditioning operation in the survey day. Moreover, around 32% of (DA-G2) temperatures fell outside the dominant range. The reason may be keeping air conditioning units working even if the students take some lessons outside their classroom. Unfortunately, monitoring the classrooms occupation periods was not possible. Almost all the temperatures of (ZA-G2) classroom in Bedford questionnaire were above the dominant range due to air conditioning failure. For the other classrooms, 80% or more of the temperatures fell within the dominant range. In winter, the explored classrooms had similar indoor air temperatures in both questionnaires as more than 70% of the measurements were within the dominant ranges. However, classroom (DA-G2) was an exception as 70% of its temperatures in Bedford questionnaire were below the range.

The proportions of outdoor air temperatures are presented in Figure 6.10. Considering ASHRAE questionnaire in summer, it is noticed that the temperatures of (NK) School were relatively cooler as around 40% of the measurements were below the dominant range. In addition, 30% approximately of the temperatures from (WK) School in Bedford questionnaire exceeded the dominant range. In general, the lowest summer temperatures were recorded in (NK) School probably because of its proximity from the Gulf of Oman taking into consideration that daytime cooling breeze can reach distances up to 800 m (Konya & Vandenberg, 2011; Koch-Nielsen, 2007; d'Energia, 2004). Moreover, the highest temperatures in summer were from (WK) School possibly because of the urban heat island influence (Charabi & Bakhit, 2011). Considering winter, it is noted that almost all measured temperatures were within the dominant range in Bedford questionnaire. In ASHRAE questionnaire, around 50%, 40%, and 30% of the temperatures in (NK), (ZA), and (DA) Schools respectively differed from the dominant ranges. A combination of the weather conditions and the urban context features of each school may justify these measurements.

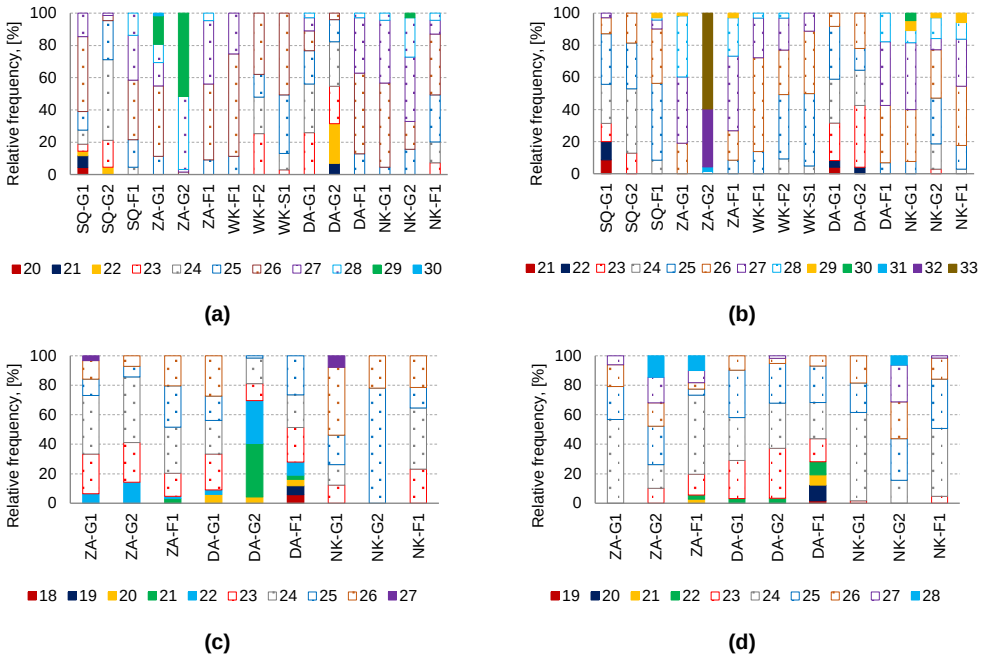


Figure 6.9: Proportions of indoor air temperature: (a) summer-ASHRAE, (b) summer-Bedford, (c) winter-Bedford, and (d) winter-ASHRAE (Dominant ranges in dotted fill)

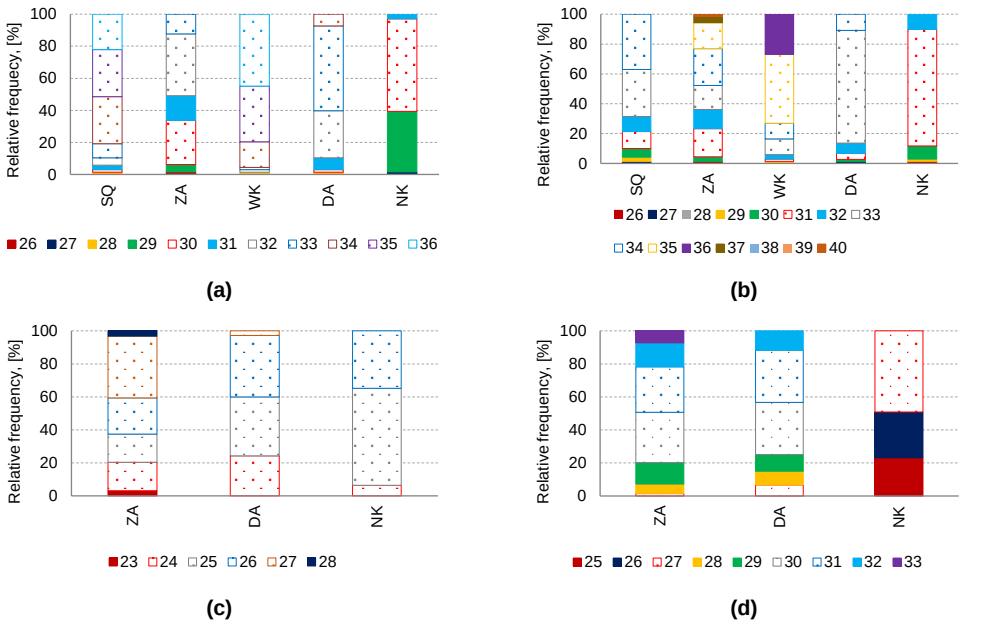


Figure 6.10: Proportions of outdoor air temperature: (a) summer-ASHRAE, (b) summer-Bedford, (c) winter-Bedford, and (d) winter-ASHRAE (Dominant ranges in dotted fill)

6.3.2 Globe temperature

As presented in Figure 6.11, around 47% and 99% of (ZA-G2) classroom globe temperatures in summer were outside the dominant range in ASHRAE and Bedford questionnaires respectively. Besides, around 26% of the temperatures in (SQ-G1) and (DA-G2) classrooms in Bedford questionnaire were below the dominant range. Considering winter questionnaires, more than 75% of the temperatures measured in

each classroom fell in the dominant ranges. An exception is (DA-G2) classroom during Bedford questionnaire as only 30% approximately of its temperatures fell in the dominant range. As mentioned earlier, this may be due to operating air conditioning units even if the students were outside their classrooms.

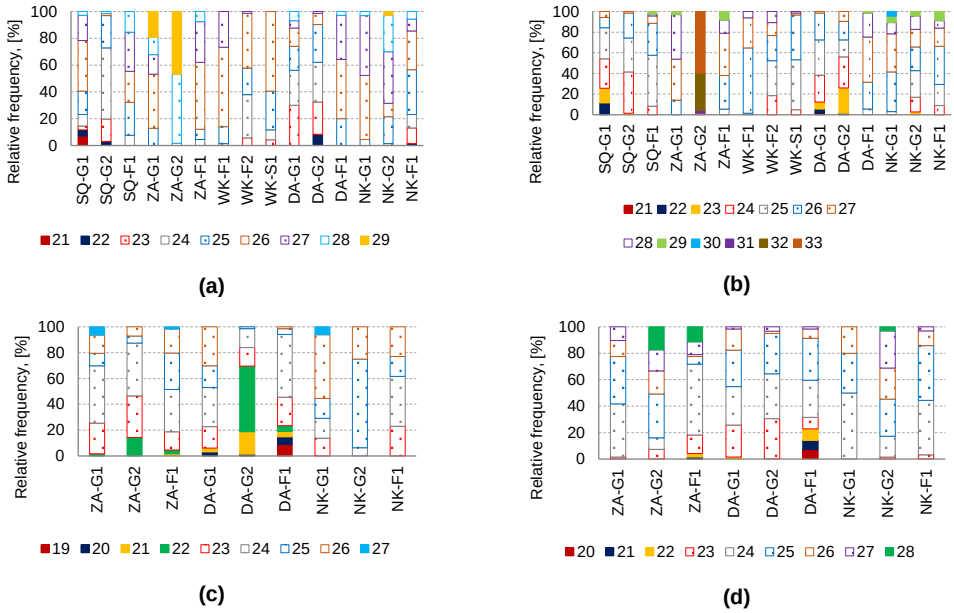


Figure 6.11: Proportions of indoor globe temperature: (a) summer-ASHRAE, (b) summer-Bedford, (c) winter-Bedford, and (d) winter-ASHRAE (Dominant ranges in dotted fill)

The proportions of outdoor globe temperatures are presented in Figure 6.12. Almost all measurements fell in the dominant ranges in Bedford questionnaire in summer and winter. Considering ASHRAE questionnaire, around 35% of (ZA) School temperatures in summer fell outside the dominant range. Besides, around 43%, 36%, and 20% of the temperatures from (NK), (ZA), and (DA) Schools respectively fell outside the dominant range in winter.

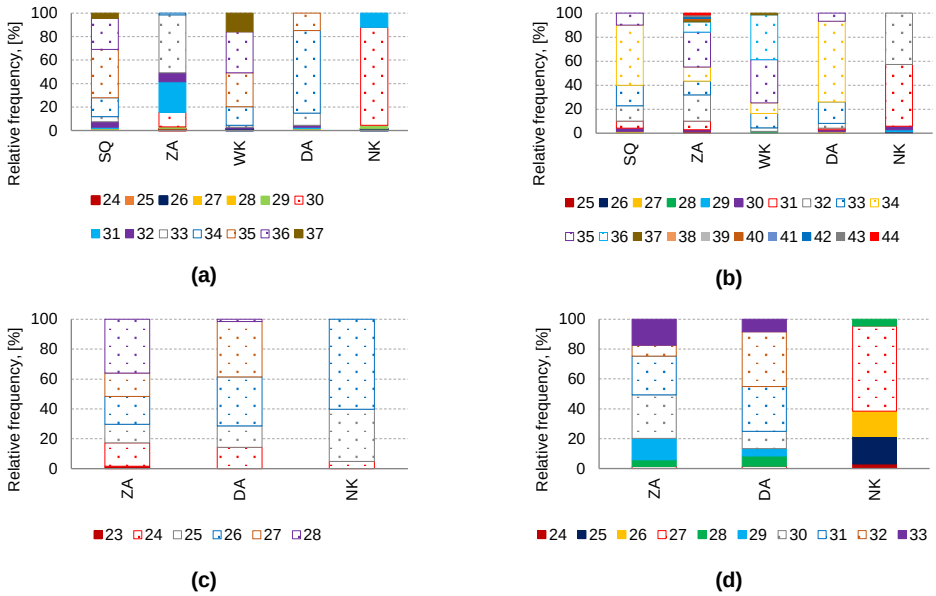


Figure 6.12: Proportions of outdoor globe temperature: (a) summer-ASHRAE, (b) summer-Bedford, (c) winter-Bedford, and (d) winter-ASHRAE (Dominant ranges in dotted fill)

6.3.3 Air velocity

In both questionnaires, around 80% or more of summer indoor air velocities were within the dominant ranges or below as indicated in Figure 6.13. However, 38% approximately of air velocities recorded in (ZA-G2) classroom during Bedford questionnaire were above 0.6 m/s. This was mainly due to the intensive use of fans resulted from defective air conditioning units. The students increased air velocity as an attempt to decrease their thermal discomfort because air velocity is positively related to the rates of convection and evaporation from the skin. In winter, most measurements were within the dominant ranges or below in both questionnaires. Yet, few exceptions existed such as (DA-F1) classroom during Bedford questionnaire and (DA-G1), (DA-F1), and (NK-G2) classrooms in ASHRAE questionnaire. It should be mentioned that these exceptions did not exceed 20% of the total measurements in any classroom.

In both questionnaires of summer study, 37% roughly of outdoor air velocities from (SQ) School were higher than the dominant ranges as plotted in Figure 6.14. Likewise, around 60% and 50% of velocities recorded in (NK) School during ASHRAE and Bedford questionnaires respectively were higher than the dominant ranges. This may be owing to the schools' locations near the Gulf of Oman. Furthermore, more than 80% of winter velocities fell within the dominant ranges or below except those recorded in (NK) School. Indeed, around 29% and 24% of the records from this school in ASHRAE and Bedford questionnaires respectively were above the dominant ranges.

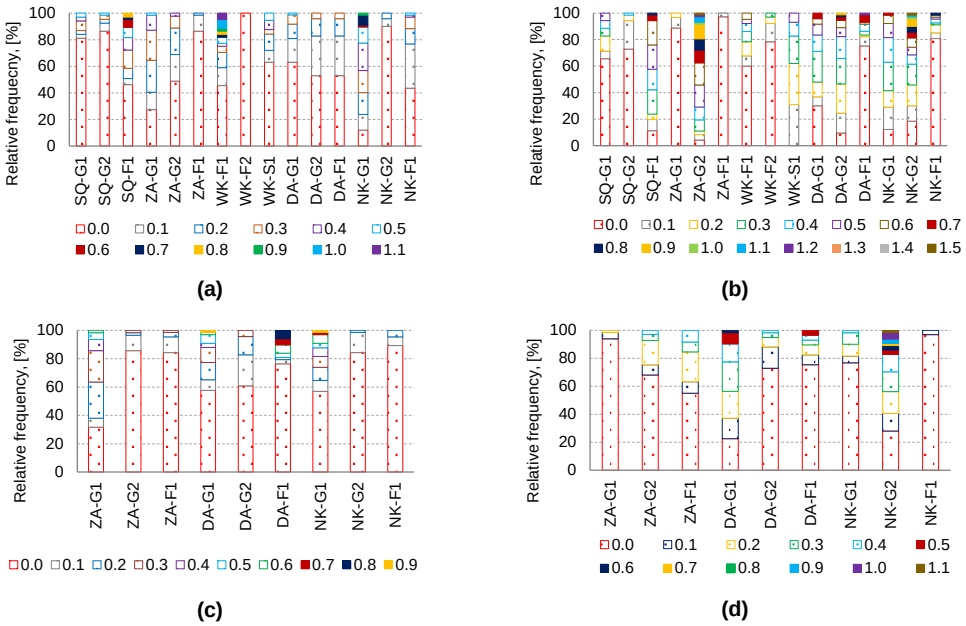


Figure 6.13: Proportions of indoor air velocity: (a) summer-ASHRAE, (b) summer-Bedford, (c) winter-Bedford, and (d) winter-ASHRAE
(Dominant ranges in dotted fill)

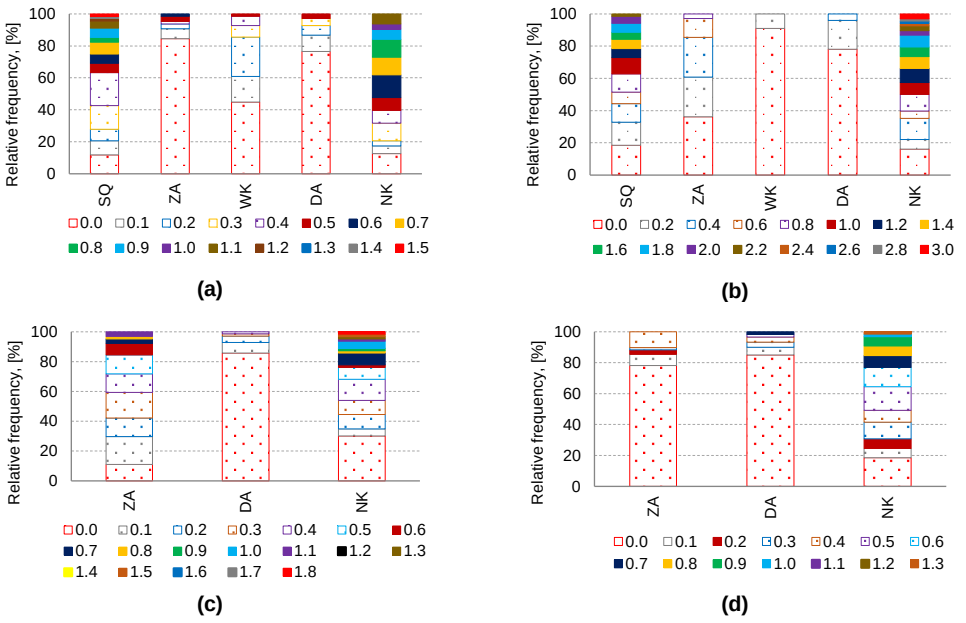


Figure 6.14: Proportions of outdoor air velocity: (a) summer-ASHRAE, (b) summer-Bedford, (c) winter-Bedford, and (d) winter-ASHRAE
(Dominant ranges in dotted fill)

6.3.4 Relative humidity

In summer, more than 93% of indoor relative humidity records in ASHRAE questionnaire were within the dominant range. Exceptions were (SQ-F1), (NK-G1) and (NK-F1) classrooms as around 18%, 24% and 22% respectively of their measurements were higher as illustrated in Figure 6.15. In Bedford questionnaire, more than 80% of the records were within the dominant range except those of (ZA-G2) classroom as around 33% were higher. Considering winter, more than 80% of the

measurements fell in the dominant ranges in both questionnaires. Exceptions were (ZA-G2) and (NK-G2) classrooms during Bedford questionnaire besides (ZA-F1) and (NK-G1) classrooms in ASHRAE questionnaire. Indeed, almost 11% and 20% of (ZA-G2) and (NK-G2) classrooms' records respectively were outside the range in the former questionnaire. In the latter, 20% and 23% approximately of (ZA-F1) and (NK-G1) classrooms' records respectively were outside the dominant range.

As plotted in Figure 6.16, around 85% of the outdoor records of summer fell within the dominant ranges except those of (WK) school in ASHRAE questionnaire as almost 22% of its records were below the range. Additionally, it is noted that 80% roughly of (NK) School records in both questionnaires clustered in one category and the widest range of relative humidity was recorded in (ZA) School. In winter, almost more than 80% of the measurements of both questionnaires fell within the dominant ranges. An exception was (NK) School as only 35% of its data in ASHRAE questionnaire were in the range.

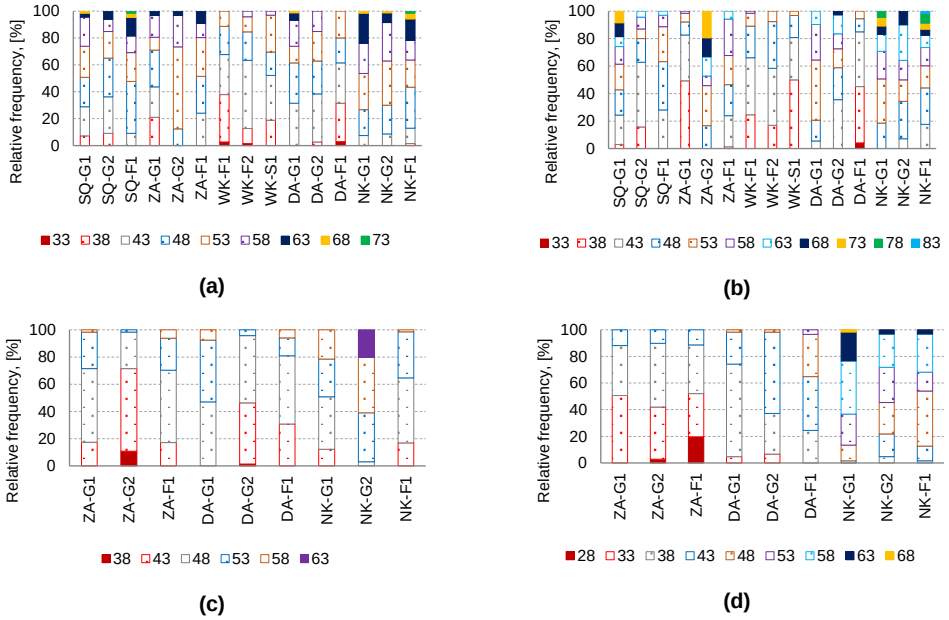


Figure 6.15: Proportions of indoor relative humidity: (a) summer-ASHRAE, (b) summer-Bedford, (c) winter-Bedford, and (d) winter-ASHRAE (Dominant ranges in dotted fill)

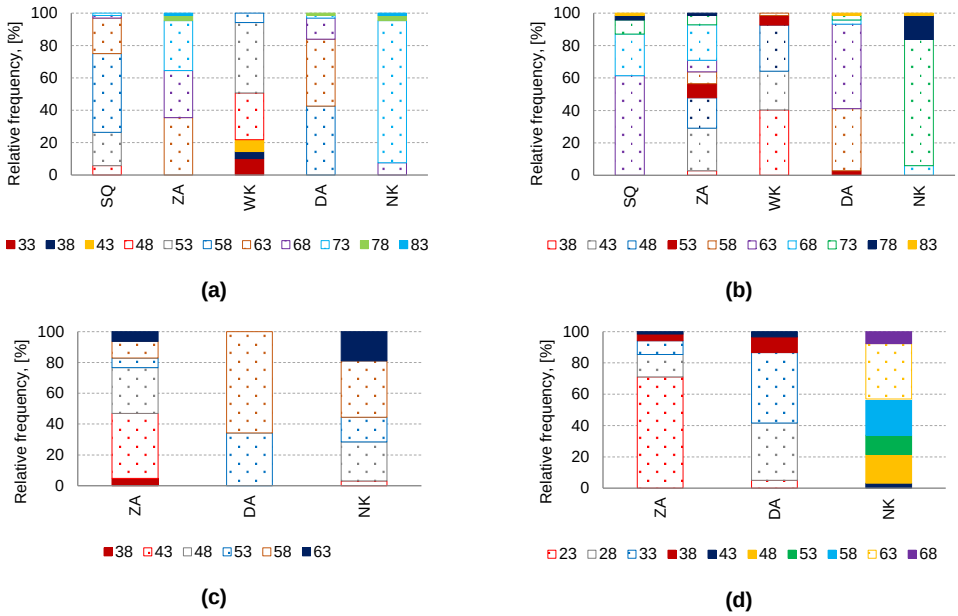


Figure 6.16: Proportions of outdoor relative humidity: (a) summer-ASHRAE, (b) summer-Bedford, (c) winter-Bedford, and (d) winter-ASHRAE (Dominant ranges in dotted fill)

6.4 Hourly Profiles

The hourly profiles of the measured variables from selected classrooms are presented in the following sections with a special focus on the conditions before distributing the questionnaires. The considered classrooms in this section were selected for further exploration because some of their measurements were outside the dominant ranges. The questionnaires' distribution times are displayed in Table 6.3.

Table 6.3: Questionnaires' distribution times

		ASHRAE	Bedford		ASHRAE	Bedford		ASHRAE	Bedford
Summer	SQ-G1	11:25	10:39	SQ-G2	12:53	11:25	SQ-F1	10:45	12:00
	ZA-G1	11:10	09:25	ZA-G2	11:40	11:05	ZA-F1	09:50	10:31
	WK-F1	11:21	11:17	WK-F2	12:39	12:04	WK-S1	12:00	10:37
	DA-G1	11:20	11:30	DA-G2	12:23	12:05	DA-F1	12:16	12:54
	NK-G1	11:23	11:25	NK-G2	12:29	11:50	NK-F1	11:05	10:41
Winter	ZA-G1	12:55	12:28	ZA-G2	09:25	10:46	ZA-F1	10:48	11:24
	DA-G1	11:44	11:30	DA-G2	11:06	11:46	DA-F1	12:28	12:36
	NK-G1	12:39	10:55	NK-G2	11: 25	13:05	NK-F1	12:01	11:29

6.4.1 Air temperature

Figure 6.17 displays the hourly profiles of indoor air temperatures for selected classrooms besides the dominant ranges. The arrows identify the questionnaires' distribution time in the classroom. Although the temperatures of (ZA-G2) classroom were generally above the dominant ranges of both questionnaires in summer, they were close to the upper limit of the dominant range in ASHRAE questionnaire. The reason was the improper operation of air conditioning in this classroom during ASHRAE questionnaire and the complete failure during Bedford

questionnaire. It is noted that the temperature of (SQ-G1) classroom at the distribution time of Bedford questionnaire was negligibly below the dominant range.

In winter, most classrooms had temperatures outside the dominant range in Bedford questionnaire as demonstrated in Figure 6.17. Yet, the temperatures of (ZA-G2), (ZA-F1), and (DA-F1) classrooms fell in the dominant range at the questionnaire distribution time. The temperatures of (ZA-G1) and (NK-G1) classrooms at the distribution time exceeded the dominant range marginally, whereas the temperatures of (DA-G1) and (DA-G2) classrooms were lower than the range by around 2 °C and 1.9 °C respectively. It is noteworthy that the temperatures of (DA-G2) classroom were generally below the dominant range for most of the time perhaps because the students took some classes in other rooms based on their schedule. Considering ASHRAE questionnaire, the arrows indicate that the temperatures of both (ZA-F1) and (DA-F1) classrooms were outside the range; the former was marginally higher and the latter was lower by 0.4 °C approximately.

Generally, air temperatures in both seasons decreased in some classrooms during or after the break time, roughly 10:30-11:00, mainly because most students spend this time in the schools' plazas. When they return, they often adjust the thermostats to cool the classrooms. This probably was the case in summer with (DA-G2) classroom during ASHRAE questionnaire and with (DA-G1) and (SQ-G1) classrooms in Bedford questionnaire. Likewise, it perhaps was the case with (DA-G1) and (DA-F1) classrooms in Bedford questionnaire of winter study and with (ZA-F1) and (DA-F1) classrooms during ASHRAE questionnaire.

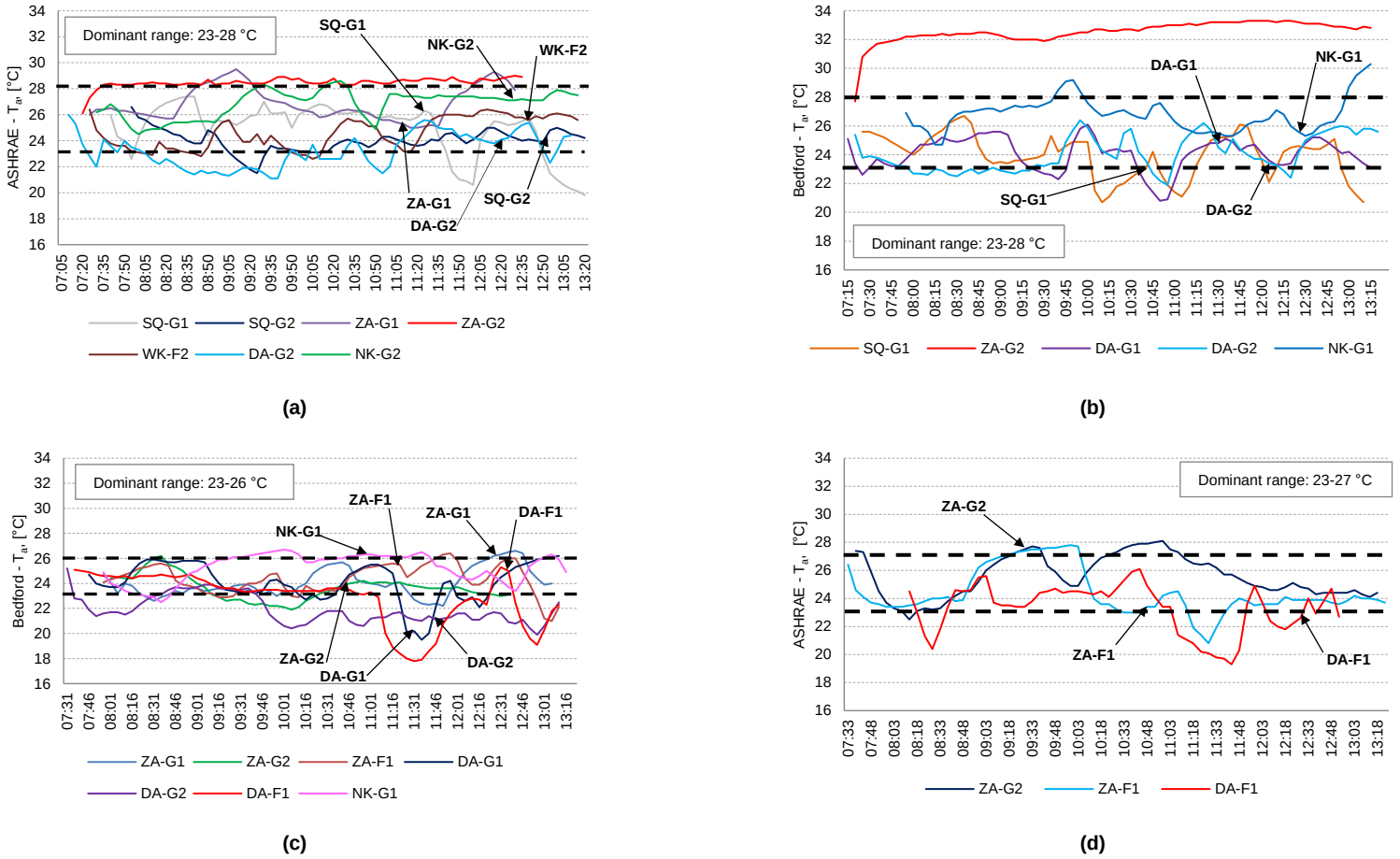


Figure 6.17: Hourly profile of indoor air temperature for selected classrooms: (a) summer-ASHRAE, (b) summer-Bedford, (c) winter-Bedford, and (d) winter-ASHRAE

6.4.2 Globe temperature

For selected classrooms, Figure 6.18 presents the hourly profiles of indoor globe temperatures. As expected, the globe temperatures of (ZA-G2) classroom in both questionnaires of summer study were above the dominant ranges. In specific, the temperature exceeded the upper limit by around 0.5 °C and 5 °C at the distribution time of ASHRAE and Bedford questionnaires respectively. Besides, the arrows indicate that the temperatures of the other classrooms fell in the dominant range at the distribution time of ASHRAE questionnaire. It is noteworthy that the temperatures of (NK-F1) classroom were negligibly above the upper limit of the dominant range at 5 and 10 minutes before distributing ASHRAE questionnaire by around 0.1 °C and 0.3 °C respectively. In Bedford questionnaire, the temperature of (SQ-G1) classroom at the distribution time was below the dominant range by 0.7 °C roughly.

Most classrooms had some temperatures outside the dominant range of Bedford questionnaire in winter as noted in Figure 6.18. For instance, the temperatures of (DA-G1) and (DA-G2) classrooms were below the range by 2.3 °C and 1.2 °C respectively and that of (ZA-G1) was marginally higher by almost 0.4 °C. In ASHRAE questionnaire, the temperatures of (ZA-G2) and (NK-G2) classrooms exceeded the upper limit of the dominant range by around 0.5 °C, whereas the temperature of (DA-F1) was below the lower limit by 0.5 °C approximately.

6.4.3 Air velocity

As noted in Figure 6.19, the hourly profile of summer air velocities indicates that (SQ-F1) classroom velocities in ASHRAE questionnaire were unreliable for most of the time. It is, additionally, demonstrated that the velocity of (WK-F1) classroom at the distribution time of this questionnaire was higher than the dominant range by almost 0.4 m/s. Considering Bedford questionnaire, the air velocities of (DA-F1) and (ZA-G2) classrooms fell in the dominant ranges and that of (NK-G2) classroom exceeded the range by almost 0.2 m/s.

Considering winter study, the arrows in Figure 6.19 indicate that the air velocities of the plotted classrooms were within the dominant range at the distribution time of Bedford questionnaire. Oppositely, the air velocity of (NK-G2) classroom at the distribution time of ASHRAE questionnaire was noticeably higher than the dominant range. As this increase occurred after the break time, it is possibly resulted from increasing the ceiling fans' speeds in an attempt to eliminate food smells and introduce fresh air to the classrooms. It is noteworthy that the air velocities in both studies generally exceeded the dominant ranges after the break.

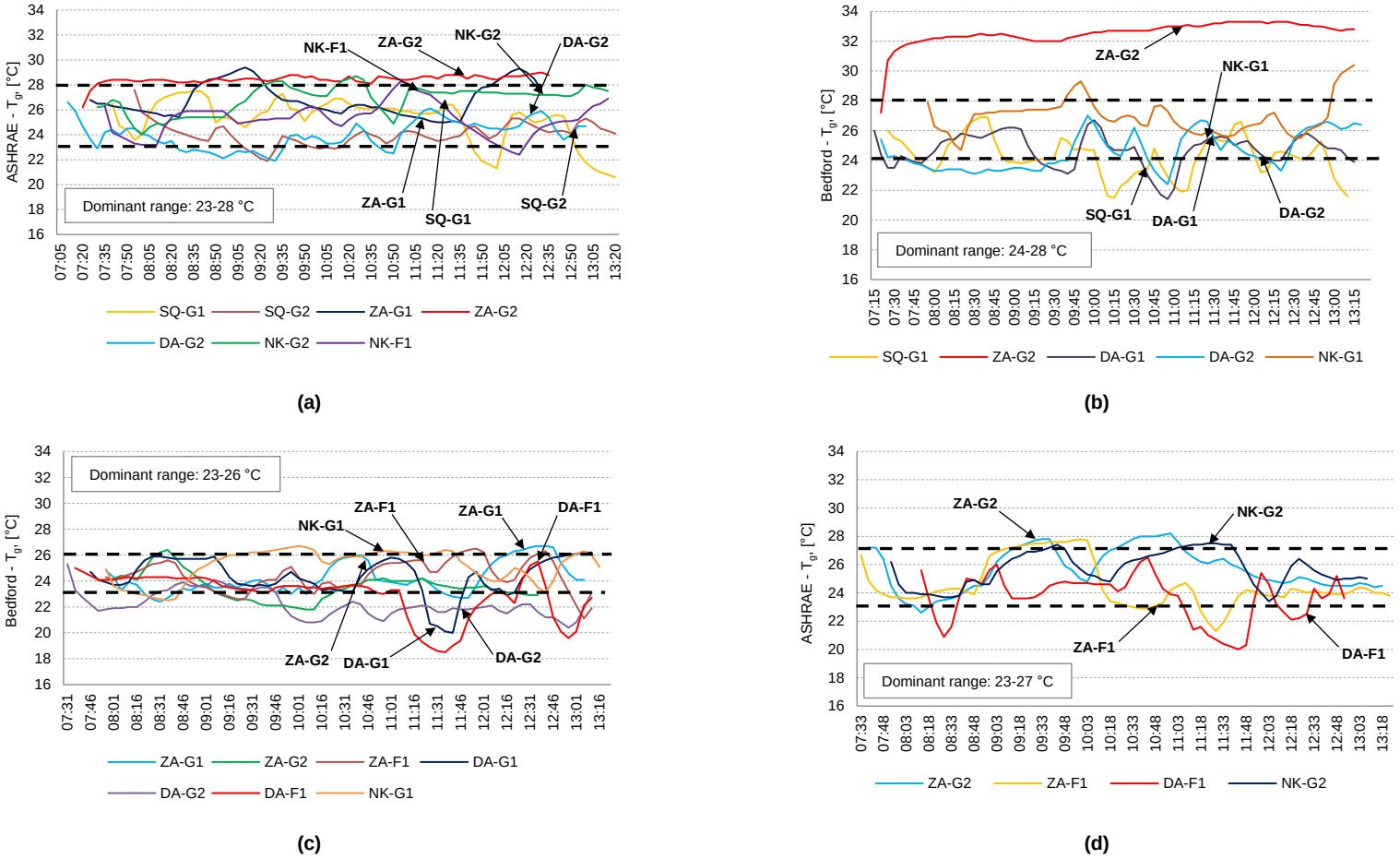


Figure 6.18: Hourly profile of indoor globe temperature for selected classrooms: (a) summer-ASHRAE, (b) summer-Bedford, (c) winter-Bedford, and (d) winter-ASHRAE

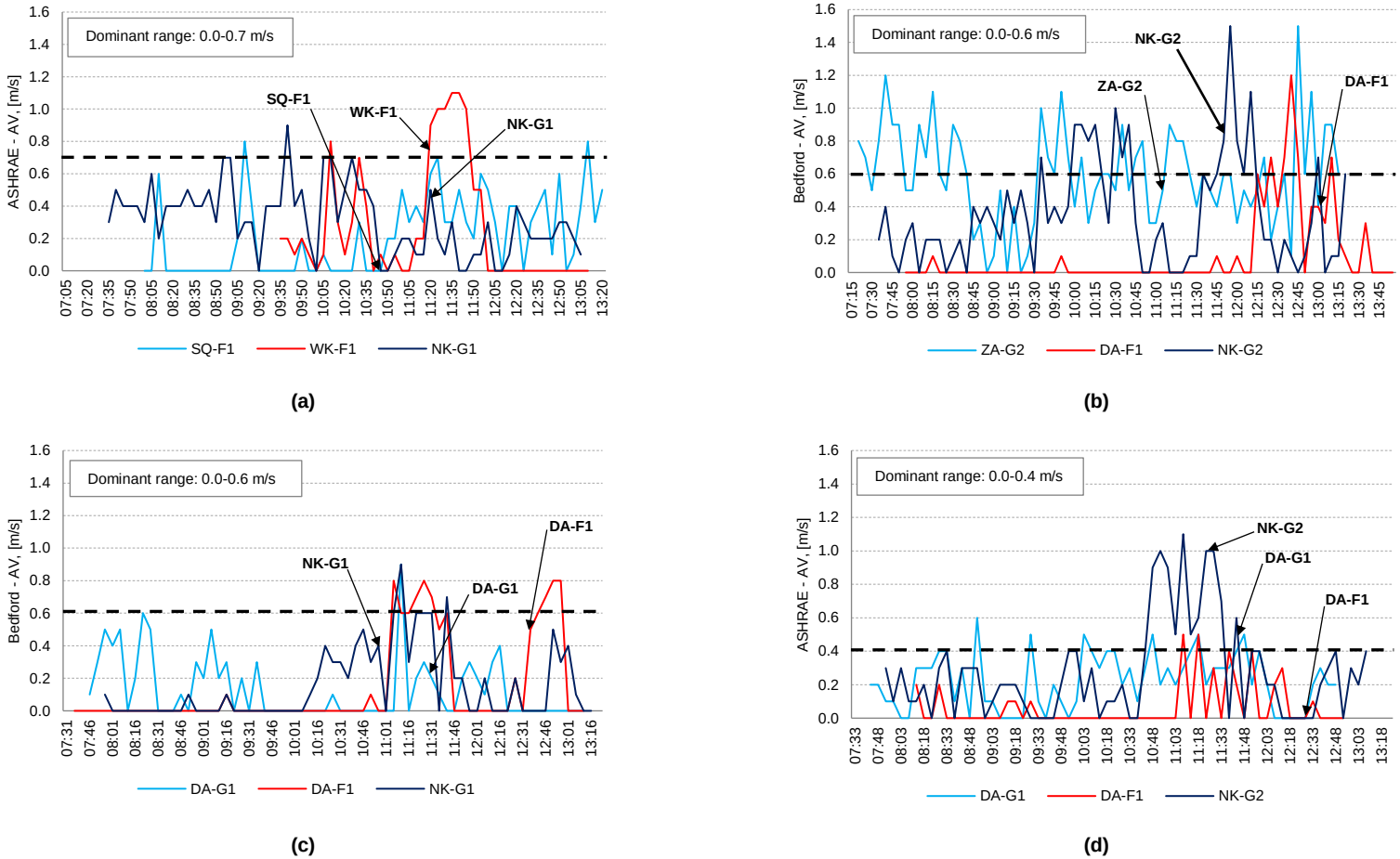


Figure 6.19: Hourly profile of indoor air velocity for selected classrooms: (a) summer-ASHRAE, (b) summer-Bedford, (c) winter-Bedford, and (d) winter-ASHRAE

6.4.4 Relative humidity

The hourly profiles of indoor relative humidity are plotted in Figure 6.20. Considering summer study, the measurements of (SQ-F1) and (NK-F1) classrooms at the distribution time of ASHRAE questionnaire were slightly above the upper limit of the dominant range by 3% and 5.1% respectively. During Bedford questionnaire, the relative humidity of (SQ-G1) classroom at the distribution time was above the dominant range by around 6.5%. Considering winter study, the measured relative humidity was within the dominant range for all classrooms in both questionnaires except (NK-F1) classroom in ASHRAE questionnaire. In this classroom, the measurement was negligibly higher by around 1.2%. As mentioned earlier, these exceptions were perhaps because of the proximity of these two schools from the Gulf of Oman. Furthermore, noticeable fluctuations in relative humidity within short periods of time are noted in summer. Considering the inverse relationship between relative humidity and air temperature under constant content of water vapour, these fluctuations may be related to the frequent opening and closing of doors as well as the frequent change in the set points of air conditioning units. As the students move from and to the classrooms based on their choice of courses, considerable volumes of hot air are introduced to the classrooms. The students respond by lowering the set points of air conditioning units and increasing air movement in the classrooms.

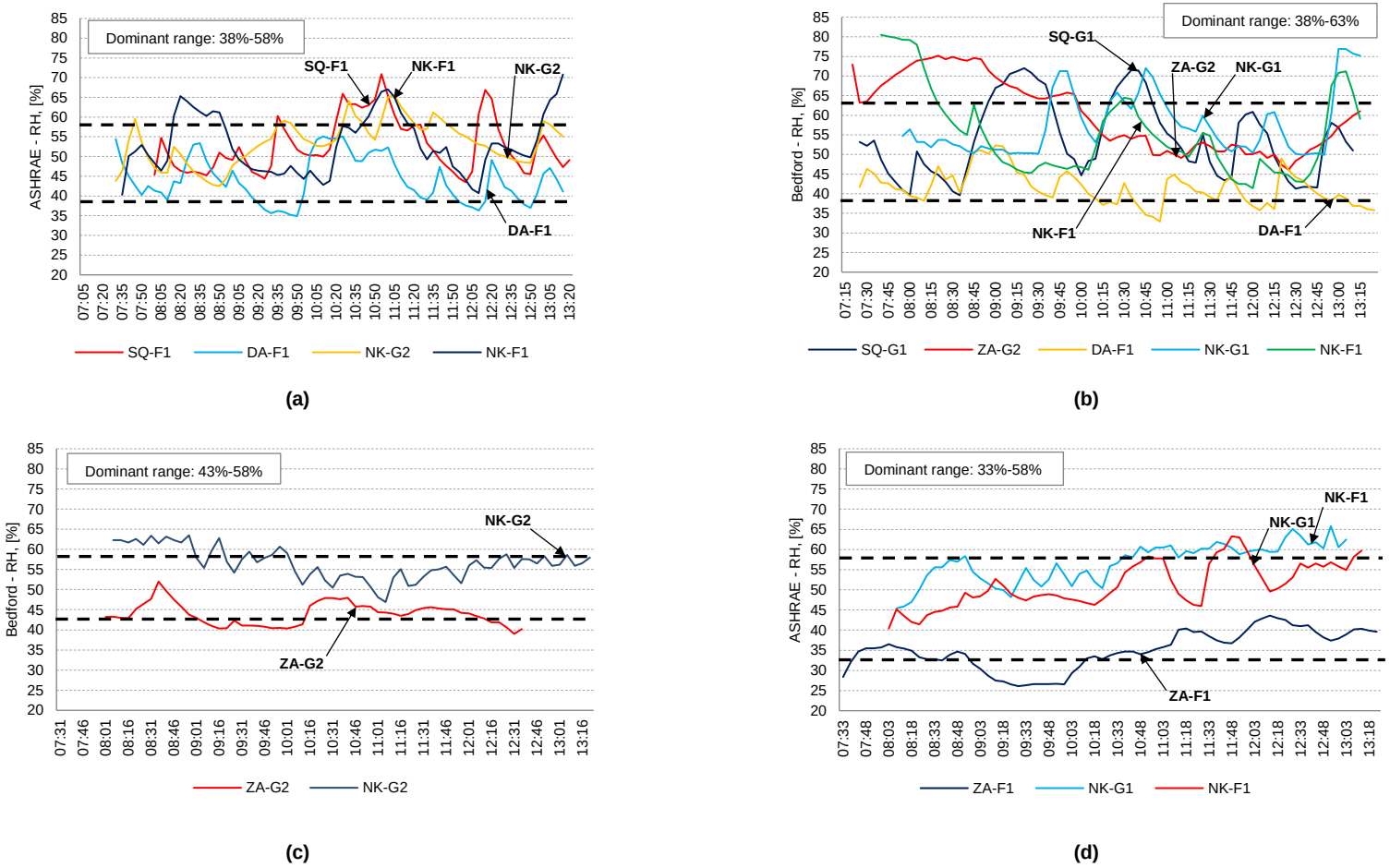


Figure 6.20: Hourly profile of indoor relative humidity for selected classrooms: (a) summer-ASHRAE, (b) summer-Bedford, (c) winter-Bedford, and (d) winter-ASHRAE

6.5 Selected classrooms for further analysis

The previous presentation of the objective measurements assisted in forming a general idea of the classrooms' thermal conditions. With the aim of specifying the classrooms with different thermal conditions, Table 6.4 displays all classrooms in which 10% or more of recorded data were outside the dominant ranges. This is crucial to avoid the negative effect of the outlying data on the regression between the subjective votes and the physical variables (Nicol et al., 2012), which is discussed in Chapter 9.

Table 6.4: Classrooms with measurements outside the dominant ranges

		T_a, [°C]	T_g, [°C]	AV, [m/s]	RH, [%]
Summer	**ASHRAE**	SQ-G1, ZA-G1, ZA-G2, DA-G2	SQ-G1, ZA-G1, ZA-G2	SQ-F1, WK-F1, NK-G1	SQ-F1, NK-G1, NK-F1
	Bedford	SQ-G1, ZA-G2, NK-G1	SQ-G1, ZA-G2, DA-G1, DA-G2, NK-G1	ZA-G2, NK-G2	SQ-G1, ZA-G2, NK-G1, NK-G2, NK-F1
Winter	**Bedford**	ZA-G1, ZA-G2, DA-G2, DA-F1	ZA-G2, DA-G2, DA-F1	DA-F1	ZA-G2, NK-G2
	ASHRAE	ZA-G2, ZA-F1, DA-F1	ZA-G2, ZA-F1, DA-F1	DA-G1, NK-G2	ZA-F1, NK-G2

It is obvious that the thermal conditions of (ZA-G2) classroom in summer study were different from those of other classrooms. Indeed, 52% and 47% of its air and globe temperatures respectively in ASHRAE questionnaire exceeded the dominant ranges. In Bedford questionnaire, all temperatures were roughly above the ranges' upper limits. This deviation in its thermal conditions was expected because of the failure of its air conditioning units. Additionally, around 20%, 26%, and 19% of air temperatures, globe temperatures, and relative humidity respectively in Bedford questionnaire from (SQ-G1) classroom were outside summer dominant ranges. Yet, it should be mentioned that the deviations in air and globe temperatures were by 1 °C and 2 °C only.

Like summer, the thermal conditions in (ZA-G2) classroom during winter seemed to be different in both questionnaires. Considering Bedford questionnaire, around 14%, 14%, and 11% of air temperature, globe temperature, and relative humidity respectively were outside the dominant ranges. During ASHRAE questionnaire, almost 14% and 17% of air and globe temperatures respectively were outside the ranges. Nevertheless, the deviations from the dominant ranges were only 1 °C in all cases. Besides, 70% approximately of each of air and globe temperatures measured in (DA-G2) classroom in Bedford questionnaire were outside the dominant ranges.

Consequently, (ZA-G2) and (DA-G2) classrooms were excluded from further analysis because of their different thermal conditions. In specific, (ZA-G2) classroom was excluded from summer study analysis

of both questionnaires. Besides, (DA-G2) classroom was omitted from Bedford questionnaire analysis of winter study.

Table 6.5 displays the central tendency and variability statistics of the physical measurements in the remaining classrooms. As expected, the standard deviations, particularly those of Bedford questionnaire in summer, were relatively lower compared with their respective values in Table 6.1. Besides, most mode values were constant in both studies.

Table 6.5: Basic statistics of the physical variables of the selected classrooms for further analysis

		Summer				Winter			
		T_a, [°C]	T_g, [°C]	AV, [m/s]	RH, [%]	T_a, [°C]	T_g, [°C]	AV, [m/s]	RH, [%]
ASHRAE	N	961	959	905	961	572	572	572	572
	Mean	25.5	25.6	0.1	49.1	24.6	24.7	0.1	43.0
	SD	1.54	1.42	0.17	7.08	1.41	1.36	0.17	8.62
	Median	25.8	25.8	0.0	48.5	24.4	24.6	0.0	41.1
	Mode	25.9	25.9	0.0	43.8	23.8	24.3	0.0	36.5
	Max.	29.5	29.4	1.1	70.9	28.1	28.2	1.1	65.8
	Min.	19.8	20.6	0.0	32.9	19.3	20.0	0.0	26.1
Bedford	N	959	959	926	959	511	511	511	511
	Mean	25.6	25.8	0.2	49.1	24.2	24.3	0.1	49.6
	SD	1.50	1.41	0.22	8.63	1.46	1.41	0.17	4.80
	Median	25.7	25.8	0.0	47.7	24.3	24.2	0.0	49.1
	Mode	25.9	25.9	0.0	45.1	23.4	23.5	0.0	48.8
	Max.	30.3	30.4	1.5	80.5	26.7	26.7	0.9	63.5
	Min.	20.7	21.4	0.0	32.9	17.8	18.5	0.0	39.0

6.6 Exploring indoor air temperature relations

It is possible to consider the ventilation mode of the classrooms as mixed mode. This is because of the frequent opening of doors, which are connected to open corridors, as the students change classrooms based on their selection of courses. Moreover, no restrictions regarding opening windows were applied. Therefore, it is thought that exploring the effect of outdoor air temperature on indoor air temperature is important besides exploring the potential association between the latter and the indoor air velocity. A linear relation is assumed and, thus, Pearson's correlation coefficients were calculated. In addition, Table 6.6 displays some statistics of the indoor air temperature in each classroom chosen for further analysis.

Table 6.6: Basic statistics of indoor air temperature

		SQ-G1	SQ-G2	SQ-F1	ZA-G1	ZA-G2	ZA-F1	WK-F1	WK-F2	WK-S1	DA-G1	DA-G2	DA-F1	NK-G1	NK-G2	NK-F1
Summer - ASHRAE	**N**	69	66	65	62	-	66	71	71	69	73	73	70	67	70	69
	Mean	24.9	24.0	26.2	26.9	-	26.3	26.1	24.6	25.4	24.5	23.2	26.2	26.4	26.9	25.4
	SD	2.0	0.9	1.0	1.3	-	0.6	0.5	1.2	0.7	1.3	1.3	0.6	0.7	1.0	1.1
	Median	25.6	24.0	26.3	26.4	-	26.3	26.1	24.6	25.5	24.2	23.3	26.3	26.2	27.3	25.5
	Mode	26.2	24.5	26.3	26.3	-	26.2	26.1	23.9	25.9	23.6	22.6	26.7	26.1	27.4	25.9
	Max.	27.4	26.6	27.8	29.5	-	27.6	27.2	26.4	26.2	27.6	26.0	27.6	27.6	28.6	27.9
	Min.	19.8	21.5	24.1	25.0	-	24.8	24.7	22.6	23.2	23.0	21.1	24.9	24.7	24.5	22.9
Summer - Bedford	**N**	70	70	71	63	-	71	65	65	62	73	73	73	65	70	68
	Mean	24.0	24.5	25.5	27.1	-	26.9	26.1	25.7	25.5	24.0	24.1	26.6	26.8	25.7	26.4
	SD	1.5	0.9	0.9	0.7	-	0.9	0.6	1.0	0.7	1.1	1.2	0.8	1.2	1.4	1.1
	Median	24.3	24.4	25.3	27.3	-	27.0	25.9	25.5	25.5	24.2	23.7	26.8	26.8	25.5	26.4
	Mode	24.6	23.5	25.3	27.3	-	27.1	25.9	25.9	25.2	24.8	22.9	26.9	26.3	26.4	26.7
	Max.	26.7	26.3	28.8	28.6	-	28.6	28.0	27.8	27.3	26.1	26.4	28.0	30.3	28.7	29.1
	Min.	20.7	23.1	24.0	25.6	-	24.7	25.1	24.2	24.2	20.8	21.9	24.6	24.7	23.3	24.4
Winter - Bedford	**N**	-	-	-	63	56	64	-	-	-	66	-	68	65	63	64
	Mean	-	-	-	24.1	23.6	24.3	-	-	-	24.1	-	22.9	25.2	25.1	24.3
	SD	-	-	-	1.1	1.0	1.2	-	-	-	1.6	-	2.0	1.2	0.4	1.0
	Median	-	-	-	23.9	23.6	24.4	-	-	-	24.1	-	23.4	25.7	25.0	24.0
	Mode	-	-	-	23.4	23.6	24.9	-	-	-	24.0	-	24.6	26.2	25.0	23.6
	Max.	-	-	-	26.6	26.2	26.4	-	-	-	26.2	-	25.3	26.7	25.9	26.3
	Min.	-	-	-	22.2	21.9	21.0	-	-	-	19.5	-	17.8	22.5	24.6	22.8
Winter - ASHRAE	**N**	-	-	-	67	69	71	-	-	-	62	59	57	59	64	63
	Mean	-	-	-	24.6	25.6	24.4	-	-	-	24.1	23.9	23.3	24.6	25.7	24.6
	SD	-	-	-	0.9	1.5	1.6	-	-	-	1.0	1.0	1.7	0.8	1.1	0.8
	Median	-	-	-	24.3	25.3	23.9	-	-	-	24.1	23.8	23.7	24.3	25.8	24.4
	Mode	-	-	-	23.8	24.4	23.6	-	-	-	23.7	22.8	24.5	24.2	25.9	24.1
	Max.	-	-	-	26.7	28.1	27.8	-	-	-	26.2	26.7	26.1	26.2	27.5	26.5
	Min.	-	-	-	23.5	22.5	20.8	-	-	-	22.4	22.0	19.3	23.4	23.8	22.6

6.6.1 Indoor air temperature and outdoor air temperature

For all classrooms with similar thermal conditions, Figure 6.21 presents indoor air temperatures against outdoor air temperatures. The association between the temperatures was weak as expected based on the cultural background of the students. The correlation coefficients were around -0.260 and -0.067 in ASHRAE and Bedford questionnaires of summer study respectively. In winter, the corresponding coefficients were -0.169 and -0.09 approximately. For the mean temperatures, the correlation coefficients were estimated at -0.404 and -0.092 in ASHRAE and Bedford questionnaires of summer study respectively. In winter, the corresponding coefficients were almost -0.222 and -0.373. As expected, the reduction in the sample size of the mean temperatures increased the correlation coefficient. Thus, it seemed that the air temperatures of the classrooms were identified in isolation of the outdoor air temperatures, which is expected in air conditioning environments.

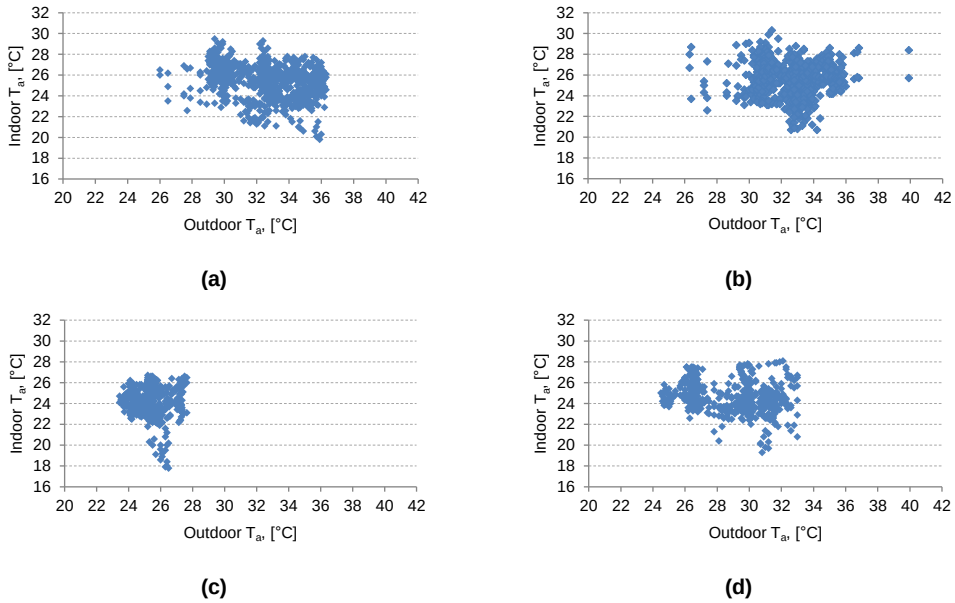


Figure 6.21: Indoor air temperature against outdoor air temperature (a) summer-ASHRAE, (b) summer-Bedford, (c) winter-Bedford, and (d) winter-ASHRAE

6.6.2 Indoor air temperature and indoor air velocity

The adaptive approach of thermal comfort assumes a positive correlation between indoor air velocity and indoor air temperature. As the latter increases, people tend to modify their thermal conditions by increasing the former. This assumption was formulated based on the findings from free-running offices in UK and Pakistan. In those offices, modifying thermal conditions was mainly achieved by increasing air movement via opening windows and switching on fans (Nicol, et al., 2012).

Exploring this assumption in the investigated classrooms revealed a weak association between air velocity and temperature as plotted in Figure 6.22. The direction of the relationship was not obvious as the correlation coefficients in summer were around 0.083 and -0.056 in ASHRAE and Bedford questionnaires respectively. The corresponding coefficients in winter were almost 0.015 and -0.186. Similarly, the coefficients of the mean temperatures and the mean velocities were around 0.420 and -0.290 in ASHRAE and Bedford questionnaires of summer study respectively and around -0.125 and 0.316 in Bedford and ASHRAE questionnaires of winter study respectively. The reduction in the samples' sizes decreased the randomness and, hence, increased the correlation coefficients. It is noteworthy that maintaining low air velocities in the classrooms was possibly intentional to avoid papers' movement.

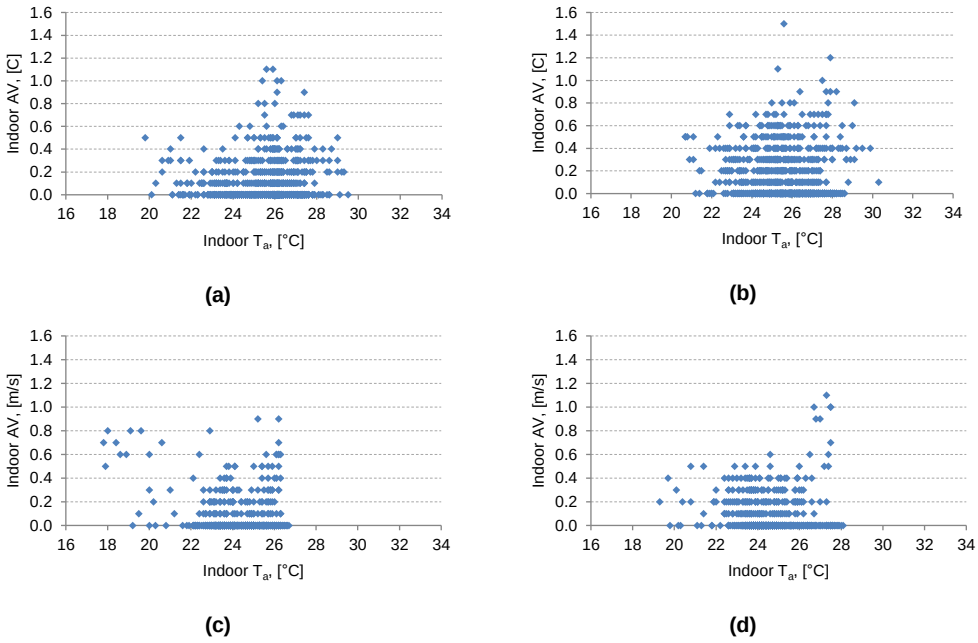


Figure 6.22: Indoor air velocity against indoor air temperature (a) summer-ASHRAE, (b) summer-Bedford, (c) winter-Bedford, and (d) winter-ASHRAE

Owing to the failure of air conditioning units in (ZA-G2) classroom in summer study, the students' dependence on increasing air velocity to decrease their thermal discomfort was expected. However, exploring the correlation between indoor air temperature and velocity surprisingly revealed a negative association. The coefficients were around -0.124 and -0.100 in ASHRAE and Bedford questionnaires respectively.

6.6.3 Indoor air temperature and indoor globe temperature

Considering the classrooms with similar thermal conditions, the relations between indoor air and globe temperatures were investigated as presented in Figure 6.23. As observed, a strong positive correlation

related the two variables. The correlation coefficients were almost 0.967 and 0.976 in ASHRAE and Bedford questionnaires respectively during summer. In winter, the corresponding coefficients were around 0.983 and 0.984. Exploring the correlations between the mean temperatures revealed similar findings. In summer, the coefficients were estimated at 0.982 and 0.967 in ASHRAE and Bedford questionnaires respectively. In winter, they were around 0.977 and 0.992 respectively. The strong correlation between air and globe temperatures indicates the absence of radiation sources (Thapa et al., 2016). Therefore, it is acceptable to construct a simple regression model between these temperatures and the thermal votes (Nicol et al., 2012).

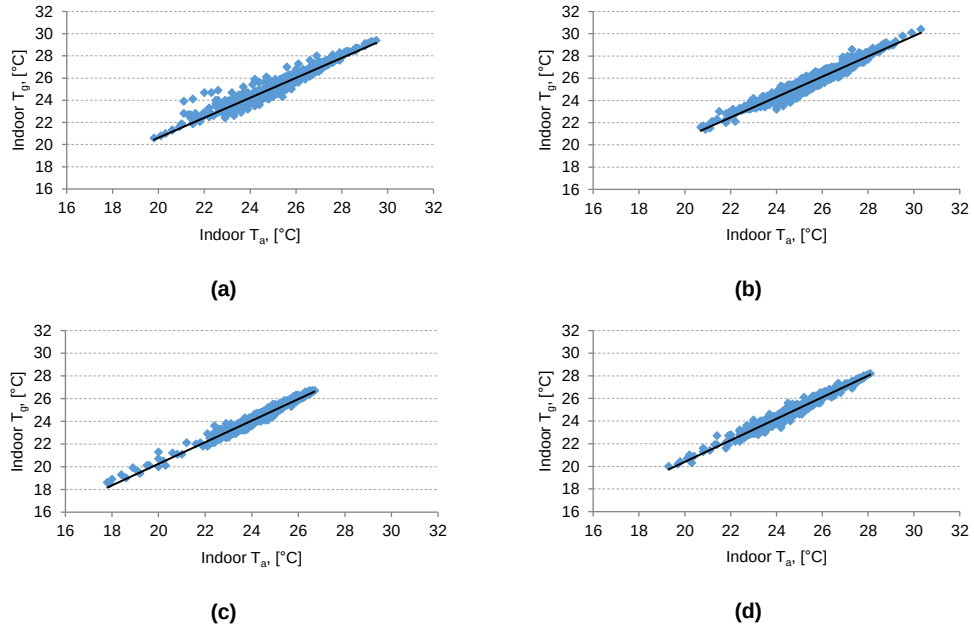


Figure 6.23: Indoor globe temperature against indoor air temperature (a) summer-ASHRAE, (b) summer-Bedford, (c) winter-Bedford, and (d) winter-ASHRAE

6.7 Thermal conditions based on ASHRAE comfort zone

The thermal conditions measured in each classroom were plotted on the ASHRAE psychrometric chart of Muscat as presented in Figure 6.24 with the aim of exploring their relationship with the comfort zone. The chart was obtained from Climate Consultant 6.0 software that presents climatic data graphically. Additionally, the software suggests passive design strategies that are suitable for the climatic conditions of the city in concern plotted on the psychrometric chart. In general, this graphical method is applicable to participants with clothing levels of 0.5 clo and 1.0 clo (ASHRAE, 2010). It is worth mentioning that the required adjustments to consider the students' clothing level were applied in the Climate Consultant 6.0 software.

As noted in Figure 6.24, most of the measured data exceeded the comfort zone with few data below the zone in winter. Indeed, the thermal conditions of 8 and 6 classrooms were totally above the zone in ASHRAE and Bedford questionnaires of summer study respectively. Overall, only 12% and 14% approximately of the data collected during ASHRAE and Bedford questionnaires of summer study respectively were inside the comfort zone. In winter, the corresponding percentages were around 49% and 52%. This improvement in the internal thermal conditions is mainly due to the improvements in the thermal conditions of (ZA) School classrooms as indicated in Table 6.7 that is discussed below.

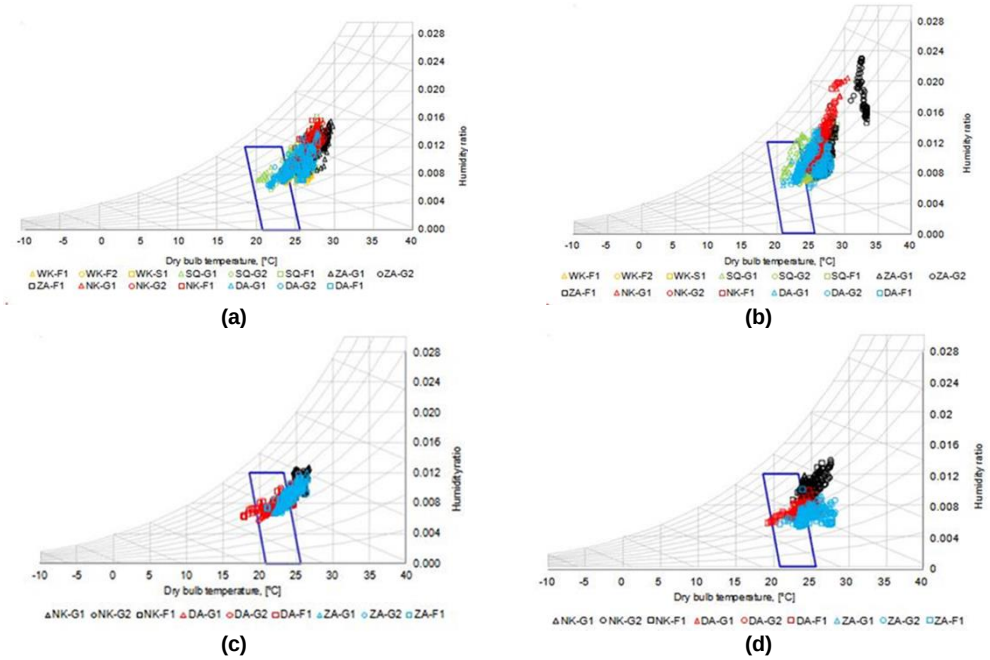


Figure 6.24: Indoor thermal conditions on ASHRAE 55 psychrometric chart of Muscat city: (a) summer-ASHRAE, (b) summer-Bedford, (c) winter-Bedford, and (d) winter-ASHRAE

Referring to Figure 6.24, around 56%, 34%, 31%, and 24% of the data from (DA-G2), (DA-G1), (WK-F2), and (SQ-G2) classrooms during ASHRAE questionnaire in summer fell in the comfort zone. Moreover, 58%, 46%, 40%, and 34% roughly of (DA-G2), (SQ-G2), (DA-G1), and (SQ-G1) classrooms' data during Bedford questionnaire were in the zone. In winter, more than 40% of the thermal conditions in each classroom fell in the comfort zone in both questionnaires. The exceptions during Bedford questionnaire were (NK-G1) and (NK-G2) classrooms as almost 82% and 100% of the data respectively were outside the zone. Considering ASHRAE questionnaire, the exceptions were (NK-G1), (NK-G2), and (ZA-G2) classrooms with around 18%, 14%, and 32% of the data respectively outside the zone. It is worth to mention that a maximum level of comfort was achieved in (DA-G2) classroom of around 99% in Bedford questionnaire of winter study.

Considering the classrooms that were investigated in both studies, Table 6.7 displays the percentages of the measured data that fell in the comfort zone. As noted, the classrooms' behaviour was different in the two seasons. Yet, both (DA-G1) and (DA-G2) classrooms relatively maintained their comfortable conditions in both studies relatively with a noticeable increase in winter. It is noteworthy that both classrooms had comparatively low modes of air temperature in both studies. It should be mentioned that the comfort zone of the psychrometric chart may not accurately represent the students' comfort zone. This is due to the absence of the specialised standards that consider the students' ages (Singh et al., 2018). Accordingly, the students' thermal sensations and comfort levels were investigated in the distributed questionnaires.

Table 6.7: Percentages of measured data within ASHRAE comfort zone, [%]

	ZA-G1	ZA-G2	ZA-F1	NK-G1	NK-G2	NK-F1	DA-G1	DA-G2	DA-F1
Summer-ASHRAE	0	0	0	0	0	10	34	56	0
Summer-Bedford	0	0	0	0	14	0	40	58	1
Winter-Bedford	68	79	44	18	0	55	50	99	59
Winter-ASHRAE	60	32	76	18	14	41	63	68	65

6.8 Conclusion

In this chapter, the thermal conditions to which the investigated students were subjected were explored by presenting the measured objective variables. The variables were symmetrically distributed around their arithmetic means as indicated from the relatively similar values of means and medians. Plotting the relative frequencies determined the dominant ranges that were generally narrow possibly reflecting the relatively constant thermal conditions in air-conditioned buildings. For instance, the dominant ranges of air and globe temperatures extended between 23 °C and 28 °C in summer and between 23 °C and 26 °C in winter.

Additionally, the proportions of the measured physical variables were presented in order to appreciate their distribution pattern in the investigated classrooms. It was crucial to identify the classrooms that had different thermal conditions in order to enhance the accuracy of the study results. Hence, the hourly profiles of the physical variables were plotted. Among the classrooms where 10% or more of the variables were outside the dominant ranges, (ZA-G2) and (DA-G2) classrooms were identified as thermally different. Hence, the former classroom was excluded from the analysis of ASHRAE and Bedford questionnaires in summer and the latter was excluded from the analysis of Bedford questionnaire in winter.

Furthermore, the relationships between indoor air temperature and other physical variables were explored. As expected in air-conditioned spaces, the association with outdoor air temperature was weak, which indicated the identification of indoor air temperature in isolation of outdoor conditions. Likewise, the relation with indoor air velocity was weak perhaps because the students maintained low air velocities to avoid papers' movement. It may worth mentioning that this was the case in (ZA-G2) classroom in summer regardless of the air conditioning failure. Moreover, investigating the association with the indoor globe temperature revealed strong correlations, which indicates the absence of radiation sources in the classrooms.

The thermal conditions of the classrooms were plotted on the comfort zone of the ASHRAE psychrometric chart of Muscat city. Most of the data were outside the zone, especially in summer. Indeed, almost 88% and 86% of the data measured during ASHRAE and Bedford questionnaires of summer study were outside the comfort zone. In winter, the corresponding percentages were around 48% and 51%. Accordingly, the thermal conditions of the explored classrooms were uncomfortable.

Chapter (7):

The Survey Subjective Results

Chapter 7 The survey subjective results

The previous chapter presented the thermal physical conditions to which the students were subjected. Their responses to those conditions are reported in this chapter by reporting the results of ASHRAE and Bedford questionnaires. The chapter starts by reporting the response rates and the steps taken to prepare the data for analysis followed by the students' personal information and activities' levels. It presents the students' evaluation of their ambience and comfort levels and explores their dependence statistically. Furthermore, the chapter presents the subjective sensation and preference votes with a special focus on thermal votes. For instance, the thermal votes are explored based on the satisfaction and comfort levels as well as the sitting locations and schools. Besides, different methods to identify unsatisfied students were compared and the relationships of the central categories votes with overall satisfaction and comfort levels were explored. The chapter concludes by investigating the students' adaptive behaviour focusing on identifying the widely used techniques and their usage time.

It should be mentioned that the categories of the subjective scales are expressed in numerical values throughout the chapter as displayed in Table 2.2 and Table 2.3 to ease the results' presentation. Sensations like (very dry) and (very fast) from the humidity and air velocity sensations scales respectively, and their equivalences in Bedford scale, were represented by (-3). Accordingly, (much humid) and (much slower) on the preference scales were represented by (-2).

7.1 Data preparation

In summer study, 401 and 402 copies of ASHRAE and Bedford questionnaires respectively were distributed. Considering winter study, the corresponding copies were 238 and 231. In order to prepare data for analysis, all questionnaires with incomplete or inconsistent answers were excluded. An example of the inconsistent answers is (no change) preference combined with thermally uncomfortable status. Following a similar approach like (Liu et al., 2017), the inconsistent answers were revealed by adding sensations and preferences votes considering the students' evaluation of their thermal comfort. Accordingly, 30 and 23 copies of ASHRAE and Bedford questionnaires respectively in summer study were excluded. In winter, the response rates were around 93% and 89% in Bedford and ASHRAE questionnaires respectively. The comparatively low response rate of the latter questionnaire was perhaps due to students' boredom as it was the last questionnaire in this study. Table 7.1 displays the numbers of the distributed and excluded copies of each questionnaire. As noted, more copies of ASHRAE questionnaire

in summer were excluded possibly because it was the first participation for almost all students in a questionnaire.

Table 7.1: Numbers of distributed and excluded questionnaires

			Distributed	Excluded		Distributed	Excluded		Distributed	Excluded
Summer	ASHRAE	SQ-G1	29	1	SQ-G2	35	0	SQ-F1	32	2
		ZA-G1	29	0	ZA-G2	29	1	ZA-F1	26	4
		WK-F1	24	1	WK-F2	24	1	WK-S1	24	3
		DA-G1	24	2	DA-G2	23	4	DA-F1	22	3
		NK-G1	25	3	NK-G2	29	4	NK-F1	26	1
	Bedford	SQ-G1	29	0	SQ-G2	34	3	SQ-F1	32	0
		ZA-G1	28	0	ZA-G2	25	0	ZA-F1	21	6
		WK-F1	20	5	WK-F2	22	1	WK-S1	24	0
		DA-G1	31	2	DA-G2	28	2	DA-F1	26	1
		NK-G1	25	0	NK-G2	31	1	NK-F1	26	2
Winter	Bedford	ZA-G1	25	1	ZA-G2	29	4	ZA-F1	24	3
		DA-G1	30	2	DA-G2	22	2	DA-F1	24	2
		NK-G1	25	0	NK-G2	27	2	NK-F1	25	1
	ASHRAE	ZA-G1	27	2	ZA-G2	29	5	ZA-F1	24	2
		DA-G1	30	0	DA-G2	28	6	DA-F1	24	2
		NK-G1	25	2	NK-G2	26	3	NK-F1	25	4

7.2 Personal information and activities' levels

The age distribution of the participated students is demonstrated in Figure 7.1. As observed, around 89% and 92% of the students were between 15 and 17 years old in ASHRAE and Bedford questionnaires of summer study. The corresponding percentages for winter study were 94% and 93% roughly. Slight variations in the age distribution between the two questionnaires of each study were noted. For instance, a difference of 8 and 2 students existed in summer and winter studies respectively. This was mainly because of the absent students. Besides, the students' continuous and individual change of their classrooms, based on the courses they selected to study, contributed partially to these variations.

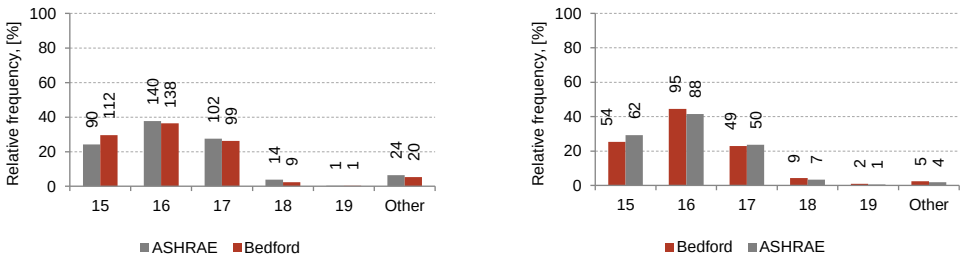


Figure 7.1: Students' age distribution in: (a) summer study and (b) winter study (Labels are students' numbers)

Excluding the data of the thermally different classrooms, based on the findings of Chapter 6, had a negligible effect on the students' age distribution. In specific, there was an increase of around 1% in the ages

15-17 in ASHRAE questionnaire during summer study. The increase in the same range was below 1% in Bedford questionnaires.

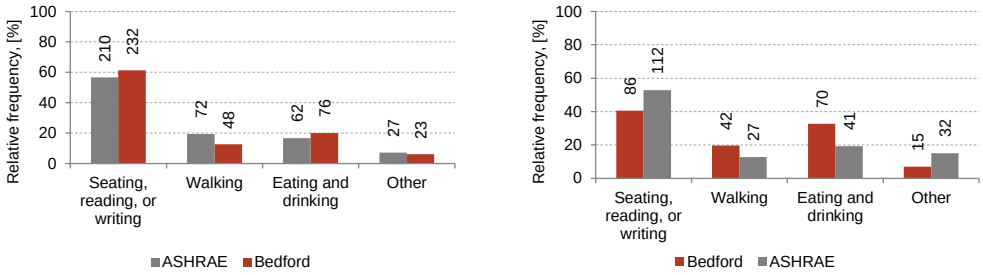
Regarding the familiarity with schools' buildings, the students were classified into three categories, namely attending the school for less than a year, one to two years, and more than two years. Around 39% and 43% of the students fell within the first category in ASHRAE and Bedford questionnaires of summer study respectively. The respective percentages of the second category were 57% and 51% approximately. In winter, the students' distribution was similar in both questionnaires. Around 52% and 38% of the students fell in the first and second categories respectively. It may worth mentioning that most students in the thermally different classrooms were from the first category. Hence, excluding these classrooms decreased the students' percentages to almost 34%, 39%, and 47% in ASHRAE and Bedford questionnaires of summer study and Bedford questionnaire in winter study respectively.

Moreover, around 62% and 75% of the students reported good health states in ASHRAE and Bedford questionnaires of summer study respectively. The corresponding percentages in winter were 80% and 85% roughly. The remaining students reported different illnesses and symptoms like sickle cell disease, anaemia, asthma, heart problems, eczema, hypertension, diabetes, headache, cold, cough, dry eyes, and breathing difficulties. It is noteworthy that a negative association was recently revealed between asthma and cool thermal conditions (Tham & Fadeyi, 2015).

Regarding clothing levels, almost 96% of the students wore the school uniform in summer questionnaires. The remaining students took off their headscarves or added a jacket. In winter, around 80% and 94% wore the uniform in Bedford and ASHRAE questionnaires respectively. In the former questionnaire, 18 students wore jackets, compared with only 3 in the latter, due to the relatively cooler weather conditions during the week of the former questionnaire.

Considering the students' activities, the majority were seating, reading, or writing just before distributing the questionnaires as they were distributed towards the end of the classes. Likewise, around 60% of the students in summer were involved in similar activities before distributing the questionnaires by 15 minutes as indicated in Figure 7.2. As observed, around 19% and 13% were walking and almost 17% and 20% were eating in ASHRAE and Bedford questionnaires of summer study respectively. Besides, 9 and 5 students were involved in physical education classes in the former and latter questionnaires respectively. Considering winter, almost 41% and 53% were seating, reading, or

writing and around 33% and 19% were eating in Bedford and ASHRAE questionnaires respectively. Additionally, 3 students were involved in physical education classes in the latter questionnaire. It is noteworthy that excluding thermally different classrooms had a negligible influence on the distribution of students' activities.



(a) **(b)**

Figure 7.2: Students' distribution based on their activities at 15 minutes before distributing the questionnaires in: (a) summer study and (b) winter study (Labels are students' numbers)

Moreover, around 50% and 37% of the students spent their break time in the school plaza and inside their classrooms respectively in both questionnaires in summer. In winter, the corresponding percentages were around 62% and 29% in Bedford questionnaire and 58% and 24% approximately in ASHRAE questionnaire. As noted, a higher number of students spent the break time outdoors during Bedford questionnaire in winter possibly because of the comparatively cooler weather conditions. It is noteworthy that examining the influence of excluding thermally different classrooms revealed their marginal effect.

7.3 Subjective sensations and preferences

7.3.1 Satisfaction and comfort levels

The percentages of the satisfied and comfortable students in each questionnaire are displayed in Table 7.2. As noted, the satisfaction and comfort levels were relatively higher in winter perhaps due to the effect of expectation (Kwok & Chun, 2003). Besides, it is noted that the levels were higher during Bedford questionnaire of both summer and winter studies. Yet, it should be emphasised that this increase may be due to random fluctuations as the thermal scales were introduced after the questions of general satisfaction and comfort. In fact, it may be more convenient to relate this increase to the climatic conditions that were relatively cooler in Bedford questionnaires compared with ASHRAE questionnaires, particularly in winter. Considering summer, the former questionnaire was distributed following the latter, which may had an effect on the students' responses as mentioned in Section 5.4.

It is observed from Table 7.2 that more students were thermally satisfied with their ambience compared with those feeling comfortable in each questionnaire. The highest levels of satisfaction and comfort were around 83% and 79% respectively in Bedford questionnaire of winter study owing to the relatively cooler conditions as indicated in Table 6.2. The lowest levels were around 66% and 61% respectively in ASHRAE questionnaire of summer study.

Table 7.2: Students' evaluation of their thermal ambience and status

		Ambience (%)		Status (%)	
		Satisfied	Unsatisfied	Comfortable	Uncomfortable
Summer	ASHRAE (N = 371)	66	34	61	39
	Bedford (N = 379)	78	22	62	38
Winter	Bedford (N = 214)	83	17	79	21
	ASHRAE (N = 212)	74	26	69	31

Generally, thermal comfort for sedentary or lightly active people is achieved when 80% are satisfied with the surrounding environment (ASHRAE, 2017). Accordingly, thermal comfort was reached in Bedford questionnaire in winter only. The students' general dissatisfaction may be owing to the characteristics of the buildings' envelopes, which was the case of (Katafygiotou & Serghides, 2014a). Other reasons include the relatively high clothing level besides the students' frequent subject to outdoor conditions as they often have to move from one classroom to another based on the courses they study. Additionally, this continuous movement resulted in opening classrooms' doors and, thus, transferring outdoor heat directly to the classrooms. It should be mentioned that the standards specify this percentage, i.e. 80%, assuming a steady state of participants. According to a recent review paper, deviations from this percentage were reported in several studies among university students mainly owing to their transient conditions resulted from their movement between classrooms (Singh et al., 2018).

Besides, the variation in the numbers of satisfied and comfortable students may create doubts regarding ASHRAE definition of thermal comfort. Therefore, the independence between satisfaction and comfort levels was investigated statistically. Basically, two statistical tests are available to explore the association between categorical sets of data, namely Fisher exact test and chi-square test (McCluskey & Lalkhen, 2007). The former test was implemented owing to its accurate results compared with the latter that depends on approximations (Kim, 2017). Additionally, considering that the sample size of any questionnaire was less than 1000 favoured the use of the former test (McDonald, 2014). Based on that, contingency tables were formed and a significant level of 0.05 was selected. It should be mentioned that the null hypothesis assumes independence between thermal satisfaction and comfort. An online calculator of Fisher exact test (Langsrud, n.d.) was used to

compute the probability against the hypothesis, i.e. p-value. It may worth mentioning that this calculator follows the procedure specified in (Agresti, 1992). For ASHRAE and Bedford questionnaires in summer, the probabilities were around 8.43E-23 and 1.56E-45 respectively. The respective values of winter study were around 3.94E-23 and 6.3E-22. Therefore, the null hypothesis was rejected as satisfaction and comfort were significantly related. This means that the variations in Table 7.2 are mainly owing to the sampling fluctuations.

For each questionnaire, the categories that form the contingency tables used in Fisher exact test are plotted in Figure 7.3. It should be mentioned that (satisfied and comfortable) category indicates desirable thermal conditions. As noted, the highest percentage of this category was around 77% and it occurred during Bedford questionnaire in winter. It is, additionally, noted that the lowest percentages of students in the other categories were in this questionnaire. On the other hand, the lowest percentage of (satisfied and comfortable) students of around 52% and the highest percentages in the other categories occurred in ASHRAE questionnaire of summer study. In particular, the (unsatisfied and uncomfortable) students were around 25%. Thus, the thermal conditions during Bedford questionnaire in winter seem to be favourable unlike those of ASHRAE questionnaire in summer.

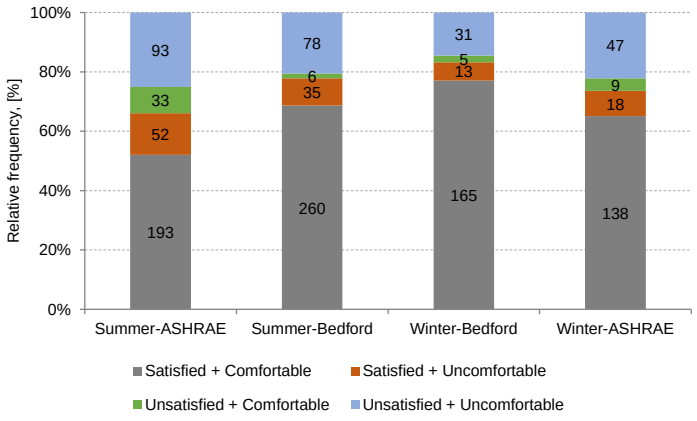


Figure 7.3: Students' distribution based on satisfaction and comfort levels (Labels are students' numbers)

For further explorations, students' distribution on satisfaction and comfort categories according to their schools are plotted in Figure 7.4. In summer, the lowest percentage of the (satisfied and comfortable) students was around 42% followed by almost 44% in (WK) and (ZA) Schools respectively in ASHRAE questionnaire. It is worth mentioning that only 4 students from (ZA-G2) classroom fell in this category during this questionnaire. The maximum percentage was 86% roughly followed by around 77% recorded in (DA) and (NK) Schools respectively in Bedford questionnaire in winter study. Additionally, no students were

(unsatisfied and comfortable) in (SQ) School in Bedford questionnaire in summer. In general, it seems that there is no obvious pattern relate the students' satisfaction and comfort levels with their schools.

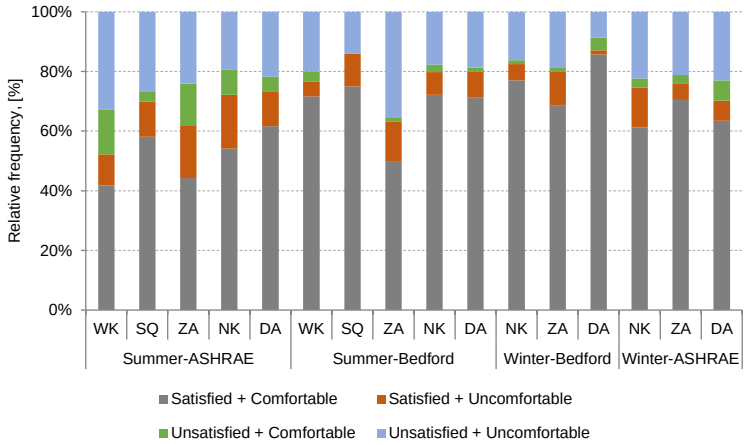


Figure 7.4: Students' distribution on satisfaction and comfort categories based on their schools

Furthermore, the students' satisfaction and comfort levels were explored based on their health status applying Fisher exact test. The results indicated a lack of association between students' health states and their satisfaction or comfort levels as the p-values were above the significant level, i.e. 0.05, in all questionnaires. However, there was an exception in ASHRAE questionnaire of winter study; the probabilities that measure the evidence against the null hypotheses were around 0.0007 for the association with both the satisfaction and comfort levels. This resulted in rejecting the null hypotheses. Accordingly, the students' satisfaction and comfort levels during ASHRAE questionnaire in winter depended on their health states. Nevertheless, this association may result from random fluctuation in the sample. It is worth to mention that a lack of dependence between health status and thermal sensation was reported based on chi-square test in a study that explored the thermal conditions of university students in Taiwan (Hwang et al., 2006).

7.3.2 Thermal sensations and preferences votes

Figure 7.5 displays the relative frequency of thermal sensation and preference votes in summer and winter. In each questionnaire, the mean and the mode of sensation votes coincided with (neutral) and (comfortable) categories. Similarly, those of preference votes fell within (a bit cooler) category. Despite the variations in the climatic and natural ventilation conditions, the overall distribution of sensation votes was similar to that of (Liu et al., 2017). To investigate the reported clustering behaviour of Bedford scale in (Wong & Khoo, 2003), the difference in central votes between both scales was computed and was less than 10%. In specific, almost 85% and 76% of summer sensation votes fell

within the three central categories of ASHRAE and Bedford scales respectively. For winter, the respective percentages were around 78% and 79%. Therefore, the votes' clustering was not limited to Bedford questionnaire. It is worth mentioning that this clustering is consistent with the findings of a recent study that explored the impact of cultural background on outdoor thermal perceptions. The study compared the thermal votes' distribution of people from the tropical, temperate, cold, and arid climates. In the arid climate, it was noted that people's votes distributed symmetrically and clustered in the three central categories (Shooshtarian & Ridley, 2016). Comparatively, the results of the Omani students are relatively higher than those of a similar investigation in three male schools. The survey was conducted in Jeddah city, Saudi Arabia, which shares similar climatic and cultural conditions with Muscat. It was revealed that around 53% and 49% of the students had thermal sensations within the three central categories (Alwetaishi, 2015). A reason for this variation may be the different surveys' settings followed in the two studies. As mentioned in Section 5.4, there were no restrictions on the students' adaptive behaviour in Omani schools. In the Saudi study, the air conditioning units were switched off before distributing the questionnaires by around 45 minutes (Alwetaishi, 2015).

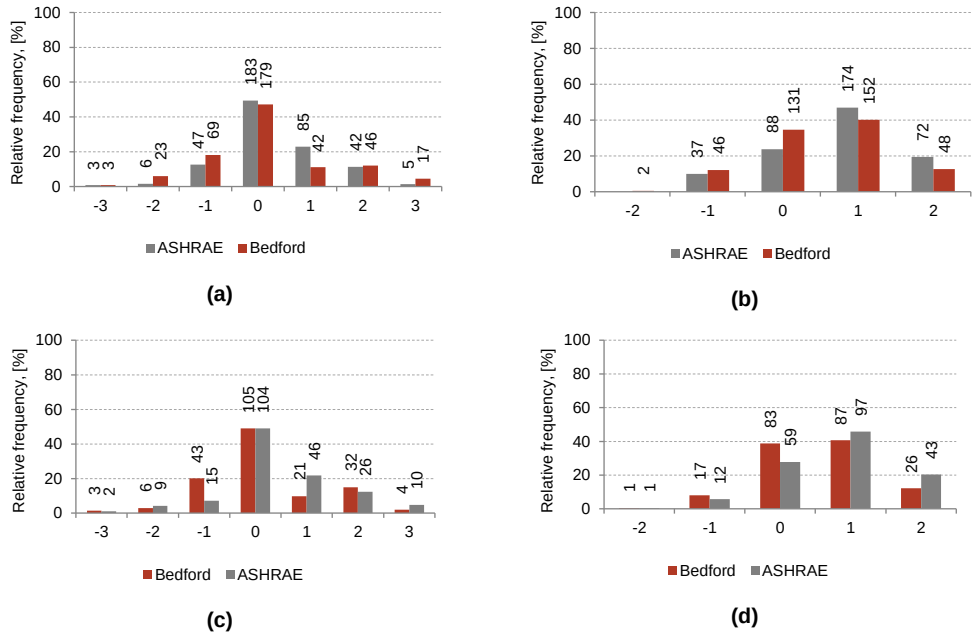


Figure 7.5: Relative frequency of: (a) TSV-summer, (b) TPV-summer, (c) TSV-winter, and (d) TPV-winter
(Labels are students' numbers)

In general, a similar number of sensation votes fell in the last two categories of the warm side. In specific, around 12% and 16% of the votes fell in these categories in ASHRAE and Bedford questionnaires respectively during summer. The percentage was 17% approximately for each questionnaire in winter. These minor variations in thermal

votes are expected in air-conditioned buildings (Nicol et al., 2012). This is mainly due to the intensive reliance on air conditioning, as revealed in Section 7.4, which eventually resulted in a weak seasonal effect.

Furthermore, it is noted that more students preferred (a bit cooler) compared with (no change) in all questionnaires. For instance, around 47% and 40% of votes fell in the former category compared with almost 24% and 35% in the latter during ASHRAE and Bedford questionnaires in summer respectively. In winter, the respective votes were 46% and 41% approximately compared with 28% and 39% roughly. Considering that most sensation votes were within the central categories, it seems that neutrality is not a preferred thermal state for the explored students. Further, around 66% and 53% of summer votes fell in both (a bit cooler) and (much cooler) categories in ASHRAE and Bedford questionnaires respectively. Interestingly, these percentages were identical in both summer and winter. This constant preference for cooler conditions may be owing to the climatic and cultural background effect besides the relatively high clothing level of students. A similar case was reported in (Hwang et al., 2009) where the explored students were over-dressed. Further, the lack of economic consequences encourages heavy dependence on air conditioning units, which was reported in a similar climatic and cultural context (Alwetaishi, 2015).

7.3.2.1 Determining unsatisfied students

Utilising five methods and considering Table 7.2 and Figure 7.5, the percentages of the unsatisfied students are presented in Table 7.3. In the first and second methods, the percentages were determined from direct questions. It should be mentioned that Table 7.3 refers to the first method as unacceptable for convenience despite that the question integrated in all questionnaires requested the students to evaluate their thermal satisfaction. Generally, both satisfaction and acceptance are used interchangeably in thermal comfort studies (Kwok & Chun, 2003). Considering the other methods, they were determined based on the students' votes in certain thermal sensation and preference categories. It is noteworthy that these methods were utilised in other studies like (Cheng et al., 2008; Corgnati et al., 2007; Hwang et al., 2006; Wong & Khoo, 2003).

Table 7.3: Percentages of thermally unsatisfied students

	Summer		**Winter**	
	ASHRAE, N = 371	Bedford, N = 379	Bedford, N = 214	ASHRAE, N = 212
Unacceptable, [%]	34	22	17	26
Uncomfortable, [%]	39	38	21	31
(-3, -2) & (+2, +3) TSV, [%]	15	23	21	22
(-3), & (+2, +3) TSV, [%]	4	11	6	10
(-2, -1) & (+1, +2) TPV, [%]	76	65	61	72

The different methods explored in Table 7.3 resulted in apparently different percentages of unsatisfied students in each questionnaire. An exception was Bedford questionnaire in winter as the uncomfortable students were equal to those with votes outside the three central sensations. In summer, the direct evaluation of comfort state resulted in a higher percentage of uncomfortable students compared with those with sensation votes outside the central categories regardless of the integration of (comfort) in these categories. This difference may be due to normal fluctuation or may be related to the head question. The students were requested to evaluate their thermal status in the first case, whereas they were asked to evaluate their thermal sensation in the latter. Hence, it seems that other factors contribute to determining the thermal status of the students besides their thermal sensation.

Considering ASHRAE questionnaire, it is noted from Table 7.3 that the students with votes outside the three central categories were less than those who expressed unacceptance to their ambience in both studies. This is opposite to the findings of (Hwang et al., 2006; Wong & Khoo, 2003). Additionally, the preference votes' method resulted in the highest percentages of unsatisfied students as the majority preferred (a bit cooler) conditions. A similar observation was noted by (Cheng et al., 2008). This possibly was the case because of the general tendency of people to prefer narrower conditions compared with what they accept (Hwang et al., 2006).

Assuming that a difference of 5% is permitted to represent normal fluctuations, more agreements in the percentages will occur in Table 7.3. For instance, the percentage of the students who evaluated their ambience as unacceptable will equal the percentage of votes outside the three central categories in all questionnaires except in ASHRAE questionnaire in summer. Likewise, the students with unacceptable thermal ambience will equal those uncomfortable in all questionnaires except in Bedford questionnaire of summer study. Hence, it seems that the percentage of unacceptance may be a good representation of the actual dissatisfied students. It may worth to mention that the association between the unacceptable and the uncomfortable categories was discussed earlier applying Fisher exact test.

7.3.2.2 Central votes' relations with satisfaction and comfort levels

The relationships between satisfaction and comfort levels on one hand and the central votes of sensation and (no change) preference on the other were investigated. Fisher exact test was applied as described earlier and the probabilities against the independence between the variables are summarised in Table 7.4. Compared to a significant level

of 0.05, the probabilities were considerably small in all questionnaires. Accordingly, the null hypothesis is rejected. This implies the statistical dependence of satisfaction and comfort levels on the central sensations and the (no change) preference for the investigated students.

Table 7.4: P-values for the association between satisfaction, comfort, central sensation votes, and (no change) preference

	Summer-ASHRAE	Summer-Bedford	Winter-Bedford	Winter-ASHRAE
Satisfaction and central sensations	2.50E-6	2.29E-24	4.17E-9	1.09E-13
Satisfaction and (no change) preference	7.62E-8	6.65E-14	2.32E-7	1.02E-7
Comfort and central sensations	5.69E-16	4.81E-33	1.34E-8	7.23E-23
Comfort and (no change) preference	1.24E-16	6.94E-23	4.76E-9	1.81E-8

7.3.2.3 Preference votes based on thermal sensation

For further explorations, the distributions of preference votes on each sensation category are displayed in Figure 7.6. It is noted that the preference votes followed the direction of the sensation votes; as the latter votes move from the cool side to the warm side of the thermal continuum, the preference change from (a bit warmer) to (a bit cooler) and (much cooler). However, a cluster of the preference votes in the warm side (i.e. cool preference) was noted in all questionnaires. For instance, 34% and 26% approximately of the students with warmer-than-neutral sensation preferred cooler conditions in the former and latter questionnaires respectively. Oppositely, around 8% and 9% with cooler-than-neutral sensations preferred warmer conditions in ASHRAE and Bedford questionnaires of summer study respectively. This pattern was maintained in winter as the corresponding percentages were around 35% and 23% compared with 5% and 6% approximately. This is consistent with the general tendency of people from warm climates to prefer cool conditions (Nicol et al., 2012).

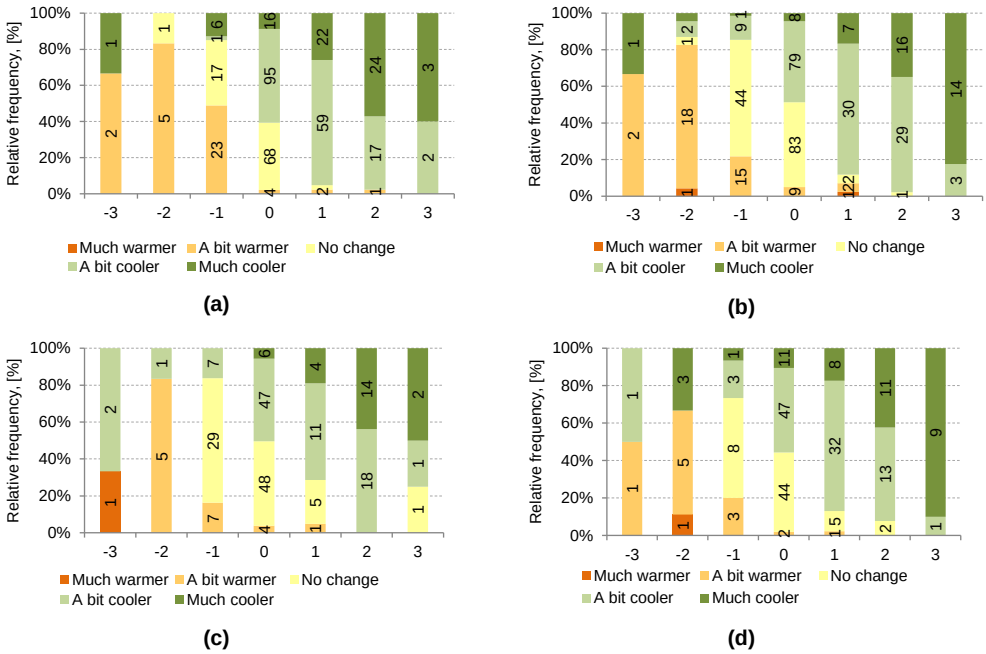


Figure 7.6: Distribution of preference votes on sensation categories: (a) summer-ASHRAE, (b) summer-Bedford, (c) winter-Bedford, and (d) winter-ASHRAE (Labels are students' numbers)

Moreover, 18% and 22% roughly of the students with (neutral) and (comfortable) sensations respectively preferred (no change) in summer compared with almost 22% and 21% respectively in winter. Considering (a bit cooler), it was preferred by around 52% and 44% in ASHRAE and Bedford questionnaires of summer study respectively. The respective percentage in winter was 45% in both questionnaires. Besides, around 36% and 64% of the students in summer with (slightly cool) or (comfortably cool) sensations respectively preferred (no change). In winter, they were almost 53% and 67% respectively. Thus, it seems that neutrality is not a preferred sensation for the investigated students; rather, they preferred cooler conditions. A similar finding was reported in other studies that had different climatic and operational conditions (Dias Pereira et al., 2014b; Hwang et al., 2009), which may suggest that cool conditions are favourable in educational buildings. Nevertheless, further explorations are highly recommended to reveal the association between cool conditions and productivity in educational buildings.

7.3.2.4 Thermal votes based on satisfaction and comfort

The distributions of satisfied and comfortable students based on their sensation and preference votes are presented in Table 7.5 in which the categories of 5% or more of votes are highlighted in colour. It is noted that the majority of the satisfied and comfortable students fell in the three central categories with a clear cluster in the middle category. Thus, it seems that the middle sensation in ASHRAE and Bedford scales is the most satisfactory and comfortable for the investigated

students. In addition, the majority of the unsatisfied and uncomfortable students fell within (too warm) category of Bedford scale and within (slightly warm) and (warm) categories of ASHRAE scale. This variation may be due to the integration of comfort into Bedford category that is equivalent to (slightly warm). It is worth to mention that the Arabic equivalent of (warm), as translated in the distributed questionnaire, is different from both the literal translation and from the translated phrases provided by the students as discussed in Section 8.1.1. As expected, the lowest percentages of dissatisfaction and discomfort occurred on the cool side of the sensation scales supporting the tendency of warm climates' people to prefer cool conditions (Nicol et al., 2012).

Table 7.5: Students' distribution on sensation categories based on satisfaction and comfort levels

		-3	-2	-1	0	+1	+2	+3
Satisfied (%)	S-ASHRAE	1	1	11	37	13	4	<1
	S-Bedford	1	3	18	43	9	4	1
	W-Bedford	1	2	20	47	7	5	<1
	W-ASHRAE	<1	3	7	45	13	4	1
Unsatisfied (%)	S-ASHRAE	<1	<1	2	12	10	8	1
	S-Bedford	<1	3	<1	4	2	8	4
	W-Bedford	<1	<1	<1	2	2	10	1
	W-ASHRAE	<1	1	0	4	8	8	4
Comfortable (%)	S-ASHRAE	1	1	10	40	9	1	0
	S-Bedford	1	2	18	41	8	2	0
	W-Bedford	<1	2	20	47	8	1	<1
	W-ASHRAE	<1	3	7	46	9	4	<1
Uncomfortable (%)	S-ASHRAE	<1	1	3	9	14	11	1
	S-Bedford	<1	4	1	7	3	10	4
	W-Bedford	1	<1	<1	2	2	14	1
	W-ASHRAE	<1	1	<1	3	13	8	4

Table 7.6 displays the distribution of the satisfied and comfortable students according to their preference votes. The categories of 5% or more of votes are highlighted in colour. Generally, the majority of the satisfied and comfortable students preferred (no change) and (a bit cooler) conditions. As noted, the percentage of the former preference was higher in Bedford questionnaire, whereas the percentage of the latter was higher in ASHRAE questionnaire. This may be related to the climatic conditions that were comparatively cooler during the former questionnaire, especially in winter. Additionally, the highest percentages of unsatisfied and uncomfortable students fell within (a bit cooler) and (much cooler) categories. The percentages were relatively similar for the former students. For the uncomfortable students, the votes in (a bit cooler) category were slightly higher than the votes of (much cooler) category. This may imply that although any preference on the cool side will achieve satisfaction, comfort is more linked to the conditions that satisfy (a bit cooler) preference.

Table 7.6: Students' distribution on preference categories based on satisfaction and comfort levels

		-2	-1	0	+1	+2
Satisfied (%)	S-ASHRAE	0	8	21	30	6
	S-Bedford	1	9	34	31	3
	W-Bedford	0	7	38	34	4
	W-ASHRAE	0	4	27	35	8
Unsatisfied (%)	S-ASHRAE	0	2	3	16	13
	S-Bedford	<1	3	1	9	9
	W-Bedford	<1	1	<1	7	8
	W-ASHRAE	<1	1	1	11	13
Comfortable (%)	S-ASHRAE	0	6	23	26	6
	S-Bedford	<1	7	34	27	2
	W-Bedford	0	7	38	32	3
	W-ASHRAE	0	3	27	31	8
Uncomfortable (%)	S-ASHRAE	0	4	1	20	13
	S-Bedford	<1	5	1	13	11
	W-Bedford	<1	1	1	9	9
	W-ASHRAE	<1	2	1	15	12

7.3.2.5 Thermal votes based on sitting locations

It is expected that sitting close to windows can result in different comfort levels compared with sitting in the middle of the classrooms (Liang et al., 2012; Puteh et al., 2012). Therefore, the students were classified into two groups according to their sitting locations regardless of the classrooms' orientations. Students sitting near windows formed one group and those sitting in the middle of the classrooms formed the other. The former group consisted of 58% and 57% approximately of the students in ASHRAE and Bedford questionnaires in summer. The respective percentages in winter were almost 71% and 68%.

In this survey, the students sitting near windows were generally less satisfied. Based on the direct evaluation of ambience, the highest level of dissatisfaction among these students was 38% approximately in ASHRAE questionnaire of summer study compared with 28% roughly for those sitting in the classroom centre. The highest percentage of discomfort occurred in the same questionnaire of around 42% for those sitting near windows compared with almost 35% for the other group. As expected, the lowest levels of dissatisfaction and discomfort were in Bedford questionnaire of winter study. They were around 18% and 21% respectively among the students sitting near windows. Considering the students sitting in the classroom centre, the corresponding percentages were 14% and 20% approximately.

Fisher exact test was applied aiming to confirm the difference in satisfaction and comfort levels between the two groups of students. The p-values are displayed in Table 7.7. Based on a significant level of 0.05, there is statistically significant evidence on the dependence of satisfaction level on students' sitting locations in ASHRAE and Bedford questionnaires of summer and winter studies respectively. Considering the comfort level, the high probabilities levels indicated the lack of

enough evidence on the reliance of comfort on sitting locations. Thus, further investigations are recommended to explore the relation between the students' sitting location and the levels of satisfaction and comfort.

Table 7.7: P-values for the relation between satisfaction and comfort levels with sitting location

	Summer-ASHRAE	Summer-Bedford	Winter-Bedford	Winter-ASHRAE
Satisfaction and sitting location	**0.035**	0.709	**0.040**	0.565
Comfort and sitting location	0.162	0.494	0.071	1.000

Furthermore, the relative frequency of thermal votes based on the sitting location is presented in Figure 7.7. The votes' distribution was generally similar in both groups with few exceptions. For instance, there were no votes in (cold) or (much too cool) categories from the students sitting near windows, which justifies votes' absence in (much warmer) preference. Besides, the sensation votes in the three central categories from those sitting in the classroom centre were higher with an estimated difference ranging between 7% and 17% in Bedford and ASHRAE questionnaires of winter study respectively.

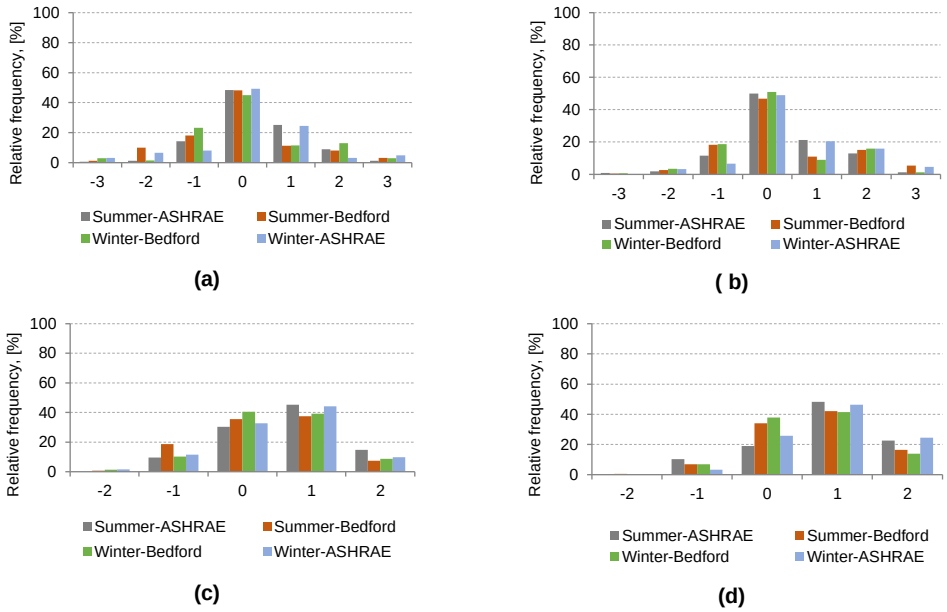


Figure 7.7: Relative frequency of: (a) TSV-classroom centre, (b) TSV-near windows, (c) TPV-classroom centre, and (d) TPV-near windows

The mean thermal sensation for both groups of students was (neutral) or (comfortable). An exception was in ASHRAE questionnaire in winter as the mean sensation of the students sitting near windows was (slightly warm). The mean thermal preference for this group of students was (a bit cooler). Considering those sitting in the classroom centre, the mean preference was (no change) except in ASHRAE questionnaire of summer study as it was (a bit cooler). Additionally, the mode of sensation and preference votes for both groups were (neutral) or (comfortable) and (a bit cooler) respectively. An exception was (no

change) preference during Bedford questionnaire of winter study for the students sitting in the middle of the classrooms.

7.3.2.6 Thermal votes based on schools

To form an overview of the thermal conditions in each school, the sensation votes' distribution based on the explored schools is plotted in Figure 7.8. As expected, the least comfortable conditions in Bedford questionnaire in summer were in (ZA) School owing to the failure of air conditioning units in (ZA-G2) classroom. The conditions in (DA) School were generally comfortable as most sensation votes fell within the three central categories in summer and winter questionnaires. This wide thermal comfort reflects the relatively cooler conditions in the school, specifically in (DA-G1) and (DA-G2) classrooms, as discussed in Section 6.3. Further, the highest percentages of (no change) preference in all questionnaires were from (DA) School as presented in Figure 7.9. However, it should be mentioned that the percentage of (no change) preference of (NK) School was marginally higher by around 1% during Bedford questionnaire of summer study.

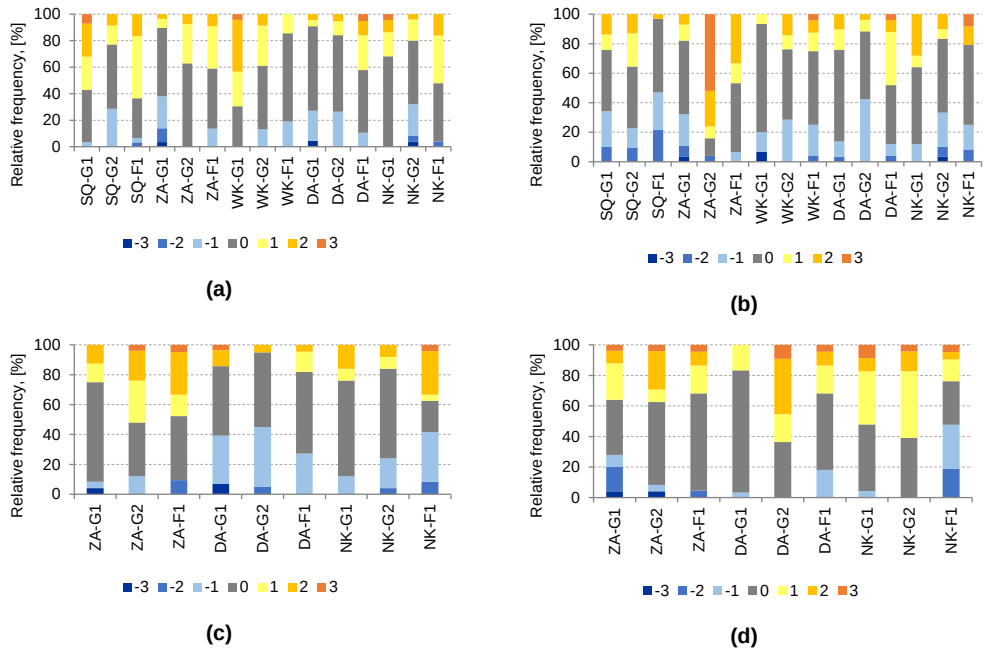


Figure 7.8: Distribution of thermal sensation votes based on schools: (a) summer-ASHRAE, (b) summer-Bedford, (c) winter-Bedford, and (d) winter-ASHRAE

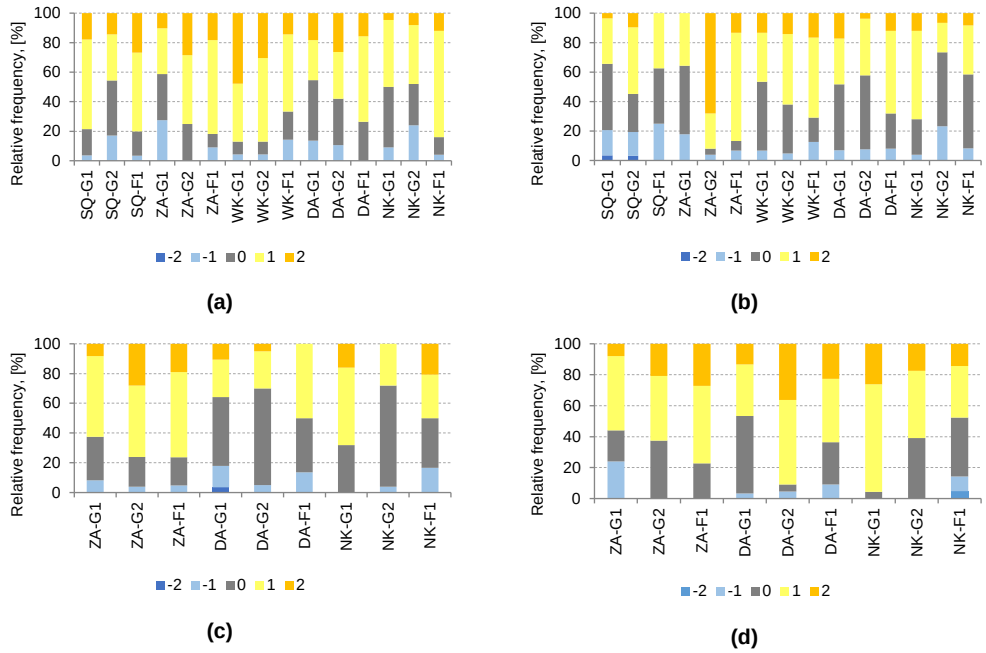


Figure 7.9: Distribution of thermal preference votes based on schools: (a) summer-ASHRAE, (b) summer-Bedford, (c) winter-Bedford, and (d) winter-ASHRAE

The mode sensation and the mode preference in each school were (neutral) or (comfortable) and (a bit cooler) in both summer and winter studies. An exception of (no change) preference mode was reported in (NK) School in Bedford questionnaire in summer and in both (DA) and (NK) Schools in Bedford questionnaire in winter. Considering the mean sensations, they ranged between (neutral) or (comfortable) and (slightly warm) or (comfortably warm). In specific, (slightly warm) was the mean sensation in (SQ) and (WK) Schools during summer and in (DA) School during winter. Considering (comfortably warm), it was the mean sensation in (ZA) School in both summer and winter studies. Besides, most of the mean preference votes were (a bit cooler). It is noteworthy that (no change) preference was the mean in (SQ) and (NK) Schools during Bedford questionnaires of summer study and (DA) School in Bedford questionnaire of winter study.

7.3.2.7 Comparing mean votes of thermal sensation

For each classroom, the percentage of unsatisfied students was computed based on the procedures mentioned in Table 7.3. Following the approach of (Katafygiotou & Serghides, 2014a) that was based on the PMV-PPD graph, these percentages were used to determine the mean votes as presented in Table 7.8. The arithmetic means of the actual sensation votes were calculated for comparison. As noted, there is no obvious pattern for the relation between the arithmetic mean votes and those resulted from the other methods. However, a total agreement between the different methods was observed in (ZA-G2), (NK-G2), and (NK-F1) classrooms in Bedford questionnaire in summer study. Hence,

Pearson's correlation coefficients between the arithmetic means of the actual sensation votes and the other means were calculated. It is possible to consider the correlation coefficients as an indicator of the agreement between the different means of sensation votes. In all classrooms, the coefficients were below ±0.61, which is less than unity that represents an ideal situation. Therefore, it seems that the different methods used to determine the unsatisfied students failed in estimating the actual mean votes. It may worth mentioning that a similar variation in the percentages of unsatisfied people determined by different methods was reported in a study, (Cheng et al., 2008), that used the methods of direct evaluation of satisfaction and the sensation votes outside the three central categories.

Table 7.8: Different values of the mean thermal sensation vote in each classroom

		SQ-G1	SQ-G2	SQ-F1	ZA-G1	ZA-G2	ZA-F1	WK-F1	WK-F2	WK-S1	DA-G1	DA-G2	DA-F1	NK-G1	NK-G2	NK-F1
Summer - ASHRAE	N	28	35	30	29	28	22	23	23	21	22	19	19	22	25	25
	Arithmetic mean	**0**	**-1**	**0**	**-1**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**-2**	**-1**	**-1**	**0**
	Unsatisfied	-1	-1	-1	-1	-2	-1	-2	-1	-1	-1	-1	-1	-1	-1	-1
	Uncomfortable	-1	-1	-1	-1	-2	-1	-2	-1	-1	-1	-1	-2	-1	-1	-2
	(-3,-2,+2,+3) TSV	-1	0	-1	-1	0	0	-1	0	0	0	0	-1	-1	-1	-1
	(-3,+2, +3) TSV	-1	0	-1	0	0	0	-1	0	0	0	0	-1	-1	0	-1
	(-2,-1,+1,+2) TPV	-2	-2	-2	-2	-2	-2	-2	-2	-2	-2	-2	-2	-2	-2	-2
Summer - Bedford	N	29	31	32	28	25	15	15	21	24	29	26	25	25	30	24
	Arithmetic mean	**-1**	**-1**	**-1**	**-1**	**-2**	**0**	**0**	**0**	**0**	**0**	**-1**	**0**	**0**	**-1**	**-1**
	Unsatisfied	-1	-1	-1	0	-2	-1	-1	-1	-1	-1	0	-1	-1	-1	-1
	Uncomfortable	-1	-1	-1	-1	-2	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1
	(-3,-2,+2,+3) TSV	-1	-1	-1	-1	-2	-1	0	-1	-1	-1	0	-1	-1	-1	-1
	(-3,+2, +3) TSV	-1	-1	0	-1	-2	-1	0	-1	-1	-1	0	-1	-1	-1	-1
	(-2,-1,+1,+2) TPV	-2	-2	-2	-2	-2	-2	-2	-2	-2	-2	-1	-2	-2	-1	-1
Winter - Bedford	N	-	-	-	24	25	21	-	-	-	28	20	22	25	25	24
	Arithmetic mean	-	-	-	**0**	**0**	**0**	-	-	-	**-1**	**-1**	**-1**	**0**	**-1**	**0**
	Unsatisfied	-	-	-	0	-1	-1	-	-	-	-1	0	-1	-1	-1	-1
	Uncomfortable	-	-	-	-1	-1	-1	-	-	-	-1	0	0	-1	-1	-1
	(-3,-2,+2,+3) TSV	-	-	-	-2	-2	-2	-	-	-	-2	-2	-2	-2	-2	-1
	(-3,+2, +3) TSV	-	-	-	-2	-2	-2	-	-	-	-2	-1	-2	-2	-2	-1
	(-2,-1,+1,+2) TPV	-	-	-	-2	-2	-2	-	-	-	-2	-1	-2	-2	-1	-2
Winter - ASHRAE	N	-	-	-	25	24	22	-	-	-	30	22	22	23	23	21
	Arithmetic mean	-	-	-	**-1**	**0**	**0**	-	-	-	**0**	**0**	**0**	**0**	**0**	**-1**
	Unsatisfied	-	-	-	-1	-2	-1	-	-	-	0	-2	-1	-1	-1	-1
	Uncomfortable	-	-	-	-1	-2	-1	-	-	-	-	-2	-1	-1	-1	-1
	(-3,-2,+2,+3) TSV	-	-	-	-1	-1	-1	-	-	-	0	-1	-1	-1	-1	-1
	(-3,+2, +3) TSV	-	-	-	-1	-1	-1	-	-	-	0	-1	-1	-1	-1	-1
	(-2,-1,+1,+2) TPV	-	-	-	-2	-2	-2	-	-	-	-1	-3	-2	-3	-2	-2

7.3.3 Humidity sensations and preferences votes

Like thermal subjective votes, the humidity votes maintained their relative distribution in both studies as presented in Figure 7.10. As observed, the humidity sensation and preference votes were obviously concentrated in the middle category of each scale. They formed around 85% and 78% of ASHRAE and Bedford sensation votes in summer study respectively. The respective votes in winter were 84% and 82% approximately. Besides, (no change) was preferred by almost 64% and 69% of the students in the former and latter questionnaires of summer study respectively. In winter, the respective percentages were almost 58% and 76%. It is possible that the votes' clustering reflects the students' unclear understanding of humidity scales as indicated by their frequent questions. In general, uncertain people tend to gather in the central categories of any Likert scale (Humphreys et al., 2016). Further, it is noted that the subjective votes in the cool side categories were relatively more than those in the warm side categories. The exceptions were the sensation votes in Bedford questionnaire of summer study and the preference votes in the same questionnaire of winter study. The warm side votes were more in the former case, whereas the votes in both sides were equal in the latter.

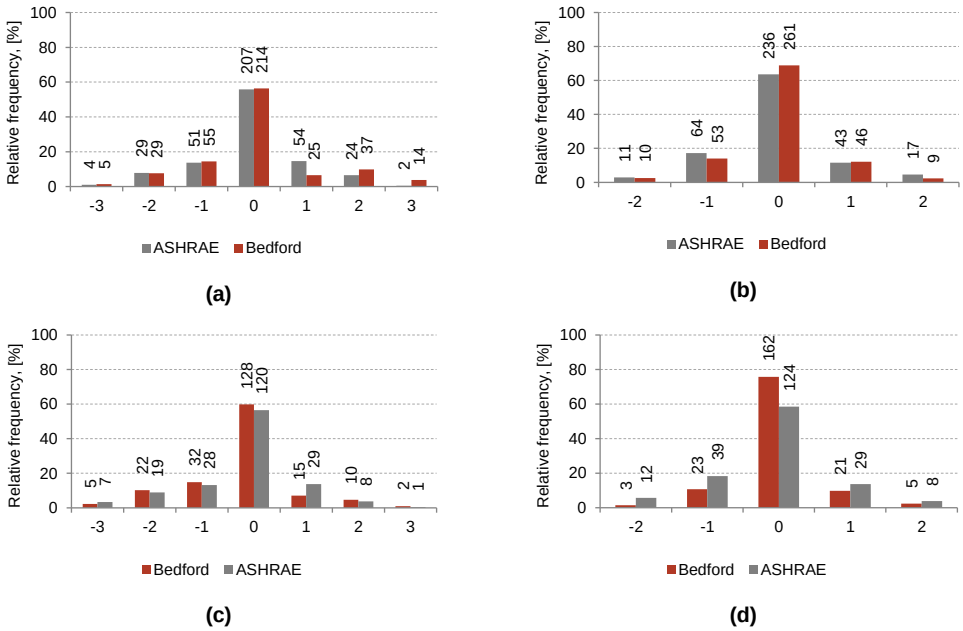


Figure 7.10: Relative frequency of: (a) HSV-summer, (b) HPV-summer, (c) HSV-winter, and (d) HPV-winter
(Labels are students' numbers)

For further investigations, the dependence of overall satisfaction and comfort levels on the central votes of sensation was determined by applying Fisher exact test. The highest p-values were almost 0.0002 and 0.0021 for the association with the satisfaction and comfort levels respectively. It is noteworthy that both levels of probability occurred in

ASHRAE questionnaire of summer study. Accordingly, the p-values provided statistical evidence on the reliance of the overall satisfaction and comfort levels on the central votes of humidity sensation. Indeed, similar statistical evidence was reported by (Kuru & Calis, 2017).

Moreover, (ZA-G2) classroom was selected for further exploration considering its comparatively warmer conditions as a consequence of the failure in its air conditioning units. The distribution of humidity votes of this classroom in summer study is displayed in Figure 7.11. As noted, most of the ASHRAE sensation votes fell in the central category with a total absence in the extreme categories. In Bedford questionnaire, the votes distributed on all categories except (comfortably warm) with more votes in the warm side. As mentioned earlier, the air conditioning units operated faulty in the former questionnaire and failed in the latter. Regarding the preference, the votes clustered in the central category of ASHRAE questionnaire and in the three central categories of Bedford questionnaire.

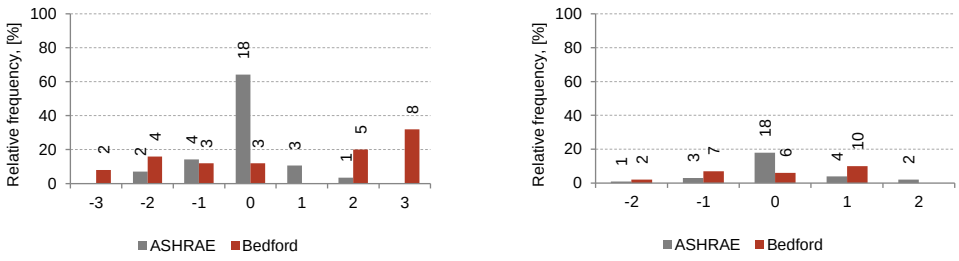


Figure 7.11: Relative frequency of: (a) HSV and (b) HPV of (ZA-G2) classroom in summer study (Labels are students' numbers)

7.3.4 Air velocity sensations and preferences votes

In both studies, air velocity votes were slightly skewed to the warm side as demonstrated in Figure 7.12. For instance, 29% roughly of the votes fell within both (warm) and (hot) categories of ASHRAE scale in summer compared with only 2% approximately in both (cool) and (cold) categories. The respective votes in Bedford questionnaire were around 34% and 3%. In winter study, the warm side votes formed around 37% and 38% of the total votes in ASHRAE and Bedford questionnaires respectively compared with almost 2% and 3% for the cool side.

Although 69% roughly of ASHRAE sensation votes in summer fell in the three central categories, almost 62% of the students preferred (a bit faster) and (much faster) air velocity. The corresponding votes in Bedford questionnaire were around 64% and 53%. In winter, almost 59% and 60% of Bedford and ASHRAE votes respectively fell in the three central categories. The respective preference votes in both (a bit faster) and (much faster) categories were around 54% and 51%. These

relatively high preference percentages of faster air velocity may reflect the effect of the students' cultural background and are consistent with the general preference tendency of warm climates' people (Nicol et al., 2012).

Besides, Fisher exact test was applied to explore the dependence of air velocity sensation votes on the overall satisfaction and comfort levels. The findings indicated a statistically significant association as the highest p-values were much lower than the significant level of 0.05. In specific, the highest probability levels were 0.000001 and 0.000002 for the satisfaction and comfort levels respectively. These values occurred in Bedford and ASHRAE questionnaires of winter study respectively. Similar evidence on this dependence was reported in (Kuru & Calis, 2017).

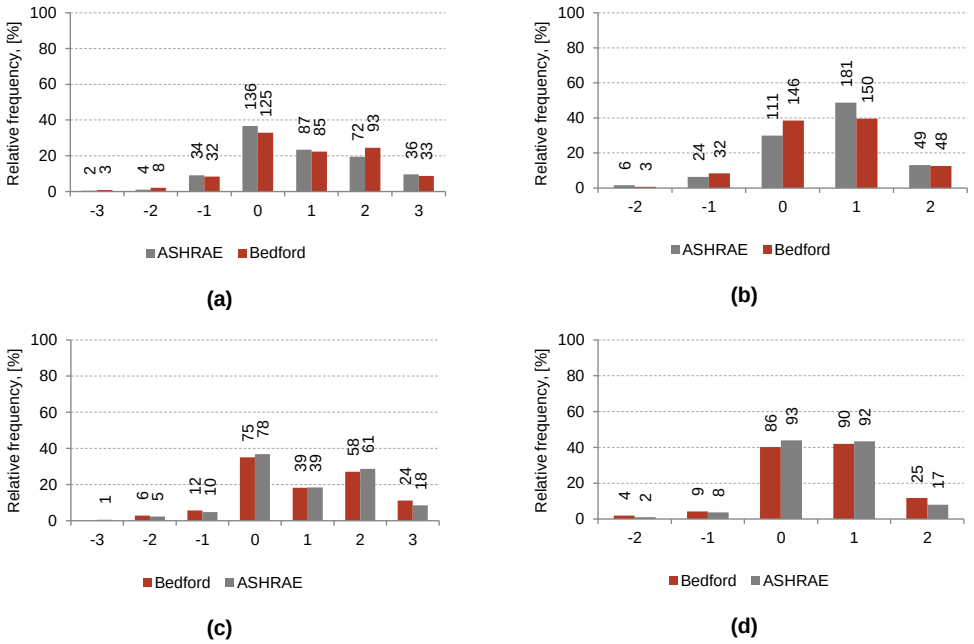


Figure 7.12: Relative frequency of: (a) AVSV-summer, (b) AVPV-summer, (c) AVSV-winter, and (d) AVPV-winter
(Labels are students' numbers)

Considering (ZA-G2) classroom in summer, 64% roughly of the votes in ASHRAE questionnaire fell in the three central categories with 21% approximately in (neutral) category. However, around 78% of the students preferred (a bit faster) or (much faster) air velocities. Almost 88% of the votes in Bedford questionnaire fell in the warm side with all preferences in (a bit faster) and (much faster) categories.

7.4 Students' adaptive behaviour

The adaptive behaviour of the participated students was explored through determining the relative frequency of utilising some adaptive opportunities besides investigating the usage time of three of them. This

exploration is crucial for better understanding of occupants' behaviour and, thus, designing efficient buildings considering that users' behaviour is significantly unpredictable (Kim & de Dear, 2018; Montazami et al., 2015).

7.4.1 Available adaptive opportunities

Considering the general restrictions on the adaptive behaviour in classrooms, the investigated students were requested to select their adaptive actions in the last few days prior to the questionnaires' days. The provided list included allowable actions in the explored classrooms. In addition, the students were encouraged to list any other actions they took. Table 7.9 summarises the pattern of adaptive opportunities usage. As noted, the adaptive behaviour in both studies was generally similar with three exceptions, namely opening windows, closing classrooms' doors, and taking no action. For instance, 20% roughly of the students in winter opened windows to modify their thermal conditions in Bedford questionnaire compared with almost 11% in ASHRAE questionnaire. The corresponding percentages were 14% and 12% approximately in summer study. The relative increase during Bedford questionnaire of winter study may be a response to the relatively cooler conditions in winter generally and in that questionnaire week specifically. Indeed, these conditions had an effect on closing classrooms' doors; around 4% reported closing doors during Bedford questionnaire in winter compared with 8% and 10% roughly in the other questionnaires. Besides, taking no action increased by almost 4%-5% in ASHRAE questionnaire of winter study compared with the other questionnaires. Similar seasonal variations in adaptive actions were noted for water intake, operating fans, and reducing clothing level in primary schools in the UK (Korsavi & Montazami, 2018).

Table 7.9: Relative frequency of using available adaptive opportunities

Adaptive opportunities	Summer		Winter	
	ASHRAE, [%] N = 975	Bedford, [%] N = 1022	Bedford, [%] N = 528	ASHRAE, [%] N = 569
Open a window	12	14	20	11
Close a window	10	8	8	7
Open the door	8	10	11	9
Close the door	10	8	4	8
Open curtains	6	7	8	9
Close curtains	5	3	2	3
Switch on/increase fans	11	10	9	9
Switch off/decrease fans	4	5	3	5
Switch on/increase AC	20	19	19	22
Switch off/decrease AC	6	8	8	8
Add on clothing	1	1	2	1
Take off clothing	3	3	5	4
Nothing	3	2	2	7
Other	0	0	0	0

In general, the adaptive actions are classified into five categories, which are actions to modify the body heat production or loss, actions to

change or modify the thermal environments, and actions to change the physiological comfort conditions (Nicol et al., 2012). As demonstrated in Table 7.9, the students depended mainly on altering their surroundings to reduce their discomfort. In specific, they lowered the air temperature and increased its velocity as they intensively depended on operating air conditioning units followed by opening windows, switching on fans, and opening doors. On average, almost 20%, 14%, 10%, and 10% of the students depended on these actions respectively. It is worth mentioning that the students' intensive reliance on operating air conditioning units is mainly due to their high efficiency in modifying thermal conditions, the influence of the students' cultural background (Al-Gharibi, 2016; Majid et al., 2014), the availability of these units (Majid et al., 2014; Hwang et al., 2006), and the absence of obvious responsibility for the economic consequences (Alwetaishi, 2015). A similar high reliance was reported in a recent study in which the students' preference of operating air conditioning units to modify their thermal ambience was higher in air-conditioned classrooms compared to naturally ventilated classrooms (Kim & de Dear, 2018). It is noteworthy that three students reported altering air direction and keeping a distance from each other as other means of their adaptive actions.

Regardless of their sitting locations, both the students sitting near windows and those sitting in the classrooms' centres depended mostly on operating air conditioning units to modify their thermal environments. However, an exception was revealed in Bedford questionnaire of winter study as the mode of the adaptive action was opening windows for both groups of students. This may be owing to the relatively cool conditions during the week of this questionnaire. In this regard, an association between the adaptive actions in classrooms and the students' sitting locations was revealed based on observations carried out recently in primary schools in the UK (Korsavi & Montazami, 2018). Thus, with the aim of investigating such relations among the explored students in this study, Fisher exact test was applied with a significant level of 0.05. An absence of enough evidence to prove the association between windows operation and sitting locations was revealed. The probability levels for ASHRAE and Bedford questionnaires in summer were 0.092 and 0.144 respectively. In winter, the corresponding levels were 0.357 and 0.178. Likewise, there was not enough evidence to support the association between sitting locations and the operation of air conditioning units, doors, and curtains in all questionnaires. A possible reason is the students' frequent change of their sitting locations based on the courses they study.

7.4.2 Perceived control impact

The intensive reliance on air conditioning raised some questions regarding the impact of the perceived control on students' productivity. In this study, the productivity is represented by the students' ability to concentrate in their classes besides the duration of full concentration. Thus, three questions were integrated into winter study questionnaires. Assuming an imaginary scenario of air conditioning failure, the students were requested to estimate the number of classes which they would be able to attend with full concentration. Besides, they were requested to identify the actions which they would perform to decrease their thermal discomfort.

It was revealed that only 29% and 24% roughly of the students in Bedford and ASHRAE questionnaires would be able to concentrate on their classes. The predicted periods of full concentration are presented in Figure 7.13. As expected, the concentration periods reduced as the numbers of classes increased. It is noted that relatively similar numbers of students estimated their full concentration periods as 1, 2, 3, and 4 classes, which is equivalent to 45-180 minutes approximately. To a certain extent, the students seem to be able to reduce their reliance on air conditioning if they have no other options. Indeed, this is consistent with the results of a study that investigated the possibility of decreasing universities' cooling loads through improving indoor thermal conditions (Cheng et al., 2008).

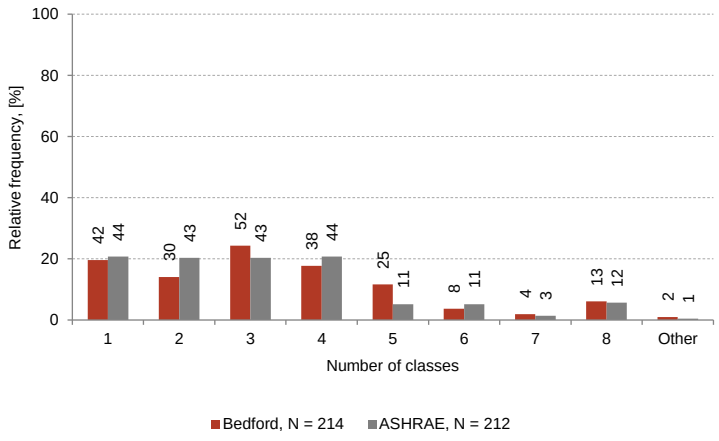


Figure 7.13: Relative frequency of predicted concentration periods (Labels are students' numbers)

Figure 7.14 displays the adaptive actions that the students would take to reduce their thermal discomfort. In general, it is possible to classify the students' actions into two groups. The first included actions to change classrooms or to alter their thermal conditions. Examples included opening windows, opening doors, opening curtains, switching on fans, and staying outside the classrooms. The other group included

actions aimed to change the students' thermal status such as reducing clothing level, drinking water, and using paper fans. Considering the relatively low percentages assigned for electric fans use, it is possible that some students assumed that the air conditioning failure is part of an electricity cut off. As noted, most students preferred opening windows followed by opening doors, staying outside classrooms, and switching on fans. The respective percentages in Bedford questionnaire for these actions were around 28%, 13%, 14%, and 11%. In ASHRAE questionnaire, they were almost 29%, 16%, 10%, and 12% respectively. In addition, three students mentioned psychological actions like trying to withstand the thermal discomfort and concentrating their thinking on other stuff rather than keep thinking of their thermal discomfort.

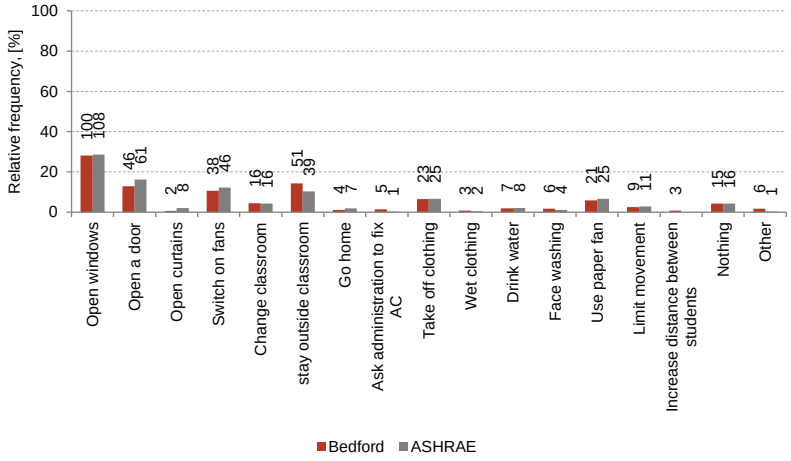


Figure 7.14: Relative frequency of adaptive actions under AC failure (Labels are students' numbers)

7.4.3 Usage time of selected adaptive opportunities

Figure 7.15 presents the usage pattern of three adaptive actions, namely opening windows, switching on air conditioning units, and switching on fans. The votes in both summer and winter studies were generally similar. Considering opening windows, there were differences of around 10% and 11% in the (not at all) and (no specific time) votes respectively. Similarly, there were differences regarding fans switching on of 11% and 12% approximately in (not at all) and (all the time) categories respectively. The highest differences in votes were around 30% and 26% in (all the time) and (no specific time) of air conditioning usage time.

As observed, the students' votes regarding windows opening fell within two categories which are (no specific time) and (after break). The former category contained 45%-56% roughly of the votes, whereas the latter contained 27%-33% approximately. It seems that the students open windows after the break mainly to introduce fresh air and remove

food smells as they are allowed to consume food inside classrooms during the break time. Investigating the behaviour of Saudi students revealed that they opened windows in winter in the morning because of the relatively cool outdoor conditions. In summer, most students chose to keep windows close (Alwetaishi, 2015). As expected, the majority of the Omani students reported operating air conditioning units all the time. However, the percentage decreased from around 85% in summer to almost 57% in winter. This heavy dependence on air conditioning is consistent with previous studies about the Omani society (Al-Gharibi, 2016; Majid et al., 2014). Besides, it is noted that around 12% and 38% of the students reported (no specific time) for operating air conditioning units in summer and winter respectively. Regarding fans, there was no clear pattern as (no specific time) was reported by almost 55%-62% of the students.

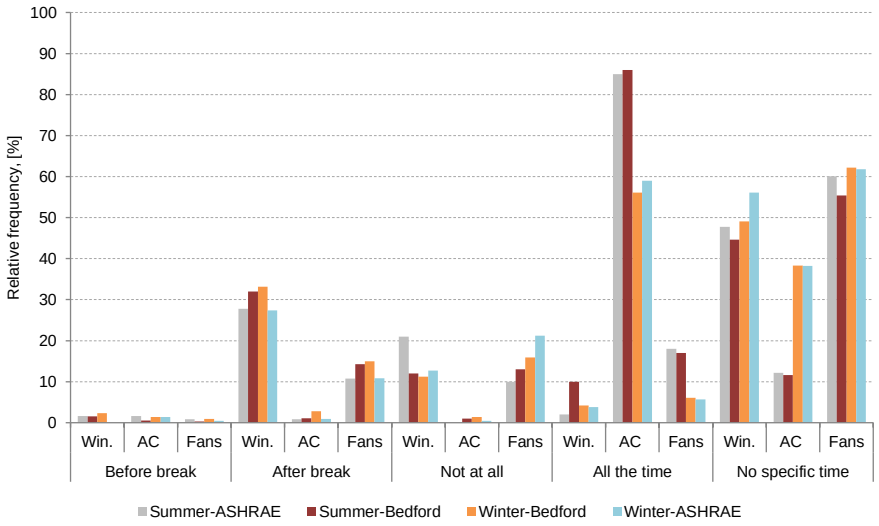


Figure 7.15: Time distribution of windows opening, AC switching on, and fans switching on

7.5 Conclusion

For both ASHRAE and Bedford questionnaires, the response rates were high; the lowest was around 89% in ASHRAE questionnaire of winter study. Most students were 15-17 years old with good health status and sedentary activities at the questionnaires' distribution time and 15 minutes before. In summer, the majority of the students were familiar with their schools as they fell within (one to two years) category. In winter, the majority fell in (less than a year) category. For both studies, around 50% or more of the students spent their break time in schools' plazas.

The satisfaction levels of the students with their thermal ambience were calculated and compared with their levels of thermal comfort. Around 66%-83% of the students expressed satisfaction with their

thermal ambience compared with almost 61%-79% reported being comfortable. It is possible that the apparent variations between the two levels were owing to sampling fluctuations as applying Fisher exact test revealed a statistically significant relationship between satisfaction and comfort levels. Based on 80% satisfaction level, comfortable conditions were achieved in Bedford questionnaire of winter study only. Reasons for dissatisfaction may include the students' high insulation level and their continuous change of classrooms. It was, additionally, revealed that the satisfaction and comfort levels were statistically independent of schools' buildings or students' health status.

The majority of the thermal sensation votes fell in the three central categories. The lowest and highest percentages of around 76% and 85% occurred in ASHRAE and Bedford questionnaires of summer study respectively. Considering the thermal preference, more students fell in the (a bit cooler) category compared with (no change). Indeed, around 40%-47% of the students fell within the former category compared with around 24%-39% in the latter category. It is noteworthy that almost 53%-66% fell in both (a bit cooler) and (much cooler) categories.

Determining the levels of dissatisfaction by different methods led to different percentages. The percentages of uncomfortable students and those with votes outside the three central categories of Bedford scale were interestingly unequal except in Bedford questionnaire of winter study. This may indicate that the thermal status of the explored students is influenced by other factors besides their thermal sensations. It is worth to mention that the preference votes' method returned the highest levels of dissatisfaction in agreement with previous research, whereas representing dissatisfaction by the votes in (-3), (+2), and (+3) categories returned the lowest percentages. Based on an allowable variation of 5%, the direct evaluation of satisfaction, i.e. by a direct question, seems to be the optimum method.

Applying Fisher exact test indicated a strong relationship between both the satisfaction and comfort levels on one hand and the central thermal sensation votes and (no change) preference vote on the other hand. Furthermore, the distribution of preference votes on sensation categories was investigated. It was revealed that most students with (neutral) or (comfortable) sensations preferred (a bit cooler) conditions. Moreover, the majority of those with (slightly cool) or (comfortably cool) sensations preferred (no change) in their conditions. This preference for cool conditions is consistent with the findings of other studies conducted in educational buildings. Hence, further explorations are recommended to reveal the influence of this preference on students' productivity. It is noteworthy that the preference of cool conditions was further confirmed

by exploring the distribution of thermal votes based on the satisfaction and comfort levels. Most satisfied and comfortable students fell in (no change) and (a bit cooler) categories, whereas most of the unsatisfied and uncomfortable students preferred (a bit cooler) and (much cooler) conditions. Besides, the former students fell in the middle categories of thermal sensation scales, whereas the latter group clustered in the warm side categories.

Moreover, classifying the students based on their sitting locations revealed that more than 50% of the students were sitting near windows in all questionnaires. The highest levels of dissatisfaction and discomfort were among those students; yet, it should be mentioned that the differences from the levels of the students who were sitting in the classrooms' centres were around 10% and 7% respectively. Moreover, a lack of enough evidence to confirm the dependence of the students' comfort on their sitting locations was revealed applying Fisher exact test. However, the association with the satisfaction level was statistically significant in two questionnaires only. This may be owing to a random fluctuation in the investigated sample of students, which emphasises the need to conduct more explorations to confirm this dependence. It is noteworthy that both groups of students had a similar distribution of their thermal sensation and preference votes.

Exploring the student's thermal conditions in each school indicated that the lowest comfort levels were reported in (ZA) School in Bedford questionnaire of summer study because of the air conditioning failure in (ZA-G2) classroom. Oppositely, the relatively highest levels were reported in (DA) School owing to the generally cooler conditions in (DA-G1) and (DA-G2) classrooms. It may worth mentioning that the highest level of (no change) preference was reported in this school. Yet, both mean and mode sensations and preferences were relatively similar and clustered in the central categories for all schools. In addition, the mean sensation in each classroom was estimated based on the percentages of the unsatisfied students. No agreement was revealed between the estimated means and the arithmetic mean of the actual votes except in three classrooms during Bedford questionnaire in summer. Exploring the relations between the different means revealed their insignificant correlation.

Considering the humidity sensation votes, the majority of students' votes clustered in the middle category of each scale. In specific, almost 85% and 78% of the votes were (neutral) or (comfortable) in ASHRAE and Bedford questionnaire of summer study. In winter, the respective percentages were 84% and 82% approximately. It should be mentioned that the students' frequent questions during the survey revealed their

unclear understanding of humidity scales. Moreover, almost 59%-69% of air velocity sensation votes fell within the three central categories. It is noteworthy that the majority of the remaining votes fell in the warm categories; the votes' difference between the two sides was 27%-35% roughly. Considering the preference votes, most students preferred (no change) in humidity level and faster air velocities. Applying Fisher exact test confirmed the association between overall satisfaction and comfort levels on one hand and the central sensation votes of humidity and air velocity on the other.

The students' adaptive actions were relatively constant during the survey. A few variations in the frequency of opening windows, closing doors, and taking no actions were noted and they were mainly due to the relatively cooler conditions during Bedford questionnaire of winter study. Based on the mean of all questionnaires' percentages, 20%, 14%, 10%, and 10% approximately of the students depended on air conditioning units, opening windows, switching on fans, and opening doors respectively to modify their thermal conditions. Their relatively heavy reliance on air conditioning units was generally because of the efficiency of these units, their availability, the influence of the students' cultural background, and the absence of obvious responsibility for the economic consequences. Moreover, no statistically significant relations were found between the students' sitting locations and their adaptive actions, namely switching on air conditioning units, switching on fans, opening windows, opening doors, and opening curtains. The students' frequent change of their classrooms and, consequently, their sitting locations is possibly the reason.

Investigating the perceived control impact, the students' ability to concentrate in classes under an imaginary failure of air conditioning units was limited to 29% and 24% roughly in ASHRAE and Bedford questionnaires respectively. In spite of their intensive reliance on air conditioning units, the students exhibited an ability to decrease this reliance. The predictions of concentration periods were almost equally distributed in the first four classes. Moreover, the students reported opening windows, opening doors, staying outside their classrooms, and switching on fans as their main adaptive actions in the absence of air conditioning. Additionally, the usage times of three adaptive actions were explored. The actions were opening windows, switching on air conditioning units, and switching on fans. It was revealed that the students' behaviour was generally constant in both seasons. The usage patterns of windows and fans were random as most students reported (no specific time). Considering the usage of air conditioning units, most

students reported (all the time), which is consistent with the findings of previous studies (Al-Gharibi, 2016; Majid et al., 2014).

Based on the students' subjective responses towards their thermal conditions and their intensive dependence on air conditioning units, it is recommended to review schools' design concentrating on their thermal performance. For instance, suggestions include planting more trees and changing the currently open corridors between classrooms to closed or semi-closed corridors. This may enhance the thermal conditions of the students and provide savings in cooling energy considering the nature of the Omani educational system. Further, it is recommended to change the current school uniform as it provides a relatively high insulation level. It is crucial to involve the students in the process of determining the new uniform for better appreciation of the required level of insulation besides to ensure its acceptance.

There is an impression that requesting students to evaluate their humidity sensations and preferences was not necessary. The reason may not be limited to the difficulty that the students faced while attempting to answer these questions; it is, additionally, owing to the limited effect of humidity in air-conditioned environments despite the relatively humid nature of Muscat. It is possible that the students' uncertainty regarding these questions had a negative influence on their response rates and intentions to collaborate with the researcher. Thus, omitting such questions from questionnaires in air-conditioned buildings may increase the subjects' response rates.

Chapter (8):

Collective Understanding of Thermal Phrases and Scales' Behaviour

Chapter 8 Collective understanding of thermal phrases and scales' behaviour

In the previous chapters, the physical environment of the students and their responses were discussed. The subjective responses were gathered by ASHRAE, Bedford, and Nicol scales. With the global spread of thermal comfort studies, thermal scales are translated into different languages to adapt local context in which the studies are applied. However, translating thermal comfort scales does not maintain the scales' behaviour associated with the original English versions. Hence, this chapter explores the collective understanding of ASHRAE scale phrases among the investigated students and investigates the behaviour of the translated scales as used in this research.

In specific, the chapter reports the findings of the first and second questionnaires besides the results of applying successive categories method on the translated versions of ASHRAE, Bedford, and Nicol scales. Usually, when more than one sensation scale is applied within one thermal survey like (Rijal et al., 2014; Feriadi & Wong, 2004), and including the current research, it is expected to select one data set for further analysis. Such selection should be supported by evidence, which reveals the importance of exploring scales' behaviour. This will eventually be reflected in an increased accuracy of the survey results. It is noteworthy that up to the researcher's level of knowledge, this study is the first attempt that investigates the behaviour of thermal scales when translated into the Arabic language.

8.1 Collective understanding of ASHRAE sensation phrases

In total, 762 copies of the first questionnaire and 612 copies of the second were distributed. Around 68% of the first questionnaire copies were excluded because of missing and inconsistent answers. Wrong translations such as calm, clean, and dangerous resulted in excluding the entire copy. Besides, other copies that translated cool as warm or warm as cold were excluded. Consequently, 245 copies of the first questionnaire were analysed. Moreover, the scale polarity of the second question was inverted in 13 copies. This was corrected as part of preparing the results for analysis. In addition, the scale's length was converted to a 100 mm. It is noteworthy that the response rate of the second questionnaire was 100%.

8.1.1 Translations of ASHRAE scale phrases

(Cold) and (hot) were translated into 13 and 14 different terms respectively, which mean that on average almost 19% and 18% of the students agreed on one phrase for the former and latter sensations

respectively. The highest number of translated phrases was 109 for (slightly cool), followed by 91, 64, 39, and 36 for (slightly warm), (cool), (neutral), and (warm) respectively. The researcher, who is a native speaker of Arabic language, merged the similar translated phrases of each sensation. Consequently, the respective translated phrases of (cold), (cool), (slightly cool), (neutral), (slightly warm), (warm) and (hot) became 7, 25, 44, 20, 42, 20 and 7.

The variation in the translated phrases used for each sensation may be related to the features of the Arabic language. Often, there are many Arabic words to describe the 'one thing'. For example, more than 100 Arabic words were used to describe (pain) according to the results of a study performed in Kuwait (Harrison, 1988). Similarly, there are almost 11 different words that mean (love) in Arabic language (Sayed, 2015). Reflecting this into the research at hand, it is possible, for instance, to identify four and two different words used as translations for (neutral) and (hot) respectively in the merged version. In addition, Arabic root words can create tens of words (Awajan, 2015), which allowed the students to create different translations for the one sensation using one root word like the cases of (cold) and (cool). Moreover, it was noted that most students translated the sensations into phrases of two words, which added to the variety of their answers considerably. It is noteworthy that merging the similar translations was possible owing to the flexible order of Arabic words (Saiegh-Haddad, 2018; Awajan, 2015).

Additionally, the unmerged translated phrases provided by 5% of the students or more are displayed in Figure 8.1. Any phrases provided by less than 5% were added to (other). As noted, more than 50% of the students agreed on one phrase for each of (cold), (neutral), (warm), and (hot). However, they did not agree on specific phrases for the remaining sensations. Possible reasons include their level of knowledge as they, frequently, asked about the meaning of (slightly) in addition to the warm climatic conditions dominant in Muscat city.

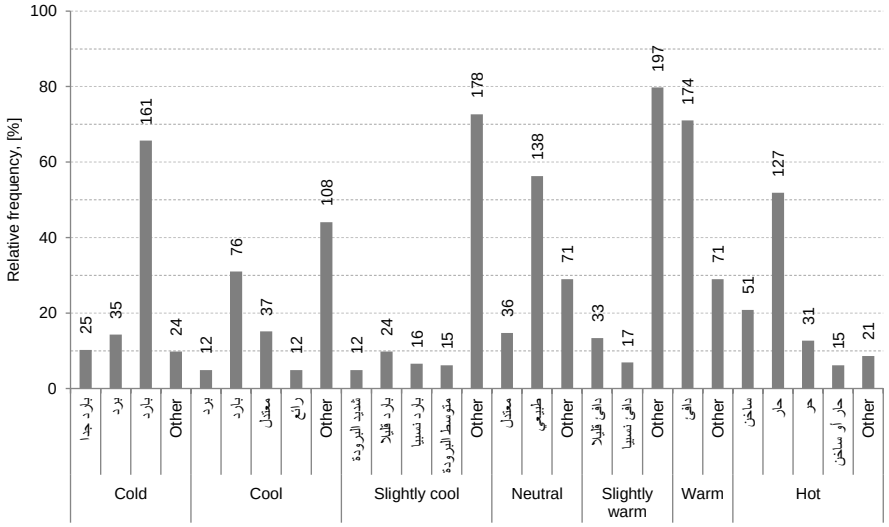


Figure 8.1: Relative frequency of unmerged translated phrases (Labels are students' numbers)

Moreover, it is noted from Figure 8.1 that some translated phrases were common between sensations. This may reflect a possible overlap in sensations' meanings for the investigated students. Overall, (cool) and (slightly cool) had the highest number of common phrases as they shared 18 terms followed by (slightly warm) and (warm) that shared 11 phrases. Besides, 10 terms were common between (cool) and (neutral) and between (neutral) and (warm). It is noteworthy that most of these phrases were provided by less than 5% of the students. Indeed, only three common phrases from the unmerged translations were provided by 5% of the students or more. These are:

- (بارد) used for (cold) and (cool) by 66% and 31% respectively;

- (برد) used for (cold) and (cool) by 14% and 5% respectively; and

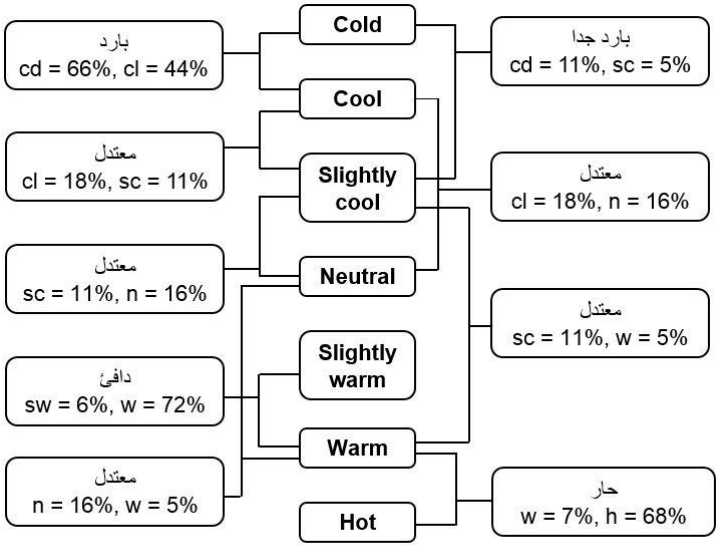
- (معتدل) used for (cool) and (neutral) by 15% and 15% respectively.

The relatively high agreement on the common phrases between (cold) and (cool) may reflect the general lack of differentiation between them in the Arabic language as mentioned in Section 2.5.3.1. In this regard, a similar lack was noticed between (warm) and (hot) in French, Greek, and Portuguese languages in the SCATs project (Humphreys, 2008).

Considering the merged translations, the common terms provided by 5% of the students or more are depicted in Figure 8.2. Based on the displayed percentages, it may be possible to assign a common phrase to a certain sensation. For instance, (slightly warm) and (warm) were translated into one phrase by 6% and 72% of the students respectively.

Thus, it may be possible to consider that common phrase as equivalent to (warm).

Further, a term that literally means (moderate), (mild), or (neither cool nor warm) was repeatedly used to express all sensations between (cool) and (warm) including both. Interestingly, the number of students who translated (cool) as (moderate) was slightly higher than those used it as an equivalent for (neutral). This may indicate that the investigated students are relatively addicted to cool conditions as they considered (cool) to be (moderate). It should be mentioned that a heavy reliance on air conditioning units among people, especially in Muscat, was reported in previous research (Al-Gharibi, 2016; Majid et al., 2014). In addition, this overlapping may be significant in the cases of (cool) and (slightly cool), (cool) and (neutral), and (slightly cool) and (neutral) as the agreement percentages were relatively similar. Besides, the repetitive use of this phrase, i.e. (moderate), (mild), or (neither cool nor warm), may indicate wide acceptance of thermal conditions for the explored students.



Key: cd = cold, cl = cool, sc = slightly cool, n = neutral, sw = slightly warm, w = warm, h = hot

Figure 8.2: Common phrases between merged translated phrases

For each sensation, the phrases provided by the highest number of students before and after merging similar translations are displayed in Table 8.1 besides the findings of the second questionnaire. Merging similar phrases resulted in using one phrase as an equivalent for both (cold) and (cool), which may indicate their cover for a similar thermal range. It is noted that the percentages of agreement increased slightly except for (hot) that increased by around 16.4%. Besides, it seems that many different phrases were provided as equivalent to (hot) possibly because of the dominant climatic conditions in Muscat city.

Table 8.1: Thermal sensations' equivalents before merging, after merging, and from the second questionnaire

Thermal sensation	Cold (%)	Cool (%)	Slightly cool (%)	Neutral (%)	Slightly warm (%)	Warm (%)	Hot (%)
Before merging	بارد (٦٥,٧)	Other (44.1)	Other (72.7)	طبيعي (٥٦,٣)	Other (79.8)	دافئ (٧١,٠)	حار (٥١,٨)
After merging	بارد (٦٦,١)	بارد (٤٣,٧)	Other (46.9)	طبيعي (٥٩,٢)	Other (60.4)	دافئ (٧١,٨)	حار (٦٨,٢)
2nd questionnaire	بارد (٨٢,٤)	معتدل (٤٤,٩)	متوسط البرودة (٣٦,٩)	طبيعي (٨٦,٩)	دافئ قليلا (٥٧,٨)	دافئ (٨٤,٨)	حار (٧٣,٢)

It should be mentioned that identifying one translated phrase for both (slightly cool) and (slightly warm) was not possible even after merging. The reason may be the students' obvious confusion regarding (slightly) meaning. Yet, the students agreed on equivalents for these sensations in the second questionnaire despite that the agreement percentages were low compared with other sensations. Additionally, the equivalent of (cool) in the second questionnaire was different from that resulted from merging. According to the second questionnaire findings, (cool) was translated as (moderate), (mild), or (neither cool nor warm). This suggests the importance of considering the climatic background effect when defining the comfort range. In this regard, the results of a thermal comfort study performed in Italian classrooms during winter worth mentioning. The actual percentage of dissatisfied people agreed better with the computed PPD when it was considered as the summation of (cold), (cool), and (hot) sensation votes. Including (warm) in the actual dissatisfied percentage resulted in underestimation of thermal dissatisfaction (Corgnati et al., 2007).

Additionally, it is noted that the students' translations summarised in Table 8.1 differ from those of the international version presented in Table 2.4 except (cool), from the merged version, and (neutral). Recalling that the considered dialect in the international translation is not known, variations may be justified because dialects affect the used vocabulary. This highlights the importance of considering participants' local context through careful translations of thermal scales. Besides, it is suggested to use phrases such as (cool and not acceptable) and (warm and not acceptable) as substitutes for (cool) and (warm).

8.1.2 Comparing categories' means

Considering the students' answers of the second question in the first questionnaire, the mean, median, range, and standard deviation values for each sensation in addition to those of thermal comfort are summarised in Table 8.2. As observed, the range of each sensation extended roughly over the whole 100 mm line, which may reflect the students' uncertainty regarding sensations' locations on the thermal continuum. Additionally, it seems that distinguishing between (cool) and

(slightly cool) was difficult as their means and standard deviations were similar. This was the case with (slightly warm) and (warm) that, besides, had identical mode values. It may worth mentioning that the modes of the former and latter sensations were determined by around 7% and 5% of the students respectively.

Table 8.2: Statistics of thermal sensations (N = 245)

	Cold	Cool	Slightly cool	Neutral	Slightly warm	Warm	Hot	Comfort
Mean	20.16	32.89	34.84	51.23	64.14	66.71	79.73	46.53
Median	14	29	34	52	65	70	87	49
Mode	13	23	34	52	74	74	86	53
SD	20.02	18.15	16.24	10.98	16.48	17.53	21.84	17.49
Max	103	91	93	102	100	99	102	93
Min	0	0	0	14	11	12	3	0
Range	103	91	93	88	89	87	99	93

Furthermore, the mean of (neutral) was marginally shifted from the centre of the thermal continuum towards the hot side. Oppositely, the mean of (comfort) was slightly shifted towards the cold side. This shift is consistent with the general preference tendency of people from warm climates (Humphreys et al., 2016; Nicol et al., 2012; de Dear et al., 1997). Additionally, the standard deviation of (comfort) was noticeably higher than that of (neutral), which may indicate wider comfort ranges.

Moreover, the possible equivalence between thermal sensations in this sample was investigated by calculating confidence intervals of sensations' means. A 0.01 level of significance was selected to allow for the possible widest intervals. Results are plotted in Figure 8.3. In spite of their close proximity, the students distinguished between (comfort) and (neutral). Besides, almost 75% of (slightly cool) interval overlapped with that of (cool) and around 50% of (slightly warm) interval overlapped with (warm) interval. This may be due to students' uncertainty regarding the meaning of (slightly).

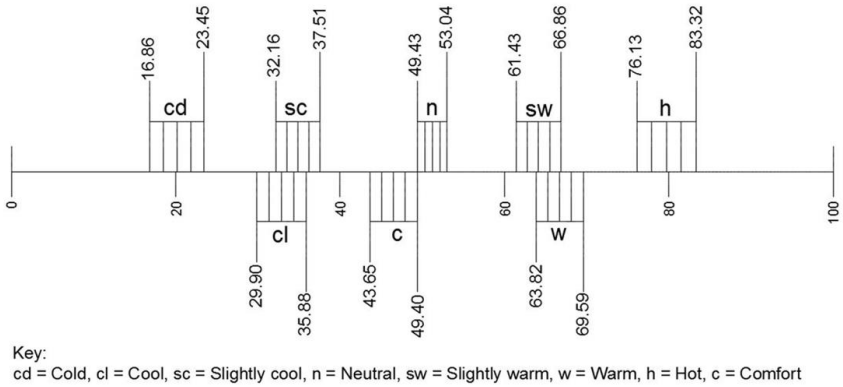


Figure 8.3: Distribution of means' 99% confidence intervals (N = 245)

8.1.2.1 Categories' means based on sensations' order

The answers to the second question in the first questionnaire were classified into two sets for further explorations based on the provided

order of sensations. The first set consisted of all the data that followed ASHRAE sensation's order and the remaining data formed the second set. Some statistics for the former set are summarised in Table 8.3 and for the latter in Table 8.4. The ranges of the first set were considerably narrower and the means had a relatively uniform distribution on the thermal continuum. In the second set, the means of (slightly cool) and (warm) categories were lower than those of (cool) and (slightly warm) respectively. In both sets, (neutral) mean was marginally higher than the thermal continuum centre, whereas (comfort) mean was slightly lower.

Moreover, the sensations' means of these two sets are graphically compared with those of the total set as plotted in Figure 8.4. Means of (comfort) and central categories sensations were almost similar in the three sets. Compared with the first set, both (cold) and (cool) were warmer in the total and the second sets. Likewise, (warm) and (hot) were cooler in the second and total sets. The influence of sample size was obvious as both means of the second and total sets had similar positions.

Table 8.3: First set statistics – ASHRAE order (N = 81)

	Cold	Cool	Slightly cool	Neutral	Slightly warm	Warm	Hot	Comfort
Mean	12.53	24.15	35.49	50.88	63.83	75.78	86.56	46.48
Median	13	23	35	52	64	77	87	49
Mode	12	23	34	53	64	80	86	53
SD	6.47	5.98	6.24	5.62	8.51	9.19	9.59	14.85
Max	29	38	46	65	80	95	102	83
Min	0	10	21	29	34	40	45	11
Range	29	28	25	36	46	55	57	72
99% Conf. int.	10.68 – 14.38	22.44 – 25.86	33.71 – 37.28	49.27 – 52.48	61.39 – 66.26	73.15 – 78.41	83.81 – 89.30	42.23 – 50.73

Table 8.4: Second set statistics – another order (N = 164)

	Cold	Cool	Slightly cool	Neutral	Slightly warm	Warm	Hot	Comfort
Mean	23.93	37.21	34.51	51.41	64.30	62.23	76.35	46.55
Median	15	35	32	52	67	65	87	49
Mode	13	41	35	52	74	63	90	47
SD	23.16	20.46	19.38	12.84	19.26	18.91	25.18	18.70
Max	103	91	93	102	100	99	100	93
Min	0	0	0	14	11	12	3	0
Range	103	91	93	88	89	87	97	93
99% Conf. int.	19.27 – 28.59	33.09 – 41.32	30.61 – 38.41	48.83 – 53.99	60.42 – 68.17	58.42 – 66.03	71.29 – 81.42	42.77 – 50.31

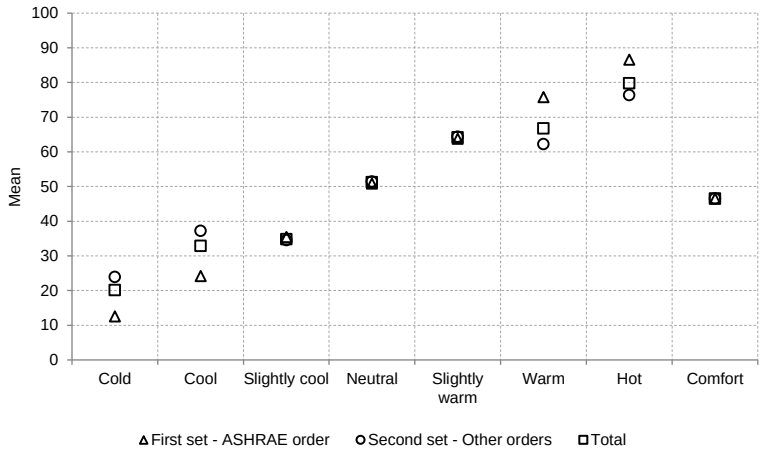


Figure 8.4: Means of thermal sensations in the first, second, and total sets

Furthermore, the 99% confidence intervals of the first and second sets' means are presented in Figure 8.5. In the former set, the students distinguished the different sensations as their means were distributed at relatively equal distances without any overlap. Therefore, it seems that the first set students exhibited better understanding of ASHRAE thermal phrases. Considering the second set, around 68% of (slightly cool) interval overlapped with that of (cool). Similarly, almost 72% of (slightly warm) interval overlapped with (warm) interval. It seems that most students who were confused about (slightly) meaning fell in this set.

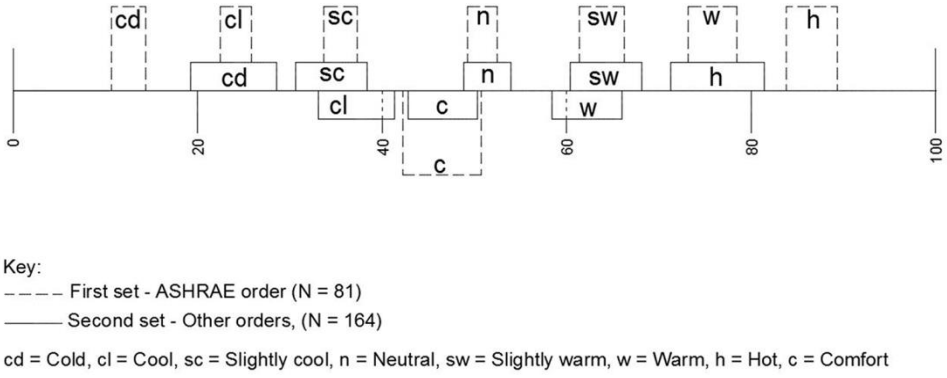


Figure 8.5: Distribution of means' 99% confidence intervals in the first and second sets

8.1.2.2 Categories' means based on season

Students' answers to the second question in the first questionnaire were divided into summer and winter sets to explore possible seasonal impact. For the former and latter sets, basic statistics are presented in Table 8.5 and Table 8.6 respectively. As noted, the ranges are relatively narrower in winter and they fell within the given scale. Oppositely, the ranges of (cold), (neutral), and (hot) of summer set exceeded the scale, which was reflected in the relatively wider standard deviations. Although the means of both sets followed ASHRAE order, the relative distances between them were not uniform.

Additionally, it is noted that the means of (cool) and (slightly cool) were closer to each other compared with other sensations in both sets, which was the case with (slightly warm) and (warm) in summer set only. Considering (comfort), it was cooler than (neutral) in both sets, which is, as mentioned earlier, consistent with the general preference of people from warm climates (Humphreys et al., 2016; Nicol et al., 2012; de Dear et al., 1997). It is noteworthy that the difference between (comfort) and (neutral) means was relatively higher in summer, which may indicate the seasonal effect on determining (comfort) for the explored students.

Furthermore, the means are graphically represented in Figure 8.6 that, additionally, displays the means from (Pitts, 2006). Compared with summer, the cool side means in winter were negligibly cooler and those of the warm side were slightly warmer. Considering each set separately, the relatively bigger differences between the means of the warm side possibly indicate wider acceptance of warm conditions. Oppositely, the relatively smaller variations between cool side means may reflect higher sensitivity towards cool conditions. Moreover, (cold) and (cool) means in (Pitts, 2006) set were noticeably cooler than their equivalents for Omani students, which may be because of the participants' thermal experiences. However, (warm) and (hot) means were surprisingly hotter in Pitts' data. The reason may be cultural considering the spread and intensive use of air conditioning units in Omani buildings (Al-Gharibi, 2016; Majid et al., 2014).

Table 8.5: First set statistics - summer (N = 163)

	Cold	Cool	Slightly cool	Neutral	Slightly warm	Warm	Hot	Comfort
Mean	20.72	33.94	35.30	50.55	63.34	64.75	77.44	43.98
Median	12	27	34	52	66	68	87	47
Mode	11	23	34	50	68	71	86	53
SD	23.39	20.74	18.66	12.19	18.95	19.43	26.09	19.52
Max	103	91	93	102	100	99	102	93
Min	0	0	0	14	11	13	3	0
Range	103	91	93	88	89	86	99	93
99% Conf. int.	14.07 – 27.38	28.05 – 39.84	29.99 – 40.61	47.08 – 54.02	57.95 – 68.73	59.22 – 70.27	70.02 – 84.86	38.43 – 49.53

Table 8.6: Second set statistics - winter (N = 82)

	Cold	Cool	Slightly cool	Neutral	Slightly warm	Warm	Hot	Comfort
Mean	19.04	30.79	33.91	52.59	65.73	70.60	84.27	51.94
Median	15	29	34	52	65	73	86	52
Mode	13	21	34	51	64	79	87	53
SD	10.54	11.20	9.86	7.93	9.82	12.18	6.65	10.93
Max	71	73	74	85	84	89	97	78
Min	4	12	16	30	21	12	61	21
Range	67	61	58	55	63	77	36	57
99% Conf. int.	16.04 – 22.04	27.61 – 33.98	31.11 – 36.72	50.33 – 54.84	62.94 – 68.52	67.13 – 74.06	82.38 – 86.16	48.83 – 55.05

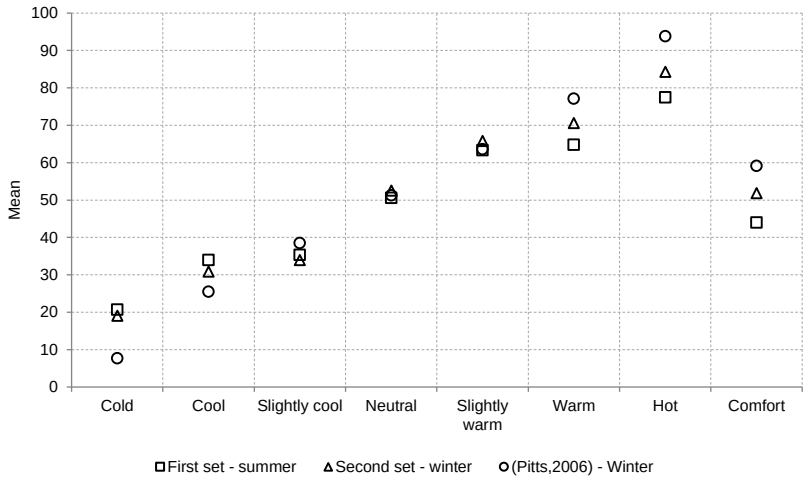


Figure 8.6: Means of thermal sensations in the first, second, and (Pitts, 2006) **sets**

Moreover, Figure 8.7 presents the 99% confidence interval of both summer and winter sets. Despite its larger size, wider intervals were noted in the former set possibly because of its considerable variability indicated by the relatively wider standard deviations. Around 93% of (slightly cool) interval overlapped with that of (cool) and almost 88% of (slightly warm) interval overlapped with (warm). Additionally, (comfort) interval overlapped with (cool), (slightly cool), and (neutral) by around 13%, 20%, and 22% respectively. Considering winter set, the relatively narrower intervals reflected less variability. Yet, two overlaps occurred between (cool) and (slightly cool) and between (slightly warm) and (warm); their respective overlaps were 45% and 25% roughly with reference to (cool) and (slightly warm) intervals. Besides, it is noted that (neutral) was totally contained within (comfort) interval.

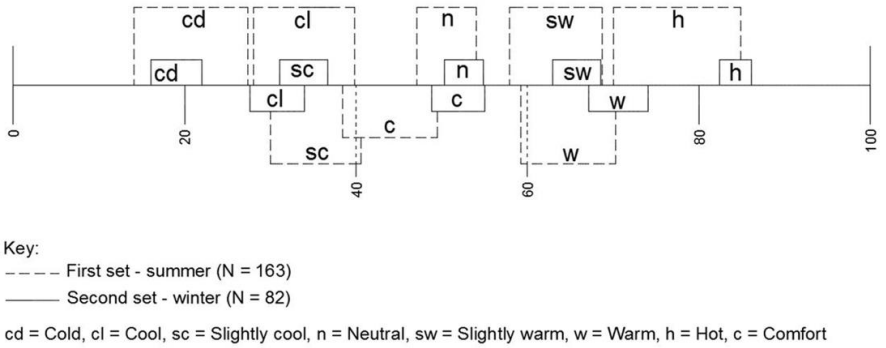


Figure 8.7: Distribution of means' 99% confidence intervals in first and second sets

8.1.3 Thermal comfort equivalent

The relative frequency of thermal sensations considered by the students as equivalent to (comfort) are displayed in Figure 8.8. In the total set, around 66% of the students considered the three central categories as equivalent to (comfort). In specific, almost 12%, 42%, and 12% of the students considered (slightly cool), (neutral), and (slightly

warm) respectively as comfortable sensations. Considering summer, the respective percentages were 12%, 38%, and 9% roughly. In winter, they were around 13%, 51%, and 18% respectively. As noted, the total percentage of these three sensations dropped in summer by around 24% compared with that of winter, which may reflect a seasonal effect. Indeed, almost 26% of the students considered both (cool) and (cold) as equivalents to (comfort) in summer compared with only around 10% in winter. Accordingly, it is suggested to consider the seasonal influence when defining thermal comfort range.

Besides, almost 63%, 64%, and 61% of the students from the total, summer, and winter sets respectively considered (cold), (cool), and (neutral) as equivalents to (comfort). In a previous study, around 90% of Omani participants reported one of these sensations without expressing thermal discomfort (Majid et al., 2014). Yet, it should be mentioned that this study was conducted on 87 participants in two hot dry cities in Oman.

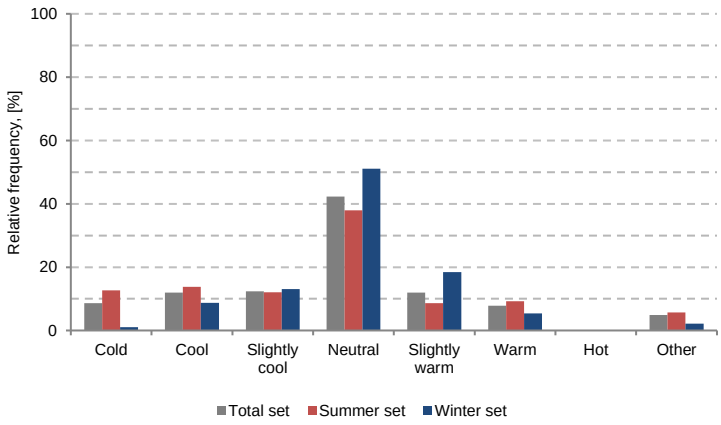


Figure 8.8: Relative frequency of sensations equivalent to comfort

8.2 Behaviour of translated ASHRAE, Bedford, and Nicol scales

As mentioned in Section 5.2.2.3, applying successive categories method requires deriving the explored scales from one thermal survey. Therefore, the thermal environments of the classrooms were explored in Chapter 6 with the aim of ensuring that the students were subjected to similar conditions. Accordingly, summer copies of (ZA-G2) classroom and winter copies of (DA-G2) classroom during Bedford questionnaire were excluded. In addition, all questionnaires with incomplete or inconsistent answers were excluded as well as those returned from students who were involved in physical education classes before participating in the survey. As a result, 333 and 349 copies of ASHRAE and Bedford questionnaires of summer respectively were included in the analysis. The corresponding copies of winter were 209 and 194.

As noted in Table 5.3, the non-central categories of both ASHRAE and Bedford scales (i.e. categories -3, -2, +2, and +3) were translated to identical Arabic phrases. This allows exploring the stability of these categories' behaviour besides exploring the translation impact on comfort range (i.e. the three central categories). It is noteworthy that both (cool) and (cold) words are often translated into one term in the Arabic language as mentioned in Section 2.5.3.1. In order to distinguish between the two sensations, the latter was literally translated as (very cold). Moreover, the literal translation of (warm) may be a desirable sensation especially in winter; thus, it was translated to a phrase that means (hot) to convey the negative impression of this category. This led to translating (hot) as (very hot), which additionally maintained the scales' symmetry. Consequently, the thermal ranges covered by the two scales' versions (i.e. English and Arabic) are different; yet, this change is acceptable as it is part of adapting scales to the local context. In the SCATs project, the French, Greek, and Portuguese versions of the scale were manipulated in a similar manner (Humphreys, 2008). In spite of this difference in the thermal ranges, both English and Arabic scales' versions are assumed to maintain similar uniform gaps between the consecutive sensations.

The successive categories method was applied to determine the probits that represent the categories upper limits. To compute the probits, the students' votes in each category were determined and the cumulative numbers of votes were calculated. The cumulative proportion of each category was calculated by dividing the cumulative number of votes in that category by the total number of votes. The cumulative proportions were then transformed into probits using the cumulative normal distribution of unit standard deviation on the psychological continuum. The application of the successive categories method in the thermal comfort field is comprehensively illustrated in chapter (18) of Adaptive Thermal Comfort: Foundations and Analysis book (Humphreys et al., 2016).

The computed probits of thermal scales in summer are displayed in Table 8.7 and those in winter are presented in Table 8.8. To visualise the findings, graphical representations of the tables are demonstrated in Figure 8.9 for the former and in Figure 8.10 for the latter. Based on these tables and figures, it is possible to compare the translated scales and investigate their behaviour through comparison with the original assumptions of the English scales. In particular, the categories' width and symmetry can be obtained from these figures in addition to the coincidence between the scales' middle categories and the thermal continuum centre. Moreover, Appendix 8.1 displays the probits and the

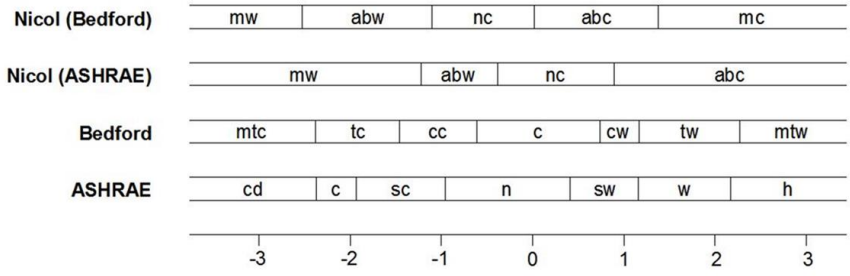
graphical representations of relative humidity and air velocity scales. More details are discussed in the following sections.

Table 8.7: Cumulative proportions, probits, and standard errors of thermal categories in summer

	ASHRAE, N = 333			Bedford, N = 349		
Category	**Cum. Prop.**	**Probit**	**SE**	**Cum. Prop.**	**Probit**	**SE**
-3	0.009	-2.37	0.173	0.009	-2.38	0.172
-2	0.027	-1.93	0.126	0.072	-1.46	0.094
-1	0.168	-0.96	0.079	0.269	-0.61	0.070
0	0.661	0.41	0.072	0.771	0.74	0.076
+1	0.877	1.16	0.093	0.880	1.17	0.092
+2	0.985	2.17	0.224	0.989	2.27	0.252
+3	1.000	-	-	1.000	-	-
	Nicol (ASHRAE), N = 333			**Nicol (Bedford), N = 349**		
-2	0.000	-	-	0.006	-2.53	0.193
-1	0.111	-1.22	0.086	0.135	-1.10	0.081
0	0.351	-0.38	0.070	0.507	0.02	0.067
+1	0.814	0.89	0.083	0.917	1.38	0.104
+2	1.000	-	-	1.000	-	-

Table 8.8: Cumulative proportions, probits, and standard errors of thermal categories in winter

	Bedford, N = 194			ASHRAE, N = 209		
Category	**Cum. Prop.**	**Probit**	**SE**	**Cum. Prop.**	**Probit**	**SE**
-3	0.015	-2.16	0.186	0.010	-2.34	0.206
-2	0.041	-1.74	0.143	0.053	-1.62	0.130
-1	0.222	-0.77	0.097	0.124	-1.15	0.105
0	0.711	0.56	0.098	0.612	0.29	0.089
+1	0.820	0.91	0.111	0.828	0.95	0.108
+2	0.979	2.04	0.270	0.952	1.67	0.171
+3	1.000	-	-	1.000	-	-
	Nicol (Bedford), N = 194			**Nicol (ASHRAE), N = 209**		
-2	0.005	-2.57	0.250	0.005	-2.59	0.248
-1	0.088	-1.36	0.118	0.062	-1.54	0.124
0	0.448	-0.13	0.090	0.344	-0.40	0.088
+1	0.871	1.13	0.123	0.804	0.86	0.104
+2	1.000	-	-	1.000	-	-



Key:

ASHRAE: cd = Cold, cl = Cool, sc = Slightly cool, n = Neutral, sw = Slightly warm, w = Warm, h = Hot
Bedford: mtc = Much too cool, tc = Too cool, cc = Comfortably cool, c = Comfortable neither warm nor cool, cw = Comfortably warm, tw = Too warm, mtw = Much too warm
Nicol: mw = Much warmer, abw = A bit warmer, nc = no change, abc = A bit cooler, mc = Much cooler

Figure 8.9: Thermal categories' widths of ASHRAE, Bedford, and Nicol scales in summer

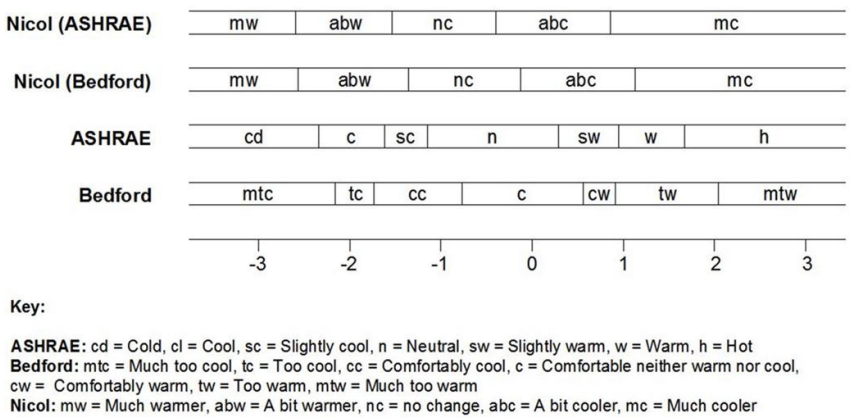


Figure 8.10: Thermal categories' widths of Bedford, ASHRAE, and Nicol scales in winter

8.2.1 Categories' widths

In the following sections, the categories' widths are compared at three levels as illustrated in Figure 8.11. In the first level, the categories' widths are compared within each scale. In the second, the compared categories are from different scales. This includes comparing widths of ASHRAE and Bedford categories besides comparing them with those of Nicol scale. Considering the third level, it compares the widths of the same categories from different questionnaires within the same survey.

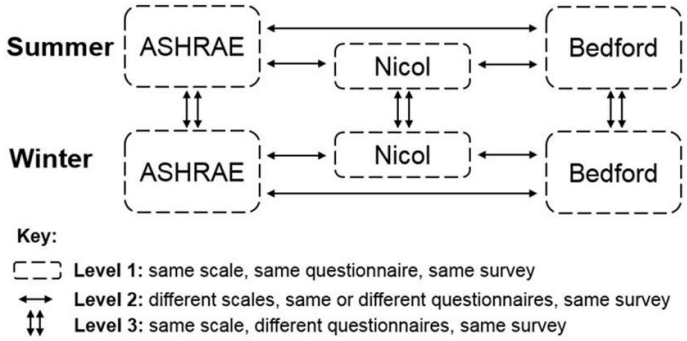


Figure 8.11: Levels of comparing categories' widths in the survey

As noted in Figure 8.9, the categories' widths were irregular in summer except perhaps those of Nicol scale in Bedford questionnaire. Accordingly, moving between categories required unequal temperature variations. It is noteworthy that (a bit cooler) from Nicol scale during ASHRAE questionnaire had no defined width owing to votes' absence in (much cooler) category. Similarly, end categories of all scales had no defined widths. Considering sensation scales, the middle categories were the widest. For instance, (neutral) width was almost double that of (slightly warm). Oppositely, the narrowest categories were (cool) and (comfortably warm). Both categories had relatively few votes, which may be justified by climatic and cultural reasons. Yet, the real reasons for their narrow widths are not clearly known. Considering Nicol scale,

(no change) category of ASHRAE questionnaire was slightly wider than (a bit warmer). In Bedford questionnaire, (a bit warmer) and (a bit cooler) had roughly an equal width that was slightly wider than that of (no change).

Like summer study, sensation categories in winter had irregular widths as indicated in Figure 8.10. It is noted that the middle categories of sensation scales were the widest and they were shifted towards the cool side. Besides, the width of (neutral) was roughly double that of (cool), (slightly warm), or (warm). These three categories had almost equal widths and the narrowest category was (slightly cool). Moreover, (comfortably cool) and (too warm) widths were almost equal. This was the case with (too cool) and (comfortably warm) that, additionally, were the narrowest categories. In Nicol scale, roughly uniform temperature differences were required to move between preference categories due to their relatively equal widths.

8.2.1.1 Comparing categories' widths within each scale

As noted in Figure 8.9 and Figure 8.10, the widths of sensation categories were irregular in both seasons. Accordingly, moving between categories required unequal temperature steps. Additionally, applying regression analysis, to compute the neutral temperature for instance, may not be totally accurate as the equation is negatively influenced by these irregularities. The middle categories were the widest, which indicates that wide ranges of temperature were considered (neutral) or (comfortable) for the explored students. In both seasons, (comfortably warm) category was noticeably narrow perhaps for climatic and cultural reasons as it is possible that the students found it difficult to combine comfort with a warm sensation. Regarding Nicol scale, roughly uniform temperature differences were required to move between preference categories due to their relatively equal widths. It is noteworthy that (a bit cooler) category during ASHRAE questionnaire of summer study had no defined width owing to votes' absence in (much cooler) category. Similarly, end categories of all scales had no defined widths.

8.2.1.2 Comparing categories' widths from different scales

The thermal continuum ranges covered by sensation categories were almost similar in summer and slightly different in winter as observed in Figure 8.9 and Figure 8.10 respectively. In both seasons, (neutral) category was shifted to the cool side of the continuum, whereas (comfortable) was almost centred on the continuum centre (i.e. zero point) regardless of their assumed equivalence. Although an identical Arabic phrase was used for both (cool) and (too cool), they had noticeably different widths in both seasons. This indicates that

translation is not the only factor that determines categories' widths. Considering Nicol scale, (neutral) and (comfortable) sensations were preferred for the investigated students as they contained the centre of (no change) category in both seasons.

8.2.2 Middle categories' shift from the thermal continuum centre

The distances between the thermal continuum centre (i.e. zero point) and the centres of (neutral) and (comfortable) categories were determined. Accordingly, the behaviour of Bedford scale in both seasons seems to be relatively better owing to the closeness between the median sensation (i.e. zero point) and the centre of (comfortable) category as demonstrated in Figure 8.9 and Figure 8.10. The reason is possibly related to the used phrase that emphasised the absence of (cool) and (warm) sensations. Besides, it seems that Bedford scale exhibited a better response to the season change. This is because the centre of its middle category moved from the warm side in summer to the cool side in winter. Additionally, the spread of air conditioning systems in Omani buildings (Al-Gharibi, 2016; Majid et al., 2014) may have an influence on the investigated students as (neutral) was shifted to the cool side of the continuum in both seasons. Supporting this influence is the shift of (no change) preference to the cool side of the continuum. It may worth mentioning that the literal translation of the phrase used for (neutral) means (moderate) or (mild).

8.2.3 Categories' symmetry

With respect to the middle category centre, the categories of ASHRAE scale seem to be more symmetrical compared with those of Bedford scale as observed in Figure 8.9 and Figure 8.10. The general asymmetry of the Bedford scale may be related to integrating (comfort) in its central categories; it is possible that the students found it difficult to feel comfortable while feeling warm as in (comfortably warm) category owing to their climatic background. It is noteworthy that the votes of (slightly warm) were almost double those of (comfortably warm) in each season. Additionally, the categories of Nicol scale were relatively symmetrical around its central category in both seasons indicating good behaviour.

8.2.4 Accuracy of categories' boundaries

To determine the accuracy of the categories' limits, it is crucial to ensure the independence of the involved data (Humphreys et al., 2016). Considering the research at hand, the analysed data were truly independent as each student provided one vote in each questionnaire. The computed standard errors of summer and winter studies are

presented in Table 8.7 and Table 8.8 respectively. The standard errors of Bedford scale categories were marginally smaller in summer, whereas those of ASHRAE scale were relatively smaller in winter. This is mainly related to the sample size and was reflected by the associated Nicol scales. Indeed, the influence of sample size on the accuracy is obvious comparing the standard errors of each scale in summer with those in winter. Likewise, the standard errors of the central categories in all scales were comparatively smaller mainly owing to the usual clustering of votes in the central categories (Humphreys et al., 2016).

It should be mentioned that the standard errors in both seasons were generally large. Consequently, the calculated widths of categories may be considered as approximate estimations. It is possible that these errors reflected the students' doubt in using the investigated scales, which may be reasonable considering that it was the first time of almost all of the students to answer a questionnaire.

8.2.5 Stability of sensation scales

The widths of sensation categories were different in the explored seasons as observed in Figure 8.9 and Figure 8.10. To investigate the stability of the scales' behaviour, the correlation between categories' widths in summer and winter are plotted in Figure 8.12. Ideally, the correlation coefficient should be unity. Nevertheless, this is highly unlikely owing to the seasonal thermal variations (Humphreys et al., 2016). In ASHRAE scale, the correlation coefficient was high (r = 0.995); yet, it was negligibly higher in Bedford scale (r = 0.996). Hence, it seems that both scales maintained their behaviour throughout the survey period.

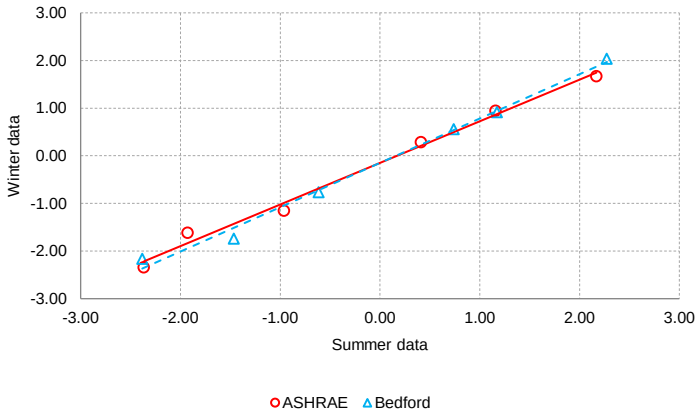


Figure 8.12: Comparing categories' widths of sensation scales

Besides, it is noted from Figure 8.12 that the plotted probits, that represent the categories upper limits, were on their assumed locations in both scales with few exceptions. In ASHRAE scale, both (cool) and

(slightly cool) were shifted towards the cool side of the continuum. The exceptions in Bedford scale were (comfortable) and (comfortably warm) as the former category was shifted to the warm side as a result of the narrow width of the latter.

8.2.6 Actual centres and basic statistics of translated thermal votes

As mentioned in Section 5.2.2.3, the successive categories method enables converting the ordinal sensation scales into interval ones. Based on the probits, the categories' centres were determined as presented in Table 8.9. It should be mentioned that the displayed centres are adjusted in order to maintain (0) as the centre of the middle categories. The computation of the centres is straightforward taking into account that the probit are the upper limits of the categories and it is possible to determine the centres of the end categories by two methods (Humphreys et al., 2016). The first method was applied in Table 8.9. Considering the centres' adjustment, it is performed by moving the computed centres so the centre of the middle category coincides with the thermal continuum centre (i.e. zero point) while maintaining the standard deviation of the scale. First, the probit of the middle category is equalised to zero by subtracting or adding its absolute value. This step is then applied to the probits of the other categories. Second, the ratio between the standard deviations of the original scale (i.e. from -3 to +3 in the case of sensation scale for instance) and that resulted from the first step is determined. Third, the resulted values from the first step are multiplied by the ratio from the second step. As observed in Table 8.9, the actual categories' centres were different from those assumed, which confirms the change in the behaviour of the translated scales.

Table 8.9: Categories' centres of ASHRAE, Bedford, and Nicol scales in summer and winter studies

	Summer				Winter			
	ASHRAE	Nicol	Bedford	Nicol	Bedford	Nicol	ASHRAE	Nicol
-3	-2.34		-2.91		-2.66		-2.53	
-2	-1.88	-	-2.15	-1.84	-2.12	-1.75	-1.81	-1.64
-1	-1.17	-0.79	-1.19	-1.05	-1.32	-1.04	-1.12	-0.97
0	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
+1	+1.06	+1.06	+0.97	+1.03	+0.96	+1.06	+1.23	+1.06
+2	+1.94	+2.13	+1.80	+1.89	+1.82	+1.93	+2.04	+2.00
+3	+2.71		+2.67		+2.78		+2.83	

Besides, Table 8.10 displays some basic statistics of the thermal votes in summer and winter studies. As noted, the thermal votes covered the whole ranges of scales' categories. Considering the new boundaries of the categories, it is noticed that the mean sensation votes fell within (neutral) or (comfortable) categories except the mean vote of ASHRAE scale in winter study that fell within (slightly warm) category. In all scales, the mode votes coincided with the centres of (neutral) or (comfortable) categories indicating votes' clustering in the middle

categories. Additionally, both the mean and mode of preference votes fell within the (a bit cooler) category except the mode of ASHRAE questionnaire in summer study that was (much cooler).

Table 8.10: Basic statistics of thermal sensation votes

	Summer				Winter			
	ASHRAE	**Nicol**	**Bedford**	**Nicol**	**Bedford**	**Nicol**	**ASHRAE**	**Nicol**
N	333	333	349	349	194	194	209	209
Mean	+0.26	+0.80	-0.06	+0.43	+0.12	+0.60	+0.47	+0.82
SD	1.00	0.89	1.09	0.84	1.15	0.84	1.14	-.84
Median	0.00	+1.06	0.00	0.00	0.00	+1.06	0.00	+1.06
Mode	0.00	+1.06	0.00	+1.03	0.00	+1.06	0.00	+1.06
Max.	+2.71	+2.13	+2.67	+1.89	+2.78	+1.93	+2.83	+2.00
Min.	-2.34	-0.79	-2.91	-1.84	-2.66	-1.75	-2.53	-1.64

8.3 Conclusion

Translating English sensation phrases does not always convey the impressions related to them, especially between international subjects. Therefore, the students' collective understanding of ASHRAE phrases was explored by means of two questionnaires. It was found that the students provided many translated phrases, ranging between 7 and 44 phrases, for each thermal sensation. This may reflect some features of the Arabic language. In addition, several common translations between sensations were noted, which may reflect possible overlapping in understating some sensations. Based on their translations, the students revealed acceptance to wide thermal conditions. The importance of careful translations that consider the participants' local context was concluded based on the variations between the students' translations and the international version.

Additionally, the results indicated that comfort was different than neutrality for the explored students as the former was slightly cooler than the latter. Examining the sensations' means based on the followed order revealed that the students who followed ASHRAE order understood the scale phrases better as the sensations' means were uniformly distributed along the thermal continuum. Estimating the sensations' means based on season indicated that the cool side means of summer were slightly hotter than their winter equivalences. However, the warm side means of the former season were relatively cooler than those of the latter. For most students, the three central categories represented thermal comfort with a slight response to the seasonal influence.

It is widely assumed that translating thermal scales maintain the characteristics of the original (English) scales. In order to investigate this assumption, the behaviour of Arabic translations of ASHRAE, Bedford, and Nicol scales were explored by applying the successive categories method. The findings revealed that:

- The categories had irregular widths and the middle sensation categories were the widest indicating wide ranges of (neutral) and (comfortable) temperatures for the investigated students.
- (Neutral) and (comfortable) categories covered different ranges on the thermal continuum despite their assumed equivalence with the former shifted to the cool side and the latter centred on the continuum centre.
- ASHRAE scale exhibited better symmetry around (neutral) category and Bedford scale exhibited a better seasonal response.
- The shift of (neutral) and (no change) categories to the cool side of the thermal continuum may indicate the influence of the air conditioning systems on the investigated students.
- Nicol scale categories had roughly equal widths and thus were relatively symmetrical around (no change) category.
- The findings confirm that categories' widths are not affected by translation only.
- The computed centres of the scales' categories were different from those widely assumed.
- The accuracy of the thermal comfort measurements applying regression analysis (like neutral temperature) is likely to be affected negatively.

Moreover, it was found that the deviations in the scales' behaviour were stable during the whole survey period. Accordingly, selecting one set of data for further analysis was not possible. It should be mentioned that the calculated categories' widths should be considered as approximate estimations considering the relatively large standard errors of the categories' boundaries.

It is recommended to conduct further explorations maintaining the implemented phrases of this study. This is because using other phrases may lead to other findings, which would be even interesting considering the lack of research regarding thermal scales' behaviour, especially in Arabic. Finally, in spite of the limited application of the successive categories method in thermal comfort studies, it is useful in revealing the behaviour of thermal scales without the need to apply the free positioning task which is usually used to study the scales' behaviour. This has the advantage of reducing the questionnaires' size, which is usually reflected in an increased participation rate and, expectedly, increasing results' accuracy.

Chapter (9):

Survey Results Integration

Chapter 9 Survey results integration

In the previous chapter, the successive categories method was applied with the aim of converting the subjective scales from categorical to continuous. This conversion is essential for the correct application of the linear regression model in this chapter. The model assumes that both independent and dependent variables are continuous and it is widely used to investigate the association between the subjective votes and the physical variables (Djamila, 2017; Humphreys et al., 2016; Thapa et al., 2016). Based on this association, it is possible to compute the neutral temperature, thermal sensitivity, and temperature steps.

This chapter explores the interaction between the students and the thermal environments of their classrooms by integrating the findings of the subjective questionnaires and those of the physical measurements. Through this exploration, the chapter attempts to answer the research questions regarding the neutral temperature, thermal sensitivity, and acceptability limits of the students. It starts by calculating the operative temperature although reporting the findings in globe or air temperature is acceptable (Nicol et al., 2012). Yet, the operative temperature was calculated to facilitate the results' comparison with previous studies. Besides, Pearson's correlation coefficients were calculated to determine the strength of the relationships between indoor temperatures, humidity, and air velocity with the corresponding subjective sensations and preferences as well as the relationships between the subjective votes. The neutral temperature, thermal sensitivity, and temperature steps were calculated utilising linear regression model and Griffiths' method. The latter was applied to avoid the unreliability in the former. The details are discussed in the following sections.

9.1 Calculating indoor operative temperatures

Indoor operative temperature determines the influence of both air temperature and mean radiant temperature on thermal comfort. It is 'the uniform temperature of an imaginary black enclosure in which an occupant would exchange the same amount of heat by radiation plus convection as in the actual non-uniform environment' (ASHRAE, 2010, p. 4). The operative temperature captures the impact of more than one factor that affects thermal comfort in a single figure, which justifies the reliance of the international standards on it to report the recommended comfort limits. As mentioned in Section 2.4.1.2, its accuracy depends on the accuracy of mean radiant temperature that, in turn, depends on the accuracy of the used instrument and the calculation method (d'Ambrosio Alfano et al., 2013a). The indoor operative temperature is calculated as (Nicol et al., 2012):

$$T_{op} = [h_c/(h_c + h_r)]\ T_a + [1 - [h_c/(h_c + h_r)]]\ T_r \quad (9.1)$$

Where:

T_{op} is operative temperature, [°C]
T_a is air temperature, [°C]
T_r is mean radiant temperature, [°C]
h_c is convective transfer coefficient, [W/m^{2}K]
h_r is linear radiation transfer coefficient, [W/m^{2}K]

To avoid the different estimations of convection and radiation transfer coefficients, the ratio between these coefficients is determined using air velocity as $(10v)^{0.5}$ (ASHRAE, 2017; Nicol et al., 2012). Thus, the operative temperature is computed as (CIBSE, 2015; Nicol et al., 2012):

$$T_{op} = [T_r + T_a\ (10v)^{0.5}] / [1 + (10v)^{0.5}] \quad (9.2)$$

In this research, the mean radiant temperature was measured by the direct method that depends on using a black globe temperature. Besides, the derivation of Equation (9.2) is detailed in Appendix 9.1.

9.1.1 Central tendency and variability statistics

The central tendency and variability statistics of the mean radiant and operative temperatures are displayed in Table 9.1. The arithmetic means of both temperatures in each questionnaire were relatively similar with similar standard deviations. This was the case with the median and mode values. The distribution of both temperatures around their means is symmetrical based on the similarity in their mean and median values. As expected in air-conditioned buildings, the seasonal variations were marginal (Nicol et al., 2012). Considering Bedford questionnaire in summer, the distributions of indoor mean radiant and operative temperatures around their means were wider, which was similar to the distribution of indoor air temperature. Additionally, the temperatures' ranges were generally wide mainly because of the failure in air conditioning units of (ZA-G2) classroom.

Table 9.1: Basic statistics of indoor mean radiant and operative temperatures

	Summer-ASHRAE		Summer-Bedford		Winter-Bedford		Winter-ASHRAE	
	T_r, [°C]	T_{op}, [°C]	T_r, [°C]	T_{op}, [°C]	T_r, [°C]	T_{op}, [°C]	T_r, [°C]	T_{op}, [°C]
N	951	951	998	998	580	580	572	572
Mean	25.7	25.7	26.3	26.2	24.1	24.0	24.8	24.7
SD	1.5	1.6	2.2	2.3	1.5	1.5	1.3	1.4
Median	25.9	25.9	26.0	25.9	24.0	24.0	24.5	24.5
Mode	25.9	25.9	26.2	26.2	23.6	23.6	24.3	24.3
Max.	29.4	29.4	33.4	33.3	26.7	26.7	28.2	28.2
Min.	20.8	20.3	21.7	21.2	19.0	18.3	20.3	19.7
Range	8.6	9.1	11.7	12.1	7.7	8.4	7.9	8.5

The same statistics were calculated for each classroom excluding those with different thermal conditions as displayed in Table 9.2. The

three central statistics were generally similar in all classrooms with marginal variations. Examples of these variations include (NK-G2) and (DA-G1) classrooms in ASHRAE questionnaire of summer study and Bedford questionnaire of winter study respectively. In specific, the mode of the operative temperature was lower than the mean and median by almost 2 °C in the former classroom and was higher by around 2 °C in the latter. The similarity in the mean and median temperatures indicates the normal distribution of the operative temperature. As expected in air-conditioned classrooms, the ranges of the operative temperature were similar in the classrooms during all questionnaires and they generally extended between 2 °C and 7 °C approximately.

The recommended design criteria for thermal comfort are similar in international standards such as EN 15251, ISO 7730, and ASHRAE 55 (Parsons, 2014). Considering a normal expectation level in classrooms, the minimum operative temperature in winter is 20 °C roughly and the maximum in summer is 26 °C approximately (BS EN 15251, 2008) with optimum temperatures of around 22 °C and 24.5 °C in winter and summer respectively (BS EN ISO 7730, 2005). For these criteria, the relative humidity is assumed around 50% with low air velocity. The activity level is considered as almost 1.2 met and the clothing level is assumed as around 1 clo in winter and 0.5 clo in summer. Considering the investigated classrooms, the indoor operative temperatures fell in, or marginally above, the recommended ranges. Yet, the school uniform has a higher insulation level, which may create thermal discomfort, especially in summer. Besides, the limitations in sensors' accuracy had a negative impact on the calculated operative temperatures.

Considering Table 6.6, the arithmetic means of air temperatures of the explored classrooms were similar to the arithmetic means of the operative temperatures. Indeed, the two means were identical in 30% of classrooms considering all questionnaires. The maximum difference was 0.8 °C approximately and occurred once in (DA-G2) classroom in ASHRAE questionnaire of summer study. Investigating the relation between air and mean radiant temperatures indicated similar findings. Therefore, it is possible to conclude the absence of radiation sources in the explored classrooms (Manu et al., 2016; CIBSE, 2015).

Table 9.2: Basic statistics of indoor operative temperature of each classroom

		SQ-G1	SQ-G2	SQ-F1	ZA-G1	ZA-G2	ZA-F1	WK-F1	WK-F2	WK-S1	DA-G1	DA-G2	DA-F1	NK-G1	NK-G2	NK-F1
Summer - ASHRAE	N	69	66	65	62	-	66	44	57	57	73	71	70	67	70	69
	Mean	25.1	24.0	26.2	26.8	-	26.2	26.1	25.1	25.3	24.5	24.0	26.2	26.5	26.8	25.3
	SD	1.8	0.9	1.1	1.3	-	0.8	0.7	0.9	0.8	1.4	1.1	0.6	0.6	1.1	1.3
	Median	25.7	24.0	26.2	26.4	-	26.2	26.1	25.5	25.8	24.0	23.9	26.2	26.3	27.2	25.4
	Mode	26.1	24.2	27.3	26.5	-	25.9	26.1	25.9	26.1	22.9	24.7	26.4	27.1	25.4	25.9
	Max.	27.5	27.6	28.0	29.4	-	27.7	27.3	26.4	26.3	27.8	26.6	27.7	27.5	28.7	28.2
	Min.	20.3	21.7	23.9	25.0	-	24.1	24.4	23.2	23.0	22.8	21.9	24.9	24.8	24.0	22.4
Summer - Bedford	N	70	70	71	63	-	71	65	65	44	73	73	73	65	70	68
	Mean	24.2	24.8	25.5	27.3	-	26.9	26.3	25.6	25.0	24.5	24.4	26.8	26.9	25.8	26.2
	SD	1.4	0.9	1.0	0.8	-	1.0	0.6	1.2	0.5	1.1	1.2	0.8	1.2	1.4	1.3
	Median	24.3	24.6	25.4	27.2	-	26.8	26.1	25.4	25.1	24.6	24.0	26.8	26.9	25.6	26.1
	Mode	25.3	23.8	25.2	26.5	-	26.8	26.0	24.7	24.9	25.4	23.1	27.6	27.3	24.0	26.2
	Max.	26.9	26.6	29.1	29.0	-	28.8	28.1	28.0	25.9	26.7	26.8	28.6	30.4	28.8	29.1
	Min.	21.2	23.4	23.7	25.8	-	24.7	25.3	24.0	24.1	21.2	22.2	24.8	24.7	23.4	23.9
Winter - Bedford	N	-	-	-	63	56	64	-	-	-	66	-	68	65	64	65
	Mean	-	-	-	24.2	23.6	24.4	-	-	-	24.3	-	22.9	25.2	25.1	24.3
	SD	-	-	-	1.2	1.1	1.2	-	-	-	1.5	-	1.8	1.2	0.4	1.1
	Median	-	-	-	23.8	23.5	24.4	-	-	-	24.3	-	23.5	25.7	25.0	23.9
	Mode	-	-	-	23.1	24.2	24.1	-	-	-	25.8	-	24.2	22.6	24.9	23.8
	Max.	-	-	-	26.7	26.4	26.5	-	-	-	26.2	-	25.3	26.7	26.0	26.3
	Min.	-	-	-	22.5	21.8	21.1	-	-	-	19.9	-	18.3	22.5	24.3	22.8
Winter - ASHRAE	N	-	-	-	67	69	71	-	-	-	62	59	57	60	64	63
	Mean	-	-	-	24.9	25.6	24.5	-	-	-	24.3	24.1	23.6	24.7	25.7	24.7
	SD	-	-	-	0.9	1.5	1.6	-	-	-	1.1	1.0	1.7	0.7	1.2	0.8
	Median	-	-	-	24.6	25.5	24.1	-	-	-	24.2	24.1	23.9	24.5	25.6	24.5
	Mode	-	-	-	24.3	24.5	24.1	-	-	-	22.8	25.3	23.6	24.3	23.8	24.3
	Max.	-	-	-	27.3	28.2	27.8	-	-	-	26.4	27.3	26.5	26.3	27.5	26.8
	Min.	-	-	-	23.0	22.6	21.1	-	-	-	22.3	22.5	19.7	23.8	23.7	23.2

9.1.2 Exploring indoor operative temperature relations

The variations between indoor operative and air temperatures in most indoor environments are minor (Djamila, 2017; Nicol et al., 2012) due to the absence of radiation sources. Assuming a linear relationship, Pearson's correlation coefficient was calculated to explore the relation between the two temperatures as well as between the former and the globe temperature. It may worth mentioning that globe temperature is widely accepted as a substitution of indoor operative temperature, especially when low accuracy sensors are used (Nicol et al., 2012). Besides, the influence of air velocity on operative temperature is indirect as altering the former affects the absolute combined value of heat transfer coefficients and their ratio (CIBSE, 2015).

A strong positive correlation was revealed between the operative and air temperatures as plotted in Figure 9.1. In ASHRAE and Bedford questionnaires during summer study, the correlation coefficients were around 0.972 and 0.983 respectively. The corresponding coefficients in winter were almost 0.988 and 0.989. Accordingly, the air temperature change explains around 95% and 97% of the variations in the operative temperature in ASHRAE and Bedford questionnaires of summer study respectively. Likewise, around 98% of winter questionnaires' variations were due to the air temperature changes. It is noteworthy that a similar high correlation coefficient, around 0.952, was reported in free-running buildings in the UK (Nicol & McCartney, 2001 in Nicol, et al., 2012).

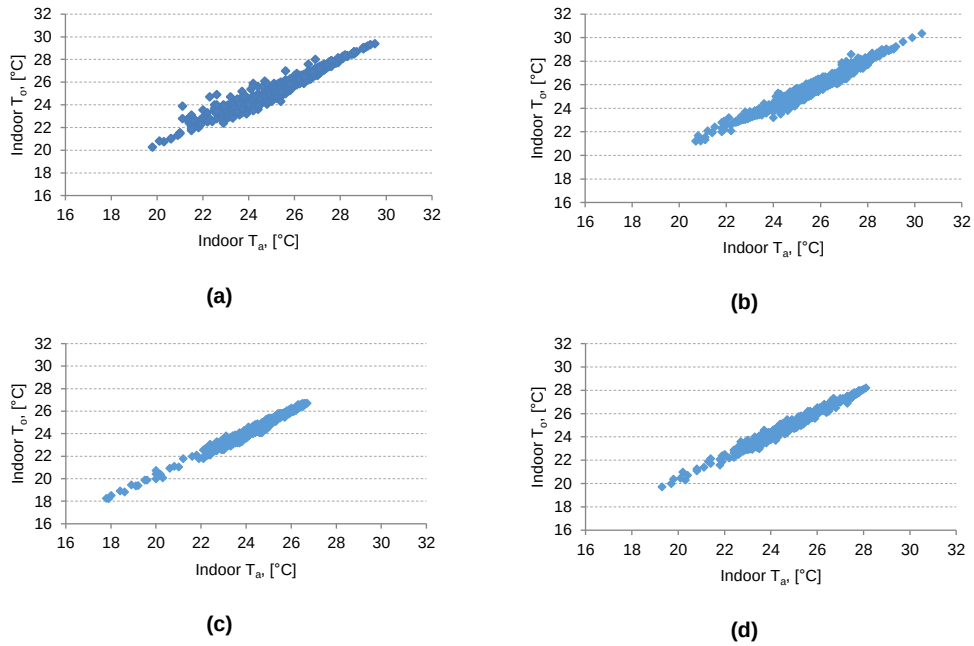


Figure 9.1: Indoor operative temperature against indoor air temperature: (a) summer-ASHRAE, (b) summer-Bedford, (c) winter-Bedford, and (d) winter-ASHRAE

Similarly, the association between the operative temperature and the globe temperature was positively strong as demonstrated in Figure 9.2. The correlation coefficients were 0.998 and 0.999 approximately in summer and winter questionnaires respectively. Therefore, the absence of direct radiation from the sun in the classrooms is concluded (Nicol et al., 2012).

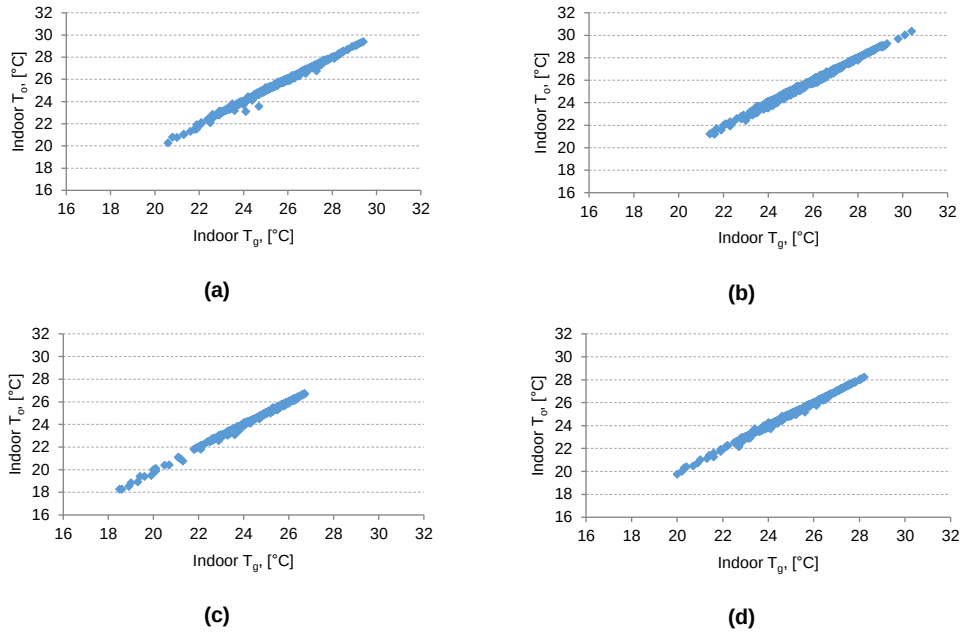


Figure 9.2: Indoor operative temperature against indoor globe temperature: (a) summer-ASHRAE, (b) summer-Bedford, (c) winter-Bedford, and (d) winter-ASHRAE

9.2 Correlations between physical variables and subjective votes

The association between the students' subjective responses and the corresponding physical variables are explored in this section. The subjective responses include the sensation and preference votes of the thermal conditions besides the humidity and air velocity levels. The physical variables include the classrooms' instantaneous data at the questionnaire distribution time, means, maximum and minimum data as well as the departure of the instantaneous data from the mean. The means, maximum, and minimum values were computed based on all measurements recorded in the questionnaire day and were considered as general representatives of the classrooms' conditions. In addition, the relations with the mean, maximum, and minimum values before distributing the questionnaires besides their departure from the instantaneous data were explored. These relations were investigated to reveal their potential effect on the subjective responses as a previous study indicated that the correlation between thermal discomfort and the departure from mean air temperature was relatively stronger than that with the mean air temperature itself (Humphreys, 1977). The variations

between these values and the overall values in the explored classrooms were marginal.

Assuming linear association, the investigated relationships were determined through computing Pearson's correlation coefficients. The analysis was limited to the classrooms with similar thermal conditions to avoid the negative influence of the different thermal environments of the excluded classrooms on the correlation coefficients (Nicol et al., 2012). As explained in Chapter 8, the successive categories method changed the subjective scales into continuous.

9.2.1 Thermal sensation and preference votes

Table 9.3 displays the correlation coefficients between indoor air temperature and thermal sensation and preference votes. In general, the associations were weak except few correlations during ASHRAE questionnaire of summer study. For instance, the relations between sensation votes and the difference between the instantaneous data and both the overall maximum data and maximum data before distributing the questionnaires were positively moderate with coefficients of around 0.326 and 0.318 respectively. Besides, the relation between sensation votes and the air temperature at the questionnaire distribution time was almost moderate with a positive correlation coefficient of 0.278 roughly. Similarly, the preference votes in the same questionnaire were almost moderately associated to the differences between the air temperature at the questionnaire distribution time and both the overall maximum and the maximum before questionnaires' distribution as the coefficients were almost 0.281 and 0.283 respectively.

Table 9.3: Pearson's correlation coefficients of individual thermal votes and indoor air temperature

	Summer-ASHRAE		**Summer-Bedford**		**Winter-Bedford**		**Winter-ASHRAE**	
	TSV, N = 333	**TPV,** N = 333	**TSV,** N = 349	**TPV,** N = 349	**TSV,** N = 194	**TPV,** N = 194	**TSV,** N = 209	**TPV,** N = 209
Instantaneous	**0.278**	0.173	0.201	0.111	0.205	0.155	0.178	0.046
Overall mean	0.084	- 0.015	0.077	0.067	- 0.026	- 0.019	0.089	- 0.004
Overall mean - instantaneous	0.236	0.225	0.219	0.093	0.220	0.167	0.204	0.070
Overall max.	- 0.068	- 0.139	- 0.013	- 0.017	0.124	0.180	0.134	0.071
Overall max. - instantaneous	**0.326**	**0.281**	0.219	0.130	0.181	0.121	0.155	0.020
Overall min.	0.028	- 0.006	0.030	0.070	0.068	0.040	0.055	- 0.028
Overall min. - instantaneous	0.180	0.136	0.210	0.047	0.132	0.112	0.147	0.074
Mean before	0.143	0.007	0.073	0.065	- 0.094	- 0.079	0.025	- 0.009
Mean before - instantaneous	0.172	0.213	0.209	0.087	0.227	0.175	0.195	0.059
Max. before	- 0.073	- 0.152	- 0.024	- 0.035	0.031	0.126	0.009	- 0.018
Max. before - instantaneous	**0.318**	**0.283**	0.236	0.148	0.196	0.129	0.191	0.059
Min. before	0.140	0.035	0.020	0.064	0.003	- 0.018	- 0.002	- 0.009
Min. before - instantaneous	0.086	0.116	0.199	0.040	0.152	0.129	0.177	0.052

The correlation coefficients between thermal votes and the indoor globe, indoor operative, and outdoor air temperatures are presented in Appendix 9.2. Considering globe temperature, the correlations were marginally lower compared with those of indoor air temperature. Indeed, this was expected considering the strong association between both temperatures as revealed in Section 6.6.3. The strongest relation was between sensation votes and the difference between the instantaneous temperature and the overall maximum in ASHRAE questionnaire during summer study. In specific, the coefficient was around -0.301 indicating a moderate relation with a negative direction. Moreover, the correlation coefficients with the indoor operative temperature fitted between those of indoor air and globe temperatures, which reflects the correlations of these temperatures as explored in Section 9.1.2. Besides, the relations of the outdoor air temperature were generally weak. However, it should be mentioned that almost moderate correlation was revealed between both thermal sensation and preference votes and the overall mean during Bedford questionnaire in winter. The respective coefficients were almost 0.298 and 0.262. This relation may be due to the comparatively cooler conditions in this questionnaire, which was consistent with a relatively high percentage of opening windows as indicated in Table 7.9.

It is worth mentioning that the calculated correlation coefficients were generally close to those reported in previous studies that were performed in a similar context. For instance, a recent thermal survey in Qatari air-conditioned offices revealed a correlation between thermal sensation votes and indoor globe temperature of 0.202 approximately (Indraganti & Boussaa, 2018). Another study that investigated Kuwaiti air-conditioned offices estimated the correlation coefficient of thermal sensation votes and globe temperature at 0.293 (AlNajjar et al., 2018). In another study carried out in a high school in the UK, coefficients of 0.37 and 0.32 approximately related thermal sensations with the air and globe temperatures respectively (Auliciems, 1969). The strength levels of the relationships calculated in this research may reflect the subjective nature of thermal sensations and preferences besides the influence of other factors in determining thermal votes. It should be mentioned that Pearson's correlation coefficient is negatively affected by the unequal widths of scales' steps (Nicol et al., 2012). As revealed in Chapter 8, the widths of sensation and preference categories were irregular.

Moreover, the relations between the arithmetic means of sensation and preference votes of each classroom and the indoor air temperature were determined and the coefficients are displayed in Table 9.4. It may be more practical to investigate the associations with the mean votes considering the subjective nature of thermal responses. Indeed, it is

thought that predicting mean sensations, and, therefore, exploring their correlations, may involve more certainty compared with the individual sensations (Auliciems, 1969).

As observed in Table 9.4, the sensations' correlations were mainly moderate such as those with the instantaneous air temperatures and their departures from the overall mean and maximum temperatures. Considering the annual relations, the corresponding coefficients were 0.424, 0.493, and 0.498 approximately. This implies that around 18%, 24%, and 25% of the variations in the sensation votes were because of the variations in air temperature and its departure from both the overall mean and maximum temperatures respectively. It is noteworthy that the air temperatures at the questionnaires' distribution time were related to the thermal sensations by coefficients of 0.5 approximately, which is in agreement with several thermal comfort studies (Humphreys, 1977). Besides, the relations with the overall mean of air temperature were weak with a coefficient of almost 0.071. This is in agreement with a previous study where the relations of thermal sensation votes with air temperature deviation from the mean was relatively stronger compared with the association with the mean itself. The latter's coefficient was estimated at 0.18 (Humphreys, 1977).

Table 9.4: Pearson's correlation coefficients of mean thermal votes and indoor air temperature

	Annual		**Summer**		**Winter**	
	TSV, N = 45	**TPV,** N = 45	**TSV,** N = 28	**TPV,** N = 28	**TSV,** N = 17	**TPV,** N = 17
Instantaneous	**0.424**	0.286	**0.574**	**0.406**	**0.476**	**0.289**
Overall mean	0.071	0.002	0.209	0.073	0.162	0.048
Overall mean – instantaneous	**0.493**	**0.378**	**0.538**	**0.465**	**0.477**	**0.313**
Overall max.	- 0.041	- 0.107	- 0.095	- 0.224	**0.437**	**0.421**
Overall max. – instantaneous	**0.498**	**0.399**	**0.644**	**0.585**	**0.338**	0.141
Overall min.	0.024	0.018	0.041	0.055	0.213	0.100
Overall min. – instantaneous	**0.391**	**0.264**	**0.475**	**0.309**	**0.261**	0.185
Mean before	0.072	0.004	**0.285**	0.111	- 0.003	- 0.045
Mean before – instantaneous	**0.457**	**0.352**	**0.444**	**0.423**	**0.496**	**0.319**
Max. before	- 0.101	- 0.163	- 0.087	**- 0.254**	0.189	0.229
Max. before – instantaneous	**0.529**	**0.428**	**0.649**	**0.611**	**0.409**	0.205
Min. before	0.060	0.052	0.191	0.141	0.070	0.036
Min. before - instantaneous	**0.338**	0.218	**0.347**	0.238	**0.335**	0.208

Moreover, the correlations with the sensation votes were relatively stronger than those with the preference votes, which may indicate the influence of other factors, besides air temperature, in determining the students' preferences. Such factors are mainly related to the climatic and cultural background and may involve other environmental factors. In addition, comparing the relations in the two seasons reveals that the students' votes in summer had a relatively stronger correlation with the indoor air temperature. However, the influence of the sample size on the correlation coefficient should not be ignored considering the small sample sizes. Besides, the relations between the mean thermal votes and the indoor globe, indoor operative, and outdoor air temperatures were explored in Appendix 9.2. Generally, the relations ranged between

weak and moderate and they had lower coefficients compared with those of indoor air temperature.

9.2.2 Humidity sensation and preference votes

The relationships between relative humidity and its subjective responses were explored and the correlation coefficients are displayed in Table 9.5. As noted, sensation and preference votes were weakly related to relative humidity at questionnaires' distribution time. Indeed, all the investigated relations were weak, which is consistent with the findings of (Uğursal & Culp, 2013a). This may reflect the students' doubt regarding the humidity scales as indicated by their questions in the survey. It is, additionally, possible that other factors affect students' responses. As mentioned earlier, Pearson's correlation assumes linear associations, which may not be the case between humidity and its subjective votes. Moreover, the absence of direct humidity sensors in the human body may justify these weak associations (Parsons, 2014). Considering the effect of air temperature in indoor conditions (Szokolay, 2014; Montazami & Nicol, 2013), its relations with the subjective votes of humidity were explored as presented in Appendix 9.2. The relations were relatively stronger than those with relative humidity.

Table 9.5: Pearson's correlation coefficients of individual humidity votes and indoor relative humidity

	Summer-ASHRAE		Summer-Bedford		Winter-Bedford		Winter-ASHRAE	
	HSV, N = 333	HPV, N = 333	HSV, N = 349	HPV, N = 349	HSV, N = 194	HPV, N = 194	HSV, N = 209	HPV, N = 209
Instantaneous	0.090	- 0.149	0.017	0.085	0.152	0.039	0.018	- 0.039
Overall mean	- 0.057	- 0.104	- 0.052	0.136	0.051	0.047	0.058	- 0.031
Overall mean – instantaneous	0.160	- 0.146	0.070	0.013	0.115	- 0.002	- 0.050	- 0.046
Overall max.	0.034	- 0.143	- 0.065	0.145	0.097	0.052	0.029	- 0.018
Overall max. – instantaneous	0.120	- 0.099	0.100	- 0.050	0.097	- 0.003	- 0.014	- 0.086
Overall min.	- 0.068	- 0.068	- 0.079	0.151	0.056	0.054	0.080	- 0.010
Overall min. – instantaneous	0.148	- 0.157	0.058	0.030	0.121	0.004	- 0.035	- 0.056
Mean before	- 0.060	- 0.114	- 0.042	0.130	0.062	0.041	0.080	- 0.031
Mean before – instantaneous	0.151	- 0.132	0.064	0.007	0.097	0.002	- 0.078	- 0.040
Max. before	- 0.004	- 0.159	- 0.062	0.135	0.137	0.015	0.057	- 0.028
Max. before – instantaneous	0.138	- 0.097	0.095	- 0.042	0.033	0.029	- 0.106	- 0.052
Min. before	- 0.049	- 0.068	- 0.055	0.138	0.056	0.037	0.087	0.001
Min. before - instantaneous	0.141	- 0.157	0.050	0.028	0.123	0.018	- 0.036	- 0.061

Table 9.6 displays Pearson's correlation coefficients between the arithmetic means of the subjective votes in each classroom with relative humidity. A few of the relations, particularly in summer, were almost moderate, whereas most of them were generally weak. Compared with Table 9.5, the relative improvement in the correlations coefficients may be because of the change in samples' sizes. Moreover, comparing the

correlation coefficients in Table 9.5 with those in Table 9.3 or the coefficients in Table 9.6 with those in Table 9.4 indicates that the students were more sensitive to the changes in indoor air temperature. Such higher sensitivity of female subjects towards the changes in air temperature compared with the changes in humidity levels was reported in previous studies like (Wang et al., 2018; Chow et al., 2010; Lan et al., 2008; Wang, 2006b; Jones et al., 1986).

Table 9.6: Pearson's correlation coefficients of mean humidity votes and indoor relative humidity

	Annual		Summer		Winter	
	HSV, N = 45	**HPV,** N = 45	**HSV,** N = 28	**HPV,** N = 28	**HSV,** N = 17	**HPV,** N = 17
Instantaneous	0.117	- 0.085	0.088	- 0.117	0.110	- 0.023
Overall mean	- 0.041	0.082	- 0.194	0.100	0.078	0.062
Overall mean – instantaneous	0.240	- 0.227	**0.282**	**- 0.252**	0.115	- 0.145
Overall max.	0.037	0.063	- 0.115	0.057	0.066	0.085
Overall max. – instantaneous	0.136	- 0.228	**0.281**	**- 0.254**	0.164	**- 0.247**
Overall min.	- 0.129	0.142	**- 0.278**	0.137	0.052	0.176
Overall min. – instantaneous	**0.245**	- 0.209	**0.251**	- 0.216	0.125	- 0.213
Mean before	- 0.012	0.069	- 0.175	0.075	0.128	0.064
Mean before – instantaneous	0.199	- 0.208	**0.267**	- 0.229	0.027	- 0.141
Max. before	0.053	0.050	- 0.140	0.060	0.164	0.032
Max. before – instantaneous	0.102	- 0.198	**0.282**	- 0.235	- 0.101	- 0.140
Min. before	- 0.106	0.135	- 0.224	0.113	0.065	0.191
Min. before - instantaneous	0.229	- 0.205	0.238	- 0.212	0.109	- 0.209

9.2.3 Air velocity sensation and preference votes

Pearson's correlation coefficients between air velocity and its sensation and preference votes are presented in Table 9.7. In general, the relations were weak with no clear direction for the former votes and negative association for the latter. Considering the correlations with air velocity at the questionnaires' distribution time, the weak correlations were negative except in ASHRAE questionnaire in summer. In spite of their weakness, the relations with the preference votes were relatively stronger compared with those of sensations. Further, it was not possible to calculate some coefficients, specifically those related to the minimum air velocities, because the physical variables were equal to 0.

Table 9.7: Pearson's correlation coefficients of individual air velocity votes and indoor air velocity

	Summer-ASHRAE		Summer-Bedford		Winter-Bedford		Winter-ASHRAE	
	AVSV, N = 333	**AVPV,** N = 333	**AVSV,** N = 349	**AVPV,** N = 349	**AVSV,** N = 194	**AVPV,** N = 194	**AVSV,** N = 212	**AVPV,** N = 212
Instantaneous	0.180	0.025	- 0.243	- 0.151	- 0.028	- 0.139	- 0.124	- 0.132
Overall mean	0.059	- 0.088	- 0.186	- 0.114	0.128	- 0.029	- 0.167	- 0.132
Overall mean – instantaneous	0.200	0.078	- 0.212	- 0.133	- 0.107	- 0.180	- 0.099	- 0.124
Overall max.	0.077	- 0.102	- 0.206	- 0.117	- 0.023	- 0.196	- 0.118	- 0.083
Overall max. – instantaneous	0.114	0.167	0.042	0.012	0.004	0.134	0.063	0.151
Overall min.	-	-	0.059	0.112	-	-	-	-
Overall min. – instantaneous	0.180	0.025	**- 0.246**	- 0.160	- 0.028	- 0.139	0.124	0.132
Mean before	- 0.001	- 0.135	- 0.178*	- 0.109*	0.050	- 0.084	- 0.167	- 0.132
Mean before – instantaneous	0.220	0.100	- 0.236*	- 0.143*	- 0.061	- 0.159	0.099	0.124
Max. before	0.055	- 0.076	- 0.136*	- 0.042*	- 0.160	**- 0.308**	- 0.118	- 0.083
Max. before –	0.127	0.111	- 0.080*	- 0.092*	0.197	0.281	0.063	0.151

instantaneous								
Min. before	- 0.034	- 0.066	-	-	-	-	-	-
Min. before - instantaneous	0.168	0.049	**- 0.249***	- 0.152*	- 0.028	- 0.139	0.124	0.132

***** N = 325

Moreover, the correlation coefficients between air velocity and the arithmetic means of sensation and preference of each classroom are displayed in Table 9.8. As noted, the correlations ranged between weak to moderate with no obvious pattern, which may be justified by the random fluctuation in the explored sample. In addition, the correlation coefficients between indoor air temperature and the arithmetic means of air velocity votes are tabulated in Appendix 9.2. The relationships were generally weak with a positive direction, especially with the indoor air temperature at the questionnaires' distribution time. This generally low sensitivity of females towards the changes in air velocity compared with their sensitivity to the changes in air temperature was reported in a previous study (Chow et al., 2010).

Table 9.8: Pearson's correlation coefficients of mean air velocity votes and indoor air velocity

	Annual		Summer		Winter	
	AVSV, N = 45	**AVPV,** N = 45	**AVSV,** N = 28	**AVPV,** N = 28	**AVSV,** N = 17	**AVPV,** N = 17
Instantaneous	0.126	- 0.210	**0.378**	- 0.109	**- 0.262**	**- 0.337**
Overall mean	0.003	**- 0.306**	0.119	**- 0.357**	- 0.106	- 0.242
Overall mean – instantaneous	0.165	- 0.102	**0.440**	0.093	**- 0.302**	**- 0.342**
Overall max.	- 0.011	**- 0.329**	0.136	**- 0.318**	- 0.217	**- 0.362**
Overall max. – instantaneous	0.214	0.162	0.180	**0.302**	0.035	0.061
Overall min.	- 0.236	- 0.229	**- 0.278**	**- 0.312**	-	-
Overall min. – instantaneous	0.224	0.005	**0.396**	- 0.086	0.143	0.105
Mean before	- 0.067	**- 0.380**	0.058	**- 0.444**	- 0.232	**- 0.314**
Mean before – instantaneous	0.293	0.080	**0.461**	0.088	0.082	0.072
Max. before	- 0.146	**- 0.398**	0.038	**- 0.325**	**- 0.429**	**- 0.528**
Max. before – instantaneous	**0.324**	0.180	**0.302**	0.244	0.218	0.201
Min. before	- 0.104	- 0.103	- 0.109	- 0.147	-	-
Min. before - instantaneous	0.235	0.018	**0.383**	- 0.065	0.143	0.105

9.3 Correlations between subjective votes

With the objective of exploring the influence of thermal sensations in determining the students' thermal preferences, their association was investigated by calculating Pearson's correlation coefficient assuming a linear relationship. A positive moderate association was revealed with a correlation coefficient of almost 0.594. Accordingly, around 35% of the preference votes' variations are explained by the changes in sensation votes. A stronger correlation of 0.71 roughly was reported in a thermal study performed in office buildings located in a similar cultural and climatic context (Indraganti & Boussaa, 2018). In addition, the prediction equation of the students' thermal preferences is:

$$TPV = 0.4710\ TSV + 0.5786,\ (p < 0.05) \qquad (9.3)$$

Based on this equation, (no change) preference corresponds to (slightly cool) or (comfortably cool) sensation. As a regression model,

the equation requires equal intervals in both sensation and preference scales. Yet, the scales' categories have irregular widths as explored in Section 8.2.1, which resulted in a negative influence on the equation gradient. It should be mentioned that the equation assumes a linear relation between thermal preferences and sensations, which may not be correct.

Besides, the effect of thermal sensation on determining humidity and air velocity sensation and preference votes were investigated as summarised in Table 9.9. As expected, the correlations with humidity scales were weak, which may be justified by the general weak influence of humidity on comfort, especially in moderate environments (CIBSE, 2015; Mishra & Ramgopal, 2015; Szokolay, 2014; Nicol et al., 2012; Konya & Vandenberg, 2011; Brown, 2010).

Table 9.9: Pearson's correlation coefficients between the subjective votes

	HSV	HPV	AVSV	AVPV
TSV	0.192	0.067	0.439	0.401

Oppositely, the relations with the sensation and preference votes of air velocity were moderate with correlation coefficients of around 0.439 and 0.401 respectively. It follows that almost 19% and 16% of the changes in air velocity sensation and preference votes respectively are explained by the changes in thermal sensation votes. This is consistent with the adaptive approach of thermal comfort that assumes a relation between indoor air temperature and velocity. In specific, the adaptive approach assumes a positive correlation between temperature and the square root of air velocity (Nicol et al., 2012). It is possible to predict both air velocity sensations and preferences assuming a linear relation as follows:

$$AVSV = 0.4874\ TSV + 0.7105,\ (p < 0.05) \quad (9.4)$$

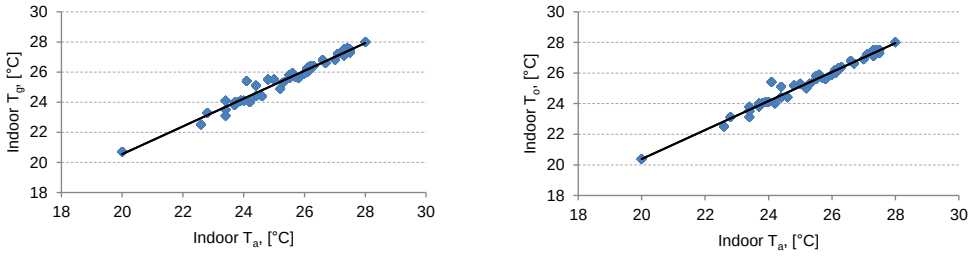
$$AVPV = 0.2992\ TSV + 0.5578,\ (p < 0.05) \quad (9.5)$$

9.4 Calculating neutral temperature by a simple linear regression

Neutral temperature is the temperature at which neutrality is the mean thermal sensation. It is usually calculated from a simple linear regression between sensation votes and temperature. Depending on the latter, neutral temperature is expressed as air, globe, or operative temperature (Djamila, 2017; Humphreys et al., 2016; Thapa et al., 2016; Nicol et al., 2012; Yao et al., 2010; Hwang et al., 2009; Karyono, 2008). The linear regression model requires that independent and dependent variables are continuous. However, several thermal comfort researchers apply the model using categorical data of thermal sensations such as (Thapa et al., 2016; Karyono, 2008; Nam et al., 2015; Teli et al., 2013). This has a relatively small negative effect on the

regression depending on the votes cluster in extreme categories (Humphreys et al., 2016).

As observed in Figure 9.3, the indoor air temperature was strongly related to indoor globe and operative temperatures with coefficients of around 0.983 and 0.988 respectively. As mentioned earlier, this indicates the absence of radiation sources in the classrooms (Thapa et al., 2016). In addition, it implies that integrating the three temperatures, or any two, in a regression model as independent variables is not necessary. Hence, a simple linear regression model is sufficient (Nicol et al., 2012; Humphreys, 1977). In this regard, it may worth mentioning that using air temperature is acceptable in the absence of radiation sources (BS EN 15251, 2008; Humphreys, 1977). Yet, three models integrating indoor air, globe, and operative temperatures were constructed in this study to compare the results with previous studies' findings considering the different formats used in literature to report results as noted by (Singh et al., 2018). Besides, the mean sensation votes in the models considered in this study were calculated for each classroom and plotted against temperature. Constructing the regression model using mean votes is more practical. Indeed, this is in agreement with the recommendations aiming to lower the uncertainty associated with using individual votes due to their subjective nature (Hwang et al., 2009; de Dear et al., 1997; Auliciems, 1969).



(a) **(b)**

Figure 9.3: Correlation between indoor air temperature and: (a) indoor globe temperature (N = 1085), (b) indoor operative temperature (N = 1085)

The first simple regression integrated indoor air temperature as presented in Figure 9.4. The relation between the variables is significant as the p-value was lower than 0.05. The coefficient of determination was almost 0.180; therefore, around 18% of the changes in mean sensation can be explained by the variations in air temperature. The equation is:

$$TSV, _{mean} = 0.124\ T_a - 2.92, (p < 0.05) \quad (9.6)$$

Based on this equation, the neutral temperature expressed in air temperature is 23.5 °C approximately. This temperature falls in the air temperature range, 22.5-25.5 °C, recommended by Dubai Municipality,

UAE (Dubai Municipality, 2014) and it is equal or marginally lower than the neutral temperatures reported for female subjects in previous studies with a maximum difference of 0.4 °C (Maykot et al., 2018; Ugursal & Culp, 2013b; Lan et al., 2008). Besides, the neutral temperature as globe and operative temperatures is around 23.6 °C and 23.5 °C respectively. The respective coefficients of determination were 0.142 and 0.149 with significant regression levels and the corresponding equations are:

$$TSV,_{mean} = 0.117\ T_g - 2.76,\ (p < 0.05) \quad (9.7)$$
$$TSV,_{mean} = 0.118\ T_o - 2.77,\ (p < 0.05) \quad (9.8)$$

The neutral operative temperature was higher than that reported for female students in primary and secondary schools in Kuwait by around 1.5°C (Al-Rashidi et al., 2009). Moreover, two thermal comfort studies were recently conducted in offices buildings in Doha (Qatar) and Al-Khaldiya (Kuwait) cities that share similar cultural and climatic conditions with Muscat city. Based on a linear regression of individual thermal sensation votes and concurrent globe temperature, the former study reported a neutral temperature of almost 24.8 °C (Indraganti & Boussaa, 2018) and the latter of around 23.0 °C (AlNajjar et al., 2018). As noted, the neutral globe temperature of the explored students is closer to that reported from the Kuwaiti offices. It is noteworthy that more international subjects participated in the Qatari study compared with that from Kuwait.

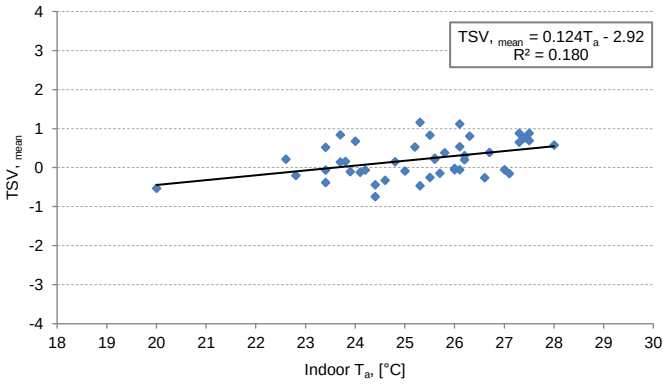


Figure 9.4: Mean thermal sensation votes against indoor air temperature (N = 45)

9.4.1 Students' thermal sensitivity

It is possible to directly determine the thermal sensitivity from the linear regression model (Humphreys & Nicol, 2018; Humphreys et al., 2016; de Dear et al., 2015; Yao et al., 2010). According to Equations (9.6), (9.7), and (9.8), the investigated students have low sensitivities. In specific, they are 0.124, 0.117, and 0.118 of mean thermal sensation for each unit change of air, globe, and operative temperatures respectively.

This means that a change of one unit in air temperature results in changing the mean sensation by 0.124 units roughly. Similarly, a unit change in globe or operative temperature is responsible for a variation of around 0.117 and 0.118 respectively in the mean sensation. These low thermal sensitivities indicate a relatively high adaptation (Indraganti & Boussaa, 2018; de Dear et al., 2015; Hwang et al., 2009), which may mostly be psychological taking into consideration the generally limited adaptive actions in schools (Indraganti & Boussaa, 2018; Korsavi & Montazami, 2018) besides the restrictions on the relatively high clothing level of the explored students. It may, additionally, be related to gender influence as female subjects exhibited better acceptance to their thermal environments as noted in previous studies (Indraganti et al., 2015; Indraganti & Rao, 2010).

Table 9.10 displays thermal sensitivities from selected previous studies for comparison. It should be mentioned that these sensitivities were computed differently. For instance, some were calculated from a linear regression of individual thermal votes with globe temperatures such as (AlNajjar et al., 2018; Indraganti & Boussaa, 2018; Auliciems, 1969) or air temperatures like (Auliciems, 1969). Unfortunately, further information is not available regarding the sensitivity reported in (Davies, 1972 in Humphreys, et al., 2016). Besides, the sensitivities of (Abdallah, 2015; de Dear et al., 2015) were calculated from a linear regression of the mean thermal votes and operative temperatures. It should be mentioned that the former study integrated PMV, whereas the latter integrated actual mean votes.

Table 9.10: Selected thermal sensitivities reported in previous studies

Study	Sample size	Subjects	Location	Season	Ventilation mode	Thermal sensitivity
(AlNajjar et al., 2018)	611	Office workers	Al-Khaldiya, Kuwait	Summer	AC	0.257
(Indraganti & Boussaa, 2018)	3742	Office workers	Doha, Qatar	Whole year	AC	0.216
(Davies, 1972 in Humphreys, et al., 2016)	-	High school students	-	Whole year	-	0.10
(Abdallah, 2015)	269	University students	Assiut, Egypt	Summer	NV	0.4048
(de Dear et al., 2015)	2850	Primary and high schools students	Australia	Summer	NV + AC + EC*	0.124
(Auliciems, 1969)	2500	High school students	Reading, UK	Winter	-	0.116**, 0.120***

*EC = evaporative cooling, **per air temperature, ***per operative temperature

It seems that the only possible direct comparison is with the sensitivity reported in (de Dear et al., 2015), that insignificantly differs from the thermal sensitivity of the investigated students expressed in operative temperature. It is noteworthy that the strong relations between air, globe, and operative temperatures as displayed in Figure 9.3 indicates that ‘they are in effect measuring much the same thing’ (Nicol

et al., 2012, p. 136). Accordingly, the comparison with the other studies is generally acceptable. As noted, the students' sensitivities were mainly similar to those in Table 9.10 except (AlNajjar et al., 2018; Abdallah, 2015).

Further, the students' sensitivity differed from the typical sensitivity of almost 0.4/K based on several field studies in offices (Humphreys et al., 2016). The reason may be related to the students' insulation level, age, and internal spaces' arrangements. It should be mentioned that the relative cluster of students' sensations on the warm side may decrease the regression gradient and, thus, their sensitivity (Humphreys et al., 2016). As noted in Figure 9.5, 14% roughly of the students' votes fell in (+2) and (+3) categories compared with around 5% in the (-2) and (-3) categories. In this regard, a reduction of around 10% in the regression gradient was reported due to lowering the categories of ASHRAE scale from seven to five (Humphreys et al., 2016). This reduction resulted in clustering the votes in the extreme categories. Relating this to the findings of Chapter 8, there may be a necessity to add finer categories, especially to the warm side of thermal scales, to fully reflect the thermal experiences of the participants from similar contexts to those explored in this study.

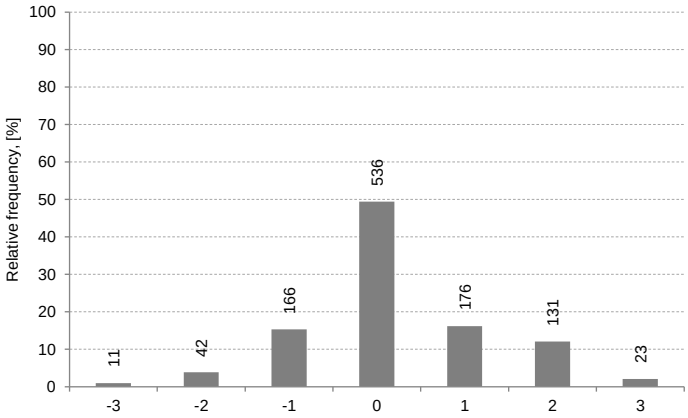


Figure 9.5: Relative frequency of thermal sensation votes (N = 1085) (Labels are votes' numbers)

The irregular widths of the thermal scales' categories, as explored in Section 8.2.1, have a negative effect on the regression gradient. This is mainly because the simple regression model assumes equal intervals of both the independent and dependent variables (Nicol et al., 2012). Besides, the questionnaires' distribution protocol and the construction method of the regression model in this study partially lowered the regression gradient. Indeed, low sensitivities are expected in thermal surveys carried out over long time periods as adaptation improves with time (Humphreys & Nicol, 2018; Humphreys et al., 2016).

In Table 9.11, the regression coefficients of the individual votes and concurrent temperatures of each questionnaire are compared with those of all questionnaires. It is worth to mention that all models were significant as their p-values were lower than 0.05. Considering the questionnaires' distribution sequence from Figure 5.6, the reduction in the regression gradients with time is noted with one exception, which is the regression of ASHRAE questionnaire in winter expressed in air temperature. This exception besides the relatively higher regression gradients of ASHRAE questionnaire in summer study may reflect the comparatively equal widths of categories of this scale as discussed in Section 8.2.1.

Table 9.11: Thermal sensitivities of individual votes and concurrent temperatures

	All	Summer-ASHRAE	Summer-Bedford	Winter-Bedford	Winter-ASHRAE
T_a	0.126	0.252	0.145	0.118	0.127
T_g	0.122	0.250	0.171	0.124	0.100
T_o	0.122	0.256	0.157	0.123	0.100

9.4.2 Temperatures' steps to change mean thermal sensation

The amount of change in temperature responsible for changing sensation is widely known as the temperature step. It is determined from the reciprocal of thermal sensitivity, i.e. regression gradient (Singh et al., 2018). According to Equation (9.6), it is required to change air temperature by around 8.1 °C to achieve a one unit change in the mean vote of thermal sensation. For both globe and operative temperatures, the required change from Equations (9.7) and (9.8), is almost 8.5 °C. A slightly higher step of air temperature, 8.6 °C roughly, was reported in secondary classrooms in the UK (Auliciems, 1969). Moreover, operative temperature steps of 8.1 °C and 8.3 °C approximately were reported in studies from Australia (de Dear et al., 2015) and the UK (Auliciems, 1969) respectively. It is worth mentioning that a general inconsistency in temperature steps required to change students' thermal sensations was reported in a recent review paper (Singh et al., 2018). The variations in the methods of constructing the linear regression models, as illustrated in Section 9.4.1, are partially responsible for such inconsistency.

Recalling from Chapter 8 that the widths of the scales' categories are irregular, the actual temperature steps are displayed in Table 9.12. It should be noted that the presented direction of steps is arbitrary, i.e. moving to the cool side of the thermal continuum requires identical steps. Expressed as air, globe, and operative temperatures, the means of the steps are around 7.3 °C, 7.7 °C, and 7.6 °C respectively. Thus, considering the actual widths of the categories seems to decrease the estimated adaptation of the students.

Table 9.12: Required steps of air, globe, and operative temperatures to change mean thermal sensation

	(-3) to (-2)	(-2) to (-1)	(-1) to (0)	(0) to (+1)	(+1) to (+2)	(+2) to (+3)
T_a, [°C]	5.2	6.6	9.7	8.5	6.8	6.7
T_g, [°C]	5.5	7.0	10.3	9.0	7.2	7.1
T_o, [°C]	5.5	7.0	10.2	8.9	7.1	7.1

9.4.3 Concerns regarding the constructed regression model

There are some concerns regarding the constructed regression model discussed above. These concerns weakened the accuracy of the model and, accordingly, of its findings. Generally, these concerns are related to the survey protocol, the investigated sample, and the model itself. Considering the survey protocol, constructing the model from 45 observations created some doubts regarding its meaning. Indeed, any thermal sensitivity determined from less than 50 observations is generally questionable (Humphreys & Nicol, 2018; Humphreys et al., 2013). Besides, it is known that the regression gradients are negatively affected by the adaptive process. As temperature changes, people take adaptive actions to maintain their comfort, i.e. to keep their sensation constant or with the minimal change, despite the change in temperature (Djamila, 2017; Nicol et al., 2012). As mentioned in Section 5.4, the nature of the survey of this study, i.e. a repeated transverse survey, enabled the students to adapt to the classrooms' thermal conditions.

For the current study, dividing the sample into batches according to schools, for instance, accounts for the thermal environment variations of each school in addition to the daily variations in indoor temperatures (Humphreys & Nicol, 2018; de Dear et al., 2015). However, the latter variations may not be an important concern in the current study as they were limited as noted in Table 6.6. Moreover, exploring the regression of individual votes may increase coefficients' accuracy due to increasing observations' number (J. Wang et al., 2018). Therefore, the regressions of the individual thermal sensation votes with the concurrent indoor temperature for each school were computed.

As observed in Table 9.13, the insignificant regression models increased as the survey progressed, which may be a sign of the students' boredom. Seven models were significant with more than 50 observations each except (ZA) School model in Bedford questionnaire in summer. This model and all insignificant models were excluded from further analysis. As observed, the thermal sensitivity varied from 0.200 to 1.861 roughly, which corresponds to temperature steps from around 5 °C to 0.5 °C respectively. The arithmetic mean of sensitivity was around 0.663 and that of temperature step was 2.1°C approximately. This indicates a noticeable increase in students' thermal sensitivity compared to the model of Equation (9.6). Likewise, the air temperature

step was decreased by 6 °C. Considering the study of (de Dear et al., 2015), calculating the regressions of individual votes and the concurrent operative temperatures almost doubled the sensitivity and halved the temperature step. Additionally, the regression models of the individual votes and concurrent globe and operative temperatures according to schools are summarised in Appendix 9.3.

Table 9.13: Regression models of individual thermal sensation votes and concurrent indoor air temperature based on schools

School	N	p-value	R^2	Intercept	Gradient	T_n	Temp. step
Summer - ASHRAE							
WK	67	0.038	0.065	-47.8	1.861	25.7	0.5
SQ	83	0.000	0.192	-7.33	0.303	24.0	3.3
ZA	51	0.003	0.172	-15.9	0.610	26.1	1.6
NK	72	Not sign.	-	-	-	-	-
DA	60	0.028	0.080	-15.3	0.621	24.6	1.6
Summer – Bedford							
WK	60	Not sign.	-	-	-	-	-
SQ	92	Not sign.	-	-	-	-	-
ZA	43	0.009	0.156	-28.4	1.057	26.9	0.9
NK	76	Not sign.	-	-	-	-	-
DA	78	0.001	0.138	-4.85	0.200	24.3	5.0
Winter – Bedford							
NK	74	Not sign.	-	-	-	-	-
DA	50	Not sign.	-	-	-	-	-
ZA	70	Not sign.	-	-	-	-	-
Winter – ASHRAE							
NK	67	Not sign.	-	-	-	-	-
DA	71	0.000	0.172	-8.74	0.385	22.7	2.3
ZA	71	Not sign.	-	-	-	-	-

Although the regression of the individual votes may seem accurate owing to the increased number of observations, it is thought that both the regression models of the mean and the individual votes failed to compute the students' thermal sensitivity accurately. A possible reason may be the narrow range of the measured temperatures. The wide reliance on air conditioning units and the small number of daily surveys resulted in a limited temperature range, which has a negative influence on the regression coefficients (Humphreys & Nicol, 2018).

Furthermore, the regression model assumes that the independent and dependent variables are free from error. This is not the case with the independent variable, i.e. the temperature. The measurement error of Data Logger PCE-WB 20 SD is ±0.6 °C as mentioned in Appendix 5.3. This error besides the equation error have a negative effect on the regression coefficient (Humphreys & Nicol, 2018; Djamila, 2017; Nicol et al., 2012). However, it should be mentioned that the influence of the measurements' error was limited because the sensors were calibrated as mentioned in Chapter 6. Additionally, the explorations of the scales' behaviour in Chapter 8 revealed irregularities in the categories' widths, which have a negative influence on the model that assumes equal intervals (Nicol et al., 2012).

Moreover, the dependent variable, i.e. thermal vote, is widely assumed to be truly independent (Djamila, 2017). This assumption implies that any thermal vote given by the student is not affected by her previous votes. In practice, this is unrealistic especially in longitudinal surveys where the participant gives more than one vote (Humphreys et al., 2016). This is, additionally, applicable to the repeated transverse surveys of this study. The thermal votes were not totally independent because many students participated in more than one questionnaire. Thus, applying Griffiths' method may be more accurate as explored in the following section.

9.5 Calculating neutral temperature by Griffiths' method

In order to overcome the unreliability of the constructed regression model in this research, Griffiths' method was applied. This method is considered as a good alternative when the number of observations is small and the range of temperatures is small (Nicol et al., 2012). In the method, the neutral temperature is determined from an arithmetic mean of several neutral temperatures, which, themselves, are unreliable as they are computed from small batches of data or even from single votes. The unreliability in the regression coefficients is resolved by using a reliable coefficient, known as Griffiths' slope, derived from climate chamber studies or, recently, field-based studies. This substitution may be a disadvantage due to the random selection of the coefficient. Further, this substitution assumes certain thermal sensitivity, which limits the method's benefit to determine the neutral or the comfort temperature as widely known (Humphreys & Nicol, 2018; Humphreys et al., 2013; Nicol et al., 2012).

Griffiths' slope is as 'an assumed value for the rate of change of thermal sensation with temperature' and it is generally assumed as 0.3/K (Nicol et al., 2012, p. 160). This value was originally applied by Griffiths derived from several climate chamber studies (Humphreys & Nicol, 2018), where no adaptation was allowed (Nicol et al., 2012). For the current study, it is more realistic to use a slope from field-based research. Regression coefficients of around 0.47/K and 0.49/K were revealed by consulting SCATs and ASHRAE databases respectively (Humphreys et al., 2013). As a single value, 0.48/K is recommended (Humphreys & Nicol, 2018). Accordingly, Griffiths' neutral or comfort temperature is calculated from (Indraganti & Boussaa, 2018; Manu et al., 2016):

$$T_c = T + (0 - TSV) / G \qquad (9.9)$$

Where:

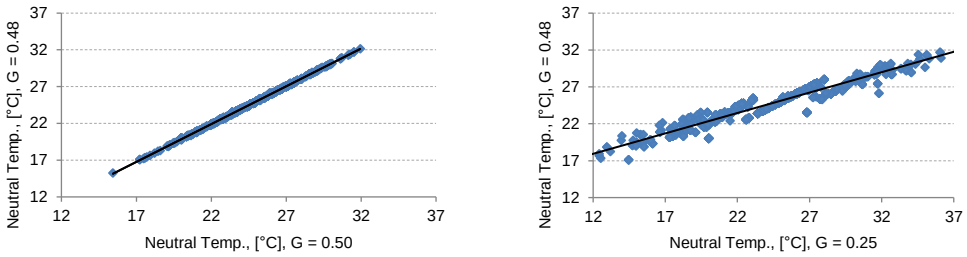
T_c is comfort (neutral) temperature, [°C]
G is Griffiths' slope, [-]

It is noteworthy that (0) in equation (9.9) corresponds to neutral thermal sensation. For the explored students, the neutral temperature was almost 24.8 °C expressed as indoor air temperature. As indoor globe or operative temperature, the neutral temperature was around 25.0 °C and 24.9 °C respectively. In Table 9.14, slightly different values of neutral temperature are presented as a consequence of applying different values of Griffiths' slope. As noted, temperatures fell in the comfort range of air temperatures recommended by Dubai Municipality (Dubai Municipality, 2014). Besides, the neutral globe temperatures applying a slope of 0.33/K for Kuwaiti and Qatari offices were around 22.5 °C and 24.3 °C respectively (AlNajjar et al., 2018; Indraganti & Boussaa, 2018), which are similar to the temperatures in Table 9.14. In addition, it is noted that the neutral temperatures of the current study and the Qatari offices (Indraganti & Boussaa, 2018) using a slope of 0.25/K are identical.

Table 9.14: Neutral temperature estimated by different Griffiths' slopes

Griffiths' slope	T_a, [°C]	T_g, [°C]	T_o, [°C]
0.50	24.9 ± 2.48	25.0 ± 2.45	25.0 ± 2.46
0.49	24.8 ± 2.51	25.0 ± 2.49	24.9 ± 2.50
0.48	**24.8 ± 2.55**	**25.0 ± 2.53**	**24.9 ± 2.54**
0.47	24.8 ± 2.59	25.0 ± 2.56	24.9 ± 2.57
0.39	24.7 ± 2.98	24.9 ± 2.97	24.9 ± 2.97
0.33	24.7 ± 3.42	24.8 ± 3.42	24.8 ± 3.42
0.30	24.6 ± 3.72	24.7 ± 3.72	24.7 ± 3.72
0.25	24.5 ± 4.39	24.6 ± 4.40	24.6 ± 4.40

The impact of selected Griffiths' slope on the neutral temperature is compared in Figure 9.6 considering two cases, namely 0.50 and 0.25. The plotted neutral temperatures were calculated based on indoor air temperature. The plots of globe or operative temperatures are similar. As noted, the correlation in the case of 0.50 Griffiths' slope is higher than that of 0.25, which is expected considering the closeness of the former slope from the base case of 0.48. The respective correlation coefficients are 0.9997 and 0.9541. Therefore, the different thermal sensitivities explored in Table 9.14 have a marginal effect on the neutral temperatures.



(a) (b)

Figure 9.6: Influence of Griffiths' slope on neutral temperature: (a) G = 0.48 against G = 0.05 and (b) G = 0.48 against G = 0.25

9.5.1 Recalculating temperature steps

The temperature steps were computed using Griffiths' method based on the actual widths of the categories as displayed in Table 9.15. As noted, the steps were lower than those calculated by the regression model presented in Table 9.12. For instance, the mean step was almost 1.9 °C compared with 7.3 °C, 7.7 °C, and 7.6°C roughly expressed in air, globe, and operative temperatures respectively. This was expected considering the lower regression gradient of Griffiths' method. It is noteworthy that the steps are constant despite the used temperature owing to the unified equation used in Griffiths' method.

Table 9.15: Temperature steps using Griffiths' method

	(-3) to (-2)	(-2) to (-1)	(-1) to (0)	(0) to (+1)	(+1) to (+2)	(+2) to (+3)
T, [°C]	1.3	1.7	2.5	2.2	1.7	1.7

9.5.2 Exploring neutral temperature relations

Considering a Griffiths' slope of 0.48/K, the relationships between the neutral temperatures and the mean indoor air, globe, and operative temperatures were investigated. The aim was to explore the influence of the students' adaptive actions. As mentioned in Section 2.3, the adaptive actions are classified into interactive and reactive. The thermal ambience is influenced by the former, whereas the personal conditions are influenced by the latter (Nikolopoulou & Steemers, 2003). Hence, these interactions result in strong associations between the neutral and mean indoor temperatures (Humphreys et al., 2016).

To investigate these associations, the neutral temperature of each classroom was plotted against the mean temperature as presented in Figure 9.7. For the correlations with the mean air, globe, and operative temperatures, the coefficients were around 0.659, 0.576, and 0.470 respectively. These moderate relations reflect the general restrictions on adaptive actions in classrooms. Additionally, the regressions were significant as p-values were < 0.05. The respective equations are:

$$T_c = 0.86\ T_a + 3.11 \quad (9.10)$$
$$T_c = 0.81\ T_g + 4.62 \quad (9.11)$$
$$T_c = 0.66\ T_o + 8.39 \quad (9.12)$$

It is noteworthy that the relation between the neutral temperature and the outdoor air temperature was insignificant as p-value was almost 0.1. Indeed, this is expected considering the weak relations between indoor and outdoor air temperatures that were investigated in Section 6.6.1. It, additionally, indicates the heavy reliance on air conditioning units in the classrooms, which is consistent with other researchers' findings (Al-Gharibi, 2016; Majid et al., 2014).

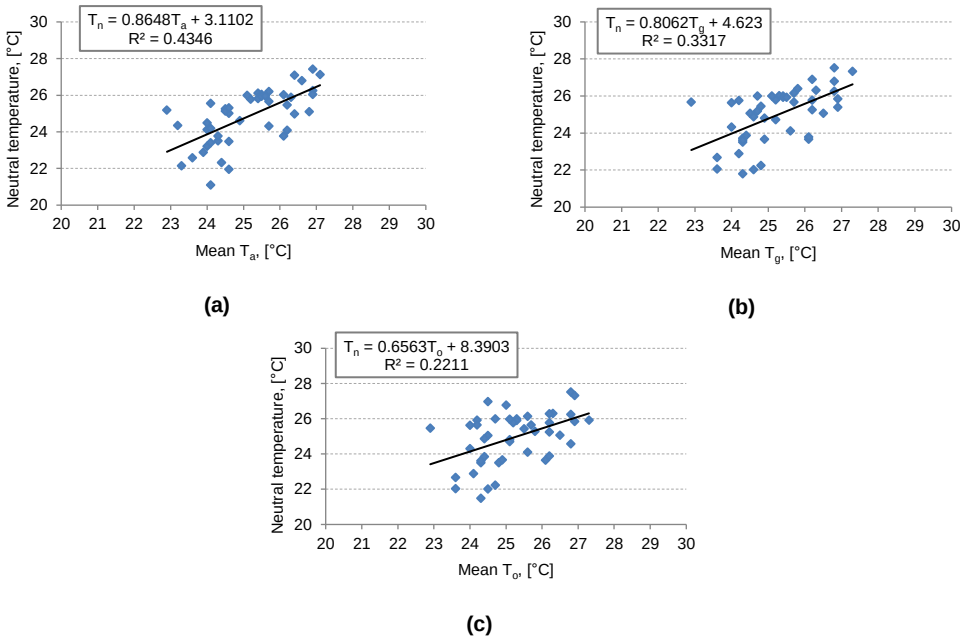


Figure 9.7: Neutral temperature correlations with mean indoor temperatures: (a) air neutral temperature and indoor air temperature, (b) globe neutral temperature and indoor globe temperature, and (c) operative neutral temperature and indoor operative temperature

9.6 Calculating acceptability limits

The thermal acceptability limits of a certain sample may be defined as the range of indoor temperatures that is considered acceptable or comfortable for a certain percentage of people from that sample. These boundaries are concentrated on the neutral temperature and can be identified using the linear regression model or Griffiths' method (Manu et al., 2016; de Dear et al., 2015; Yao et al., 2010). When using the former, it should be constructed based on the mean thermal sensation votes and mean indoor temperatures (de Dear et al., 2015).

In determining these limits, it is assumed that thermal acceptability is equivalent to thermal comfort. This assumption is based on ASHRAE definition of thermal comfort as presented in Section 2.2 considering the interchangeable use of acceptance and satisfaction in thermal comfort research (Kwok & Chun, 2003), which is applicable to this study as

discussed in Section 7.3. Based on ASHRAE Standard 55, the comfort zone corresponds to 80% of satisfied people, which corresponds to a mean thermal sensation of ±0.85. For 90% of satisfaction, the mean sensation is estimated at ±0.5 (ASHRAE, 2017; ASHRAE, 2010).

Due to the unreliability associated with the simple linear regression model of this study, Griffiths' method, with a slope of 0.48/K, was applied to determine the acceptability limits as displayed in Table 9.16. Calculating the limits in air, globe, or operative temperatures resulted in negligible variations reflecting the strong relationships between these temperatures as discussed in Section 9.1.2. The upper boundaries of acceptable air temperature were higher than those advised by Dubai Municipality (Dubai Municipality, 2014) by around 1.1 °C and 0.4 °C for the 80% and 90% acceptability levels respectively.

Table 9.16: Thermal acceptability limits (Ranges in squared brackets)

	T_a, [°C]	T_g, [°C]	T_o, [°C]
80% acceptability level	23.1-26.6, [3.5]	23.2-26.7, [3.5]	23.2-26.7, [3.5]
90% acceptability level	23.8-25.9, [2.1]	23.9-26.0, [2.1]	23.9-26.0, [2.1]

For each questionnaire, the percentages of indoor temperatures within the acceptability limits are displayed in Table 9.17. As noted, the percentages of globe and operative temperatures differ noticeably in spite that they have identical ranges as presented in Table 9.16. The 80% acceptability limit formed more than 60% of the air and globe temperatures in each questionnaire. For the operative temperature, the maximum percentage that fell in the 80% acceptability level was around 20% in both ASHRAE and Bedford questionnaires in summer and winter respectively. Besides, the highest percentages of air and globe temperatures of both acceptability levels were achieved in ASHRAE questionnaire of winter study. However, the percentages of satisfied and comfortable students were not the highest as noted from Table 7.2 and the distribution patterns of thermal sensation and preference votes were similar to those of the other questionnaires as observed in Figure 7.5. This confirms the previous observations that other factors, besides the physical variables, determined the students' thermal comfort.

Table 9.17: Percentages of indoor temperatures within acceptability limits

		Summer - ASHRAE	Summer - Bedford	Winter - Bedford	Winter - ASHRAE
T_a, [°C]	**80% accept. level**	67.3	64.5	77.1	81.5
	90% accept. level	38.7	42.5	48.1	58.4
T_g, [°C]	**80% accept. level**	70.3	68.9	75.9	80.6
	90% accept. level	44.4	44.6	46.7	61.2
T_o, [°C]	**80% accept. level**	20.0	15.6	20.0	14.9
	90% accept. level	14.6	12.2	12.8	11.9

9.7 Conclusion

Indoor operative temperature is widely reported in thermal comfort studies owing to its consideration of more than one factor of those affecting thermal comfort. For the explored classrooms, the operative temperatures were normally distributed as the values of the arithmetic means and medians were relatively similar. It seems that there were no radiation sources in the classrooms due to the similarity between indoor operative and air temperatures, which was confirmed by determining Persons' correlation coefficients. The coefficients were almost unity in all questionnaires, which was, additionally, the case with the coefficients of the correlation between the operative and globe temperatures.

The correlations between the physical variables and the respective subjective votes were calculated assuming linear relations. In general, weak correlations related both the individual thermal sensation and preference votes to the indoor and outdoor air temperatures, indoor globe temperature, and indoor operative temperature. The weakness in these relationships may reflect the subjectivity of thermal sensations and preferences in addition to the influence of other factors, like the cultural and climatic background, in determining these votes. Besides, substituting the individual votes by the arithmetic means resulted in increasing the correlations coefficients slightly. Yet, it is possible that the increase was due to the reduced randomness in the sample. For both the individual and mean votes, the calculated coefficients were similar to the results of previous research from similar context (AlNajjar et al., 2018; Indraganti & Boussaa, 2018; Auliciems, 1969). Besides, the sensation votes related to the departure from the mean air temperature in a relatively stronger correlation compared to the association with the mean air temperature itself. A similar observation was reported in a previous research (Humphreys, 1977). Considering relative humidity, the explored relationships were weak as reported in a previous study (Uğursal & Culp, 2013a). This weakness may be attributed to the students' confusion regarding the humidity scales and the generally weak effect of humidity on comfort in moderate environments. Similarly, the relations of air velocity with its sensation and preference votes were generally weak.

Besides, the reliance of the subjective votes on thermal sensations was investigated. Considering thermal preference, it was revealed that around 35% of its changes were explained by the variations in thermal sensations. Assuming a linear relationship, the preferred sensation for the students, coincides with (no change) preference, was (slightly cool) or (comfortably cool). It is noteworthy that the correlation was weakened by the irregularity in the categories' widths. Additionally, the humidity

subjective votes were weakly related to the thermal sensation votes. Considering the air velocity sensation and preference votes, positive moderate associations were revealed with correlation coefficients of around 0.439 and 0.401 respectively.

The mean thermal sensations and the concurrent temperatures were integrated into a simple linear regression model. As a result, the neutral air, globe, and operative temperatures were around at 23.5 °C, 23.6 °C, and 23.5 °C respectively. The neutral air temperature is in the optimum range defined by the Municipality of Dubai (Dubai Municipality, 2014). Likewise, the neutral globe and operative temperatures were similar to those reported in previous studies carried out in Kuwait and Qatar that generally share a similar climate and culture with Oman (AlNajjar et al., 2018; Indraganti & Boussaa, 2018).

Besides, the thermal sensitivities of the investigated students were estimated directly from the regression models at 0.124, 0.117, and 0.118 of mean thermal sensation per unit change of air, globe, and operative temperatures respectively. In general, these sensitivities were close to those reported in previous studies conducted in similar contexts. As a result, it is possible to conclude the students' adaptation to relatively wide thermal conditions. Considering the generally limited adaptive behaviour in schools, such adaptation may generally be psychological. However, these sensitivities may not be reliable for three main reasons, which are the relative clustering of students' votes in the warm side categories, the irregularity in categories' widths, and the questionnaires' distribution protocol that increased students' adaptation. Indeed, the negative effects of the second and third reasons were witnessed when the regression coefficients of the individual votes and concurrent temperatures were calculated. Therefore, it is suggested to explore the potentially positive impact of implementing finer categories to accurately capture the participants' thermal experience, especially in the warm side. Besides, it is suggested to investigate the thermal sensitivity based on transverse questionnaires.

The reciprocals of thermal sensitivities determine the temperature steps required to change thermal sensations. For the explored students, the steps were around 8.1 °C, 8.5 °C, and 8.5 °C in terms of air, globe, and operative temperatures respectively. These steps were generally consistent with previously reported steps in classrooms from Australia (de Dear et al., 2015) and the UK (Auliciems, 1969). Considering the actual widths of thermal categories, the arithmetic means of the air, globe, and operative steps were computed as almost 7.3 °C, 7.7 °C, and 7.6 °C respectively. The difference in the steps indicates that the regression model seems to overestimate the students' adaptation.

It is important to consider the results of the regression models of this study with caution as they seem to be unreliable. The small number of observations and the survey's nature as a repeated transverse survey contributed to the model unreliability. In specific, the survey's protocol improved the adaptation process that is negatively related to the regression gradient. Hence, in an attempt to increase the number of observations and to capture the thermal variations of the schools, new regression models were constructed from the individual thermal votes and concurrent temperature of each school. As a result, the arithmetic means of the thermal sensitivity and the air temperature step were 0.663 and 2.1 °C respectively. However, the heavy dependence on air conditioning units in the explored classrooms besides distributing the questionnaires once daily in each classroom narrowed the ranges of the measured temperatures. In turn, this negatively affected the regression coefficients. Moreover, the error of the measured temperature, the error of the regression equation, and the assumption of true independence in thermal votes contributed to the regression model unreliability. In order to reduce the unreliability of the regression models, it is recommended to increase the sensors' accuracy, calibrate the sensors, and select the phrase of the thermal scales carefully.

To overcome the regression model unreliability, Griffiths' method was applied to determine the students' neutral temperature. The neutral air, globe, and operative temperatures were around 24.8 °C, 25.0 °C, and 24.9 °C respectively using a Griffiths' slope of 0.48/K. These temperatures were consistent with the regionally reported comfort range (Dubai Municipality, 2014) and neutral temperatures (AlNajjar et al., 2018; Indraganti & Boussaa, 2018). Investigating other Griffiths' slopes revealed their insignificant effect on the neutral temperatures. Besides, the mean actual step was reduced to around 1.9 °C because Griffiths' slope was lower than the regression coefficients. Further, the limitations in the adaptive actions taken by the students were indicated by the moderate correlations that related the neutral temperatures to their respective air, globe, and operative temperatures.

Considering Griffiths' method, the students' acceptability limits were identified based on 80% and 90% acceptability levels. Considering air temperature, the former limit was around 23.1-26.6 °C. It is worth to mention that determining the neutral temperature in globe or operative temperatures resulted in negligible variations because of the strong correlations between these temperatures. The students exhibited higher acceptability to warm conditions compared with a range recommended regionally. Comparing the recorded temperatures in the classrooms with the acceptable range revealed that the majority of air and globe

temperatures were satisfactory to 80% of the students. However, these percentages were not reflected in the students' satisfaction and comfort levels, which confirms the contribution of other factors in determining the students' comfort in addition to the physical variables.

It should be mentioned that comparing the findings of this study with those of previous research was not possible in some cases due to the different formats applied in literature to present the results. This inconsistency was mentioned in Chapter 3 and it emphasises on the necessity of a generally unified format for presenting the results of thermal comfort studies.

Chapter (10):

Conclusions and Recommendations

Chapter 10 Conclusions and recommendations

This chapter concludes the research at hand that was conducted with the aim of exploring the thermal conditions of female students in high schools' buildings in Muscat and their perceptions of thermal scales integrated into thermal comfort studies. The chapter presents the conclusions of the literature review, the thermal conditions of the explored classrooms, the students' responses towards their thermal environments, their collective understanding of the thermal scales, the translated scales' behaviour, and the integration of the objective and subjective data. Indeed, this chapter is an attempt to synthesise the answers to the research questions. The last two sections present the research limitations besides the recommendations and the suggested future work are.

10.1 Research conclusions

The main motivators to conduct this research were the heavy reliance on air conditioning systems in Omani buildings, as reported in previous studies, combined with the relatively large amount of energy consumed for cooling purposes and the increased amounts of the GHG emissions. Maintaining the neutral temperature and the acceptability limits are crucial for the success of any architectural design from an energy perspective. Therefore, the findings of this research should be useful for the architects, engineers, and the regulators considering the lack of well-established regional standards.

The importance of the current research evolves from the relative lack of thermal comfort studies in the hot arid climate, especially in the Arabic region. Indeed, the research, up to the researcher's level of knowledge, is the first study that investigates the thermal conditions in Omani high schools. Besides, the research contributes to the current knowledge of thermal scales' behaviour and the influence of translation. Up to the researcher's level of knowledge, this study is the first attempt to explore the collective understanding of ASHRAE scale phrases among Arabic subjects as well as to explore the behaviour of ASHRAE, Bedford, and Nicol scales when translated into the Arabic language. These explorations are important as any deviation from the scales' original assumptions has a negative influence on the results of the thermal comfort studies. In specific, the irregularity in categories' widths has a negative effect on the results of the regression analysis. This analysis is widely applied in thermal comfort studies and it requires equal intervals of both the dependent and independent variables (Nicol et al., 2012).

As discussed earlier, the aim of the research was broken down into five objectives from which the research questions were derived as noted in Figure 1.3. The third part of the thesis discussed the answers to these questions and the following sections synthesise them in one context as explained in Figure 10.1.

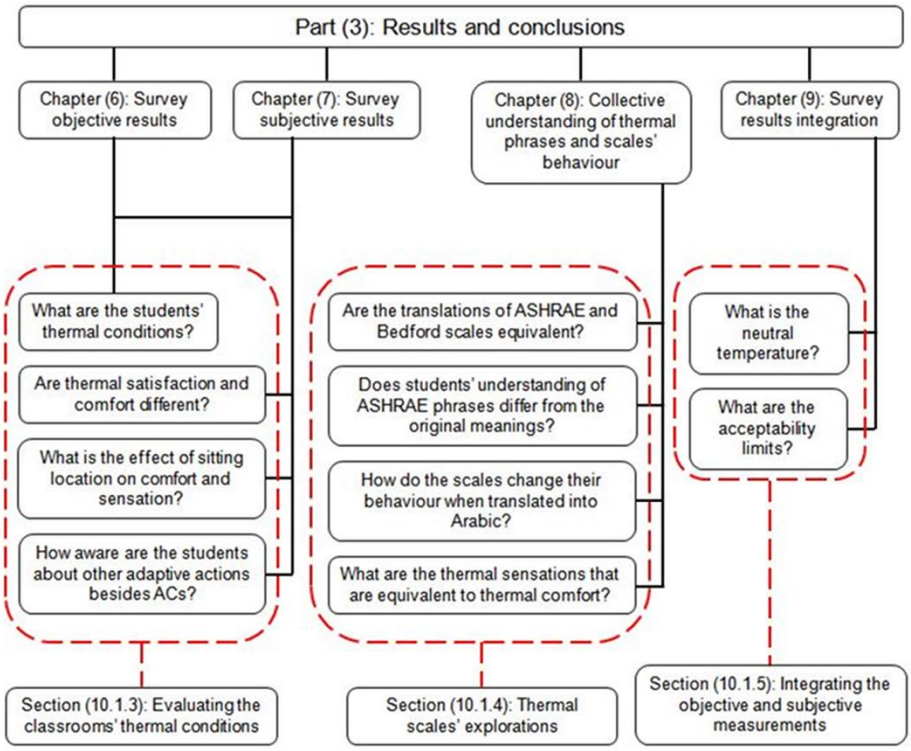


Figure 10.1: Relationships between research questions, part (3) chapters, and chapter (10) sections

10.1.1 Literature review conclusions

To perform this research, it was necessary to review the literature in two main directions. The first focused on thermal comfort generally with a special concentration on thermal scales and the challenges that associate their application. The second focused on the previous studies investigating thermal comfort in educational buildings.

Considering the first direction, the review confirmed the limited influence of humidity on comfort in moderate environments and the wide acceptance of replacing mean radiant temperature by globe temperature, particularly when sensors with limited accuracy are used. The indistinct influence of gender as a secondary factor on thermal comfort was revealed. Moreover, some Arabic translations of ASHRAE scale obtained from recent studies were compared with the international version. Variations between the investigated versions were revealed. In addition, the comparison indicated a possible association of desirable impressions to some sensations outside the three central categories in the explored translations including the international version.

A narrative review of 54 published papers was performed to explore thermal comfort studies conducted in educational buildings. It was revealed that the majority of the reviewed papers were from the temperate and tropical climates. This indicated a lack of research in the arid climate generally and the Arabic region specifically considering its cultural and climatic speciality. Moreover, the frequent comparisons of the actual thermal votes with PMV reported wide disagreements. This emphasises the unavailability of specialised standards for educational buildings in addition to the lack of age consideration in the current international standards (Singh et al., 2018; Zomorodian et al., 2016; Fabbri, 2013). Therefore, it is crucial to establish regional models of thermal comfort with which the findings of the regional studies can be validated. Additionally, although a few of the reviewed studies explored the adaptive actions of the students, none considered the influence of sitting location on thermal comfort. Besides, the dominance of a certain sensation in educational buildings was not obvious, unlike preference as most studies reported a preference for cool conditions. In addition, the influence of controlling ventilation rates and students' numbers in classrooms was highlighted in the reviewed studies. Interestingly, the review revealed different formats applied in reporting the results of thermal comfort studies in educational buildings, which may sometimes prevent findings' comparisons.

10.1.2 Local context and pilot studies' conclusions

Some preparations were considered prior to conducting this research including reviewing the literature, exploring the local context of the survey, and conducting two pilot studies. Considering the local context, an overview of the Sultanate of Oman indicated that the official religion is Islam and the official language is Arabic. In high schools, female students wear a uniform that has an insulation level of 1.07 clo roughly. From a climatic perspective, the academic year and, thus, any selected period for conducting the survey may not be representative. In Muscat, the year is climatically divided into two periods, which are a hot humid period extending from April to October including both and a relatively cooler period for the remaining months. In the former period, the main air temperature extends between 29.5 °C and 34.7 °C roughly. In the latter, the range of temperature is almost 20.8-25.8 °C. The respective ranges of relative humidity are around 41.5%-74.3% and 57.5%-65.6%. Additionally, five high schools of female students were selected to conduct the research. The schools were classified into four groups according to their architectural features. In each school, three classrooms participated in the survey that was carried out in March and September. Both months may not be representative climatically; yet, they were selected to decrease disturbance levels.

Two pilot studies were performed in this research. They provided good opportunities to test and improve the survey. In particular, the first pilot study concluded sensors' appropriateness to achieve the research objectives and provided good feedback regarding the questionnaires' design. The second pilot study confirmed the feasibility of full-scale studies and provided an opportunity to practice data analysis. Besides, the measurements revealed a narrow range of indoor air temperature, sensations' clustering in the central categories, a general preference of cool conditions, and a comparatively heavy reliance on air conditioning units to modify classrooms' thermal conditions. Based on the students' differentiation between thermal comfort, neutrality, and acceptance, it was suggested to investigate these variations further. Additionally, applying successive categories method revealed the irregularity in the categories' widths. Based on the constructed simple linear regression model, the students' thermal sensitivity was 0.203 and 0.104 roughly in terms of air and globe temperatures respectively.

10.1.3 Evaluating classrooms' thermal conditions

The thermal conditions of the classrooms were evaluated based on the physical measurements obtained from the sensors and the subjective responses collected from the questionnaires. Considering the former, the indoor and outdoor air and globe temperatures, air velocity, and relative humidity were measured. For the subjective responses, two versions of typical thermal comfort questionnaires integrating translated versions of ASHRAE and Bedford sensations scales were distributed. Nicol scale was used in both versions as a preference scale. In summer and winter studies, the number of the investigated classrooms was 15 and 9 respectively.

In general, the arithmetic means and medians of the physical variables were similar, which indicated the symmetrical distribution of the data around their means. The dominant ranges of the measured variables were identified by plotting their relative frequency. The ranges were relatively small as generally expected in air-conditioned buildings. In summer and winter, the ranges of indoor air temperatures were around 23-28 °C and 23-26 °C respectively. Moreover, comparing the proportions of indoor thermal variables concluded the necessity of excluding the data of (ZA-G2) and (DA-G2) classrooms from further analysis. Thus, the data of the former classroom were excluded from summer study, whereas those of the latter were excluded from Bedford questionnaire in winter. This exclusion was required to increase the results' accuracy. Based on ASHRAE psychrometric chart of Muscat city, it is concluded that the classrooms' thermal environments were not comfortable, especially during summer. Indeed, only around 12% and

15% of the data measured in ASHRAE and Bedford questionnaires in summer were within the comfort zone. In winter, the corresponding percentages were 52% and 49% approximately.

Considering that thermal comfort is reached with a satisfaction level of 80%, the uncomfortable conditions of the explored classrooms were revealed except in Bedford questionnaire of winter study. These uncomfortable conditions were mainly because of the relatively heavy clothing level and frequent subject to outdoor conditions. However, more than 75% of the votes in all questionnaires fell in the three central categories. More students preferred cool conditions as 53%-66% roughly preferred (a bit cooler) and (much cooler) conditions compared with 24%-39% approximately preferred (no change) in their conditions. The former category alone formed almost 40%-47% of the preferences.

The percentages of unsatisfied students differed according to the used method. The percentage of uncomfortable students, based on the direct evaluation of comfort, was interestingly not equal to the percentage of votes that were outside the three central categories of Bedford scale in summer. This may reflect the influence of other factors, besides thermal sensations, in determining students' comfort. It was concluded that the optimum method to determine satisfaction is the method of direct evaluation, i.e. by direct questioning, provided that a variation level of 5% is allowable.

Investigating the distribution of preference votes on sensation categories revealed that neutrality was not a preferred sensation and the students exhibited a preference tendency towards cool conditions. This tendency is consistent with both the preferences of warm climates people and the preferences reported in previous research of thermal comfort in educational buildings. Moreover, exploring the distributions of students' sensations and preferences based on their satisfaction and comfort levels indicated that all students' groups preferred (a bit cooler) conditions. The sensations of the (satisfied and comfortable) students clustered in the middle categories of sensation scales, whereas the sensation of the (unsatisfied and uncomfortable) students clustered on the warm side of the thermal continuum.

Students' sensations and preferences of humidity and air velocity levels were investigated. Considering the former, the results revealed a general misunderstanding of its scales among the students as revealed by their frequent questions. The high clustering of their votes in the middle categories was noted. Considering the sensations of air velocity, the three central categories formed around 59%-69% of the total votes

with an obvious skewing to the warm side of the thermal continuum. Consequently, the preferences were for faster air velocities.

Investigating the adaptive behaviour of the students revealed its consistency during the survey. The students depended mainly on the air conditioning units followed by opening windows, switching on fans, and opening doors. On average, around 20%, 14%, 10%, and 10% of the students reported these actions respectively. The students' reliance on air conditioning units may be justified by the efficiency of these units in modifying thermal conditions, their availability, the lack of economic responsibility, and the influence of cultural background.

The relation between perceived control and students' productivity was explored. The latter was represented by the students' self-reported duration of full concentration under an imaginary scenario of air conditioning failure. The results revealed a relatively limited ability to concentrate estimated by 29% and 24% of the students in ASHRAE and Bedford questionnaires of winter study respectively. It is noteworthy that roughly equal numbers of students expected full concentration during each of the first four classes. Under air conditioning units' failure, the students preferred opening windows, opening doors, staying outside their classrooms, and switching on fans to modify their conditions. It is concluded that the students have the ability to decrease their relatively heavy dependence on air conditioning units when they have no other options. Besides, the actual frequency of usage time of three adaptive actions was explored. These actions were switching on air conditioning units, opening windows, and switching on fans. Consistent with the findings of previous studies in Oman (Al-Gharibi, 2016; Majid et al., 2014), the air conditioning units were operated (all the time) according to most students. Random patterns of usage were reported for other actions. Table 10.1 synthesises the statistical findings of some explored relations related to the classrooms' thermal conditions.

Table 10.1: Results of exploring some relations related to classrooms' thermal conditions

Relations between:	Findings
Pearson's correlation	
Indoor and outdoor air temperatures	Insignificant, r = -0.09, -0.067, -0.169, -0.260
Indoor air temperature and velocity	Insignificant, r = +0.015, -0.056, +0.083, -0.186
Indoor air and globe temperatures	Strong, r = +0.967, +0.976, +0.983, +0.984
Different methods of determining unsatisfied students	Insignificant
Fisher exact test	
Satisfaction and comfort levels	Significant dependence, p < 0.05
Satisfaction level and health status	Sign. dependence in one questionnaire, p = 0.000
Comfort level and health status	Sign. dependence in one questionnaire, p = 0.000
Satisfaction level and central sensation votes	Significant dependence, p < 0.05
Comfort level and central sensation votes	Significant dependence, p < 0.05
Satisfaction level and (no change) votes	Significant dependence, p < 0.05
Comfort level and (no change) votes	Significant dependence, p < 0.05
Satisfaction level and sitting near windows	Significant dependence confirmed in two questionnaires only
Comfort level and sitting near windows	Lack of evidence, p = 0.071, 0.162, 0.494, 1.000
Satisfaction level and humidity central sensations	Significant dependence, p < 0.05
Comfort level and humidity central sensations	Significant dependence, p < 0.05
Satisfaction level and air velocity central sensations	Significant dependence, p < 0.05
Comfort level and air velocity central sensations	Significant dependence, p < 0.05
Sitting locations and adaptive actions	Lack of evidence, p > 0.05

10.1.4 Thermal scales' explorations

Regardless of their wide application in thermal comfort studies, the literature concerning thermal scales is relatively limited. In this research, explorations of scales' behaviour were performed with two objectives. The first objective investigated the students' collective understanding of ASHRAE sensation phrases and the second explored the translation influence on the behaviour of ASHRAE, Bedford, and Nicol scales when translated into the Arabic language.

To achieve the first objective, two questionnaires were distributed. In the first, the students provided several translations for each sensation reflecting some features of the Arabic language. The translated phrases indicated acceptance for wide conditions as the students frequently translated the sensations between (cool) and (warm) including both into a term that literally means (moderate) or (mild). Moreover, the common translations provided by the students for different sensations revealed a possible overlapping in their understanding of these sensations. For instance, the differentiation between (slightly cool) and (cool) was weak, which was the case of (slightly warm) and (warm). This may reflect the effect of the climatic background of Muscat besides the students' level of knowledge based on their frequent questions regarding the meaning of (slightly). Hence, it is crucial to consider the effect of the participants' climatic background when translating thermal phrases.

Moreover, the two questionnaires revealed the students' ability to differentiate between neutrality and comfort. As expected, it was found that comfort was cooler than neutrality. The students were classified into two groups based on the order they provided for the translated

sensations. A uniform distribution of the sensations' means was provided by the group that followed the order of ASHRAE sensation scale. This indicates a relatively better understanding of the scale. The means of the warm side sensations in summer study were slightly warmer compared with winter study and the cool side sensations were marginally cooler. Thus, the seasons' effect on students' understanding of thermal sensations was negligible. Besides, thermal comfort was equivalent to the three central categories for the explored students.

Considering the second objective, the behaviour of the translated ASHRAE, Bedford, and Nicol scales was investigated applying the successive categories method. The findings confirmed the deviation of the scales from the original assumptions. The categories were irregular in width, asymmetrical around the centre of the thermal continuum, and the centres of the middle categories did not coincide with the continuum centre. Based on the categories' widths, wide conditions were (neutral) and (comfortable) for the explored students. The shift of both (neutral) and (no change) categories to the cool side of the thermal continuum indicated the effect of air conditioning systems on the students. Further, the translated versions of ASHRAE and Bedford scales covered different ranges on the thermal continuum regardless of their assumed equivalence. It is noteworthy that the deviations in the behaviour of the translated scales were stable in both summer and winter studies and they have a negative effect on the accuracy of thermal comfort results. Accordingly, it was concluded that identifying a particular set of data for further analysis was not possible. Moreover, the width irregularity of the non-central categories, regardless of their identical Arabic phrases, indicated that other factors, besides translation, influence the behaviour of the thermal scales. It should be mentioned that the calculated probits had relatively large standard errors, which implies that the categories' boundaries are approximate estimations on the thermal continuum.

10.1.5 Integrating objective and subjective measurements

With the objective of calculating the neutral temperature of the investigated students, a simple linear regression model was constructed based on the mean thermal sensations and the concurrent air, globe, and operative temperatures. The corresponding neutral temperatures were 23.5 °C, 23.6 °C, and 23.5 °C roughly. The thermal sensitivity was estimated at 0.124, 0.117, and 0.118 expressed in sensation changes per a unit change of air, globe, and operative temperatures respectively. Hence, the students exhibited adaptation to wide thermal conditions, which is mainly achieved by psychological means taking into account the general restrictions on adaptive actions in schools. Although the sensitivities were in agreement with the findings of other studies, they

may be unreliable because of three reasons. These are the relative clustering of votes in the warm side categories, the irregular width of the categories, and the protocol of distributing the questionnaires. Besides, the temperature steps were around 8.1 °C, 8.5 °C, and 8.5 °C in terms of air, globe, and operative temperatures respectively. These steps exhibited a good agreement with steps reported in Australian (de Dear et al., 2015) and British classrooms (Auliciems, 1969). Additionally, calculating the steps based on the actual widths of thermal categories resulted in arithmetic means of around 7.3 °C, 7.7 °C, and 7.6 °C in terms of air, globe, and operative temperatures respectively. Hence, it seems that the regression model tends to overestimate the students' adaptation.

According to the regression models of the individual schools, the arithmetic means of thermal sensitivities and air temperature steps were almost 0.663 and 2.1 °C respectively. Despite that the samples' sizes were increased, the new models were generally unreliable. Several reasons contributed to this unreliability including the narrow range of measured temperatures, errors in measuring temperatures, errors in the regression equations, and the survey's protocol.

Therefore, Griffiths' method was adopted as an alternative to the regression model applying a slope of 0.48/K. The neutral temperatures were recalculated as 24.8 °C, 25.0 °C, and 24.9 °C expressed in air, globe, and operative temperatures respectively. Integrating other values of Griffiths' slope resulted in statistically insignificant variations in the neutral temperatures. Besides, the new arithmetic mean of temperature steps based on the actual width of the sensation categories reduced to 1.9 °C roughly reflecting the low value of Griffiths' slope. The moderate correlations between the neutral temperature and the corresponding air, globe, and operative temperatures revealed some limitations in the adaptive actions of the students.

The acceptability limits of the investigated students were identified applying Griffiths' method. With reference to 80% acceptability level, the limits of air temperature were 23.1-26.6 °C approximately. Expressing the limits in globe and operative temperatures resulted in negligible variations compared with those of air temperature because of the strong relationships between these temperatures. The students' acceptability of warm conditions was higher than the regionally recommended range. Besides, the majority of the measured air and globe temperatures in the classrooms fell within the corresponding acceptability limits. Comparing this with the satisfaction and comfort levels revealed that other factors affect the students' thermal comfort besides the physical variables.

10.2 Research limitations

Participating in the survey, particularly in the first questionnaire as presented in Appendix 5., requires a certain level of English language capacity. The participated students spent at least nine years studying English as a second language and, thus, had acquired a sufficient level of the language. However, applying this research in high schools was associated with some limitations. For instance, the accessible schools by the researcher were located in Muscat city. The unique climatic and urban nature of the city distinguishes it from other cities in Oman. In addition, conducting the research in schools restricted it to the school day hours and the academic year months, which may not be climatically representative. Indeed, most of the hot and humid months fall outside the studying period. Moreover, it was the first time for almost all students to participate in a questionnaire and the majority thought that the questionnaires will be graded. This perhaps led some of them to provide answers that will possibly please the researcher. Besides, some teachers were restricted regarding time, which created unnecessary tension on the students. Moreover, the genders' separation applied by the educational system owing to the conservative nature of the Omani society created a selection bias. Accordingly, votes perhaps clustered in some categories as noted in previous studies (Nam et al., 2015; Katafygiotou & Serghides, 2014a; Yan & Yang, 2014; Kim et al., 2013; Schellen et al., 2013; Karjalainen, 2012; Karjalainen, 2007; Wang, 2006a; Parsons, 2002) that explored the difference in thermal responses among different genders. Additionally, the unforeseen challenges in (SQ) and (WK) Schools in winter study caused access limitation in the research, which was negatively reflected on the sample size.

The geographical distribution of the schools combined by the lack of financial resources to purchase more sensors prevented the researcher from being present in more than one school at the one day. Therefore, it was not possible to conduct the survey in all schools simultaneously to minimise the daily climatic fluctuations and their effect on students' thermal sensations. Besides, the limited budget prevented purchasing more sophisticated equipment with higher accuracy levels, which negatively affected the measurements' accuracy.

The nature of thermal comfort research, in specific its dependence on subjective questionnaires as an essential tool, is associated with some limitations. For instance, some questions in the current research like those of the adaptive actions depended on students' memories. It is possible that the students were selective in remembering their adaptive actions or they reported general actions that were not specific to the

mentioned period in the questions. Indeed, a student reported opening curtains in a classroom that had no curtains in the first pilot study. In addition, it is possible that the sequence of questionnaires' distribution limited the students' participation rate and collaboration willingness. It is noteworthy that the first questionnaire, that explored students' collective understanding of ASHRAE sensation scale, was difficult for most of them and it preceded the distribution of either ASHRAE or Bedford questionnaires in summer study.

Within these limitations, it is unacceptable to generalise the thermal comfort results to other schools unless some similarities are guaranteed in, for instance, the thermal characteristics of the explored classrooms and the gender, age, and insulation level of the students. Conducting more preparations to guarantee teachers' involvement in the research is likely to overcome some of these limitations maintaining a similar level of financial resources. Considering the findings of thermal scales' explorations, the nature of these explorations do not really require a representative sample as stated by (Humphreys & Hancock, 2007, p. 868): "For an exploration of the interior dynamic of the scale, it was not necessary to choose respondents by representative sampling, nor thermal environments strictly representative of the respondents' thermal experience, and nor was comprehensive measurement of the thermal environment required."

10.3 Research recommendations and future work

The following recommendations are derived from this research with the aim of enhancing the thermal experience of Omani female students in addition to improving the findings of thermal comfort studies generally and those concerning thermal comfort in educational buildings specifically. Considering students' experience, it is recommended to decrease the clothing level. This can be achieved via simplifying the school uniform or considering more varieties of uniforms from which the students can choose what to wear. Involving the students in the process of specifying the uniform is crucial to ensure its thermal appropriateness and appealing to students. It is, additionally, recommended to increase the students' awareness of adaptive actions and encourage them to actively adapt to the classrooms' thermal conditions considering other means besides air conditioning units. Besides, it is recommended to maintain classrooms' air temperatures between 23.1 °C and 26.6 °C generally and at 24.8 °C preferably.

Considering the interchangeable influence of thermal comfort demands and buildings' thermal performance, investigating the latter is highly recommended in the explored schools. Based on the conducted

study, exploring the feasibility of converting the open corridors between classrooms to closed or semi-closed corridors besides implementing passive cooling techniques is recommended. For the latter, planting more trees in the plazas and in the corridors between classrooms has generally a good potential to improve the students' thermal comfort and the buildings' thermal performance.

For a complete appreciation of the students' environments, future studies are advised to explore the visual, acoustical, and air quality conditions and their influence on students' productivity and health. It is recommended to integrate a few questions concerning the mentioned aspects of comfort in thermal comfort questionnaires. Exploring the thermal characteristics of the outdoor environments in Omani schools is recommended in addition to conducting continuous measurements and distributing questionnaires more than once during the school day. Good preparations are, additionally, highly advised to guarantee schools' participation throughout the study. Besides, sensors' locations in the classrooms should be carefully selected to avoid any negative effect on learning activities.

It is recommended to extend the research to include Omani male students besides other studying levels and other cities in Oman. Comparing the results of the current research with the findings of similar regional studies such as (Alwetaishi, 2015) is recommended. The latter study was carried out in male students' schools in Saudi Arabia. The comparison will, additionally, be an attempt to explore the effect of gender on thermal comfort. On a larger scale, it is suggested that more researchers consider conducting thermal comfort studies in the arid climate and the Arabic region in specific considering the relative lack of research in this region.

Considering thermal scales, it is recommended to investigate their behaviour in future studies of thermal comfort due to their effect on the findings' accuracy. In this regard, it should be mentioned that translation is not the only factor that determines thermal scales' behaviour. Thus, explorations are recommended to identify these factors and reveal their roles. The results of thermal scales' explorations combined with the comparisons of students' direct evaluations of their satisfaction and comfort levels with their sensations recommended the importance of emphasising the negative impressions associated with the sensations outside the three central categories. To account for the influence of translation, climatic, and cultural background, it is suggested to consider using phrases like (cool and not acceptable) and (warm and not acceptable) in the Arabic translations of thermal scales and similar contexts where (cool) and (warm) may be desirable sensations. Further,

it is suggested to construct Arabic thermal sensation and preference scales as they have the advantage of capturing the climatic and cultural background effects. A recommended procedure may involve collecting all the possible phrases used to describe thermal sensations and order them to produce a local thermal continuum. Additionally, it is advised to apply the implemented methodology to different groups of Eastern and Western Arabs to confirm and compare the findings.

As known, humidity has a relatively limited influence on thermal sensations, especially in moderate environments. Thus, the avoidance of humidity questions in the questionnaires is recommended in order to increase the participation rate and, potentially, improve the results' accuracy. Besides, increasing sensors' accuracy within the allowable budget limits and calibrating them contribute positively to the results' accuracy.

The lack of a relatively unified format for reporting the results of thermal comfort studies was highlighted in Chapter 3 and Chapter 9. It is thought that maintaining unity in format facilitates comparing and validating thermal comfort studies, which contributes positively to the topic's understanding. A suggested format involves identifying the context of the study represented in the city, season, general climatic conditions, buildings' type, ventilation mode, and any special features of the studied buildings. Attention should, additionally, be directed to the demographic features of the participants like their age, gender, and thermal history if relevant. Mentioning the number of analysed questionnaires is essential to understand the results. Moreover, it is suggested to report the types of measured variables with the sensors' accuracy in addition to the types of distributed thermal scales. In the case of translated scales, providing the specific wordings assists in appreciating the subjects' responses. Considering the results, it is recommended, as a minimum, to report the subjective votes' distribution and the optimum temperatures' type and calculation procedure.

References

Abdallah, A.S.H. 2015. Analysis of Thermal Comfort and Energy Consumption in Long Time Large Educational Halls (Studios), Assiut University, Egypt. *Procedia Engineering*, 121: 1674–1681.

Abdul-Wahab, S., Salem, N. & Sappurd, A. 2015. Investigation of the environmental indicators at the main library of Sultan Qaboos University (SQU) in the Sultanate of Oman. *Sustainable Environment Research*, 25(3): 131–139.

Abdul-Wahab, S.A., Charabi, Y., Al-Maamari, R., Al-Rawas, G.A., Gastli, A. & Chan, K. 2015. CO2 greenhouse emissions in Oman over the last forty-two years: Review. *Renewable and Sustainable Energy Reviews*, 52: 1702–1712.

Abdul-Wahab, S.A., Charabi, Y., Al-Rawas, G.A., Al-Maamari, R., Gastli, A. & Chan, K. 2015. Greenhouse gas (GHG) emissions in the Sultanate of Oman. *Greenhouse Gases: Science and Technology*, 5(3): 339–346.

Aboulnaga, M.M. 2006. Towards green buildings: Glass as a building element—the use and misuse in the gulf region. *Renewable Energy*, 31(5): 631–653.

Agresti, A. 1992. A Survey of Exact Inference for Contingency Tables. *Statistical Science*, 7(1): 131–153.

Al-ajmi, F.F. 2010. Thermal comfort in air-conditioned mosques in the dry desert climate. *Building and Environment*, 45(11): 2407–2413.

Al-ajmi, F.F., Loveday, D.L., Bedwell, K.H. & Havenith, G. 2008. Thermal insulation and clothing area factors of typical Arabian Gulf clothing ensembles for males and females: Measurements using thermal manikins. *Applied Ergonomics*, 39(3): 407–414.

Al-Azri, N., Zurigat, Y. & Al-Rawahi, N. 2013. Selection and Assessment of Passive Cooling Techniques for Residential Buildings in Oman Using a Bioclimatic Approach. *The Journal of Engineering Research [TJER]*, 10(2): 52.

Al-Azri, N.A., Zurigat, Y.H. & Al-Rawahi, N.Z. 2013. Development of bioclimatic chart for passive building design. *International Journal of Sustainable Energy*, 32(6): 713–723.

Al-Badi, A.H., Malik, A. & Gastli, A. 2011. Sustainable energy usage in Oman—Opportunities and barriers. *Renewable and Sustainable Energy Reviews*, 15(8): 3780–3788.

Al-Gharibi, H. 2016. Urbanisation and changing lifestyle patterns in Muscat. In S. Nebel & A. von Richthofen, eds. *Urban Oman: Trends and perspective of urbanisation in Muscat capital area*. Zurich: LIT Verlag: 73–79.

Al-Hinai, H., Batty, W.J. & Probert, S.D. 1993. Vernacular architecture of Oman: Features that enhance thermal comfort achieved within buildings. *Applied Energy*, 44(3): 233–258.

Al-Khatri, H. & Gadi, M.B. 2014. Using a New Programme to Predict Thermal Comfort as a Base to Design Energy Efficient Buildings. *International Journal of Students' Research in Technology & Management*, 2(5): 172–177.

Al-Najar, N. 2016. View of education development in Oman. *International Journal of Academic Research in Education and Review*, 4(1): 10–18.

Al-Rashidi, K.E., Loveday, D.L. & Al-Mutawa, N.K. 2009. Investigating the Applicability of Different Thermal Comfort Models in Kuwait Classrooms Operated in Hybrid Air-Conditioning Mode. In *Sustainability in Energy and Buildings*. Berlin, Heidelberg: Springer Berlin Heidelberg: 347–355.

Al-Sallal, K.A. 1998. Sizing windows to achieve passive cooling, passive heating, and daylighting in hot arid regions. *Renewable Energy*, 14(1–4): 365–371.

Al-Shaqsi, S. 2010. Care or Cry: Three years from Cyclone Gonu. What have we learnt? *Oman medical journal*, 25(3): 162–7.

Alhinai, M.Y. 2011. Tropical cyclone gonu: number of patients and pattern of illnesses in the primary health centers in a'seeb area, muscat, sultanate of oman. *Oman medical journal*, 26(4): 223–8.

Ali, S.M., Martinson, B.D., Al-Maiyah, S. & Gaterell, M. 2018. Effects of ceiling fans on the thermal comfort of students in learning environments of Bayero University, Kano, Nigeria. In *10th Windsor Conference: Rethinking comfort*. Windsor: NCEUB (Network for Comfort and Energy Use in Buildings): 194–208.

Almeida, R.M.S.F. & de Freitas, V.P. 2015. IEQ Assessment of Classrooms with an Optimized Demand Controlled Ventilation System. *Energy Procedia*, 78: 3132–3137.

AlNajjar, R.W., Al-Mumin, A. & Indraganti, M. 2018. Thermal comfort in office buildings during the summer season: Findings from a field study in Kuwait. In *10th Windsor Conference: Rethinking comfort*. Windsor: 555–581.

Alnaser, W.E. & Alnaser, N.W. 2011. The status of renewable energy in the GCC countries. *Renewable and Sustainable Energy Reviews*, 15(6): 3074–3098.

Alsmearat, K., Al-Ayyoub, M., Al-Shalabi, R. & Kanaan, G. 2017. Author gender identification from Arabic text. *Journal of Information Security and Applications*, 35: 85–95.

Alwetaishi, M.S. 2015. *Human thermal comfort and building performance of schools in hot and humid climate with a particular reference to Saudi Arabia, Jeddah.* University of Nottingham.

Amin, N.D.M., Akasah, Z.A. & Razzaly, W. 2015. Architectural Evaluation of Thermal Comfort: Sick Building Syndrome Symptoms in Engineering Education Laboratories. *Procedia - Social and Behavioral Sciences*, 204: 19–28.

Arslanoglu, N. & Yigit, A. 2016. Experimental and theoretical investigation of the effect of radiation heat flux on human thermal comfort. *Energy and Buildings*, 113: 23–29.

ASHRAE. 2017. *2017 ASHRAE Handbook Fundamentals*. SI. Atlanta: ASHRAE (American Society of Heating, Refrigerating and Air-Conditioning Engineers).

ASHRAE. 2010. *ANSI/ASHRAE Standard 55-2010 Thermal Environmental Conditions for Human Occupancy*. Atlanta: ASHRAE (American Society of Heating, Refrigerating and Air-Conditioning Engineers).

Auliciems, A. 1969. Thermal requirements of secondary schoolchildren in winter. *The Journal of hygiene*, 67(1): 59–65.

Auliciems, A. & Szokolay, S. V. 2007. *PLEA Notes: Thermal Comfort*. Brisbane.

Awajan, A. 2015. Keyword Extraction from Arabic Documents using Term Equivalence Classes. *ACM Transactions on Asian and Low-Resource Language Information Processing*, 14(2): 1–18.

Bhutto, A.W., Bazmi, A.A. & Zahedi, G. 2014. A review of progress in renewable energy implementation in the Gulf Cooperation Council countries. *Journal of Cleaner Production*, 71: 168–180.

Billé, R. 2010. Action without change? On the use and usefulness of pilot experiments in environmental management. *Surveys and Perspectives Integrating Environment and Society*, 3(1): 1–6.

Bölük, G. & Mert, M. 2014. Fossil & renewable energy consumption, GHGs (greenhouse gases) and economic growth: Evidence from a panel of EU (European Union) countries. *Energy*, 74: 439–446.

Brager, G.S. & de Dear, R.J. 1998. Thermal adaptation in the built environment: a literature review. *Energy and Buildings*, 27(1): 83–96.

Broday, E.E., Xavier, A.A. de P. & de Oliveira, R. 2014. Comparative analysis of methods for determining the metabolic rate in order to provide a balance between man and the environment. *International Journal of Industrial Ergonomics*, 44(4): 570–580.

Brown, R.D. 2010. *Design with microclimate: The secret to comfortable outdoor space*. Washington: Island Press.

Brown, R.D. & Gillespie, T.J. 1995. *Microclimatic Landscape Design: Creatng Thermal Comfort and Energy Efficiency*. New York: John Wiely & Sons, Inc.

Bryman, A. 2012. *Social research methods*. 4th ed. Oxford: Oxford University Press.

BS EN 15251. 2008. *BS EN 15251: 2007 Indoor environmental input parameters for design and assessment of energy performance of buildings addressing indoor air quality, thermal environment, lighting and acoustics*. Brussels: CEN (European Committee for Standardization).

BS EN ISO 11399. 2001. *BS EN ISO 11399: Ergonomics of the thermal environment - Principles and application of relevant international standards*. Brussels: CEN (European Committee for Standardization).

BS EN ISO 7726. 2001. *BS EN ISO 7726: Ergonomics of the thermal environment - Instruments for measuring physical quantities*. Brussels: CEN (European Committee for Standardization).

BS EN ISO 7730. 2005. *BS EN ISO 7730: 2005 Ergonomics of the thermal environment - Analytical determination and interpretation of thermal comfort using calculation of the PMV and PPD indices and local thermal comfort criteria*. Brussels: CEN (European Committee for Standardization).

Buratti, C., Palladino, D. & Ricciardi, P. 2016. Application of a new 13-value thermal comfort scale to moderate environments. *Applied Energy*, 180: 859–866.

Burt, S. 2012. *The weather observer's handbook*. New York: Cambridge University Press.

Cao, B., Luo, M., Li, M. & Zhu, Y. 2016. Too cold or too warm? A winter thermal comfort study in different climate zones in China. *Energy and Buildings*, 133: 469–477.

Cao, B., Zhu, Y., Ouyang, Q., Zhou, X. & Huang, L. 2011. Field study of human thermal comfort and thermal adaptability during the summer and winter in Beijing. *Energy and Buildings*, 43(5): 1051–1056.

Chadderton, D. V. 2007. *Building Services Engineering*. 5th ed. Oxon: Taylor & Francis.

Chappells, H. & Shove, E. 2005. Debating the future of comfort: environmental sustainability, energy consumption and the indoor environment. *Building Research & Information*, 33(1): 32–40.

Charabi, Y. & Bakhit, A. 2011. Assessment of the canopy urban heat island of a coastal arid tropical city: The case of Muscat, Oman. *Atmospheric Research*, 101(1–2): 215–227.

Cheng, M.-J., Hwang, R.-L. & Lin, T.-P. 2008. Indoor and Built uilt Environment Field Experiments on Thermal Comfort Requirements for Campus Dormitories in Taiwan. *Indoor and Built Environment*, 17(3): 191–202.

Chow, T.T., Fong, K.F., Givoni, B., Lin, Z. & Chan, A.L.S. 2010. Thermal sensation of Hong Kong people with increased air speed, temperature and humidity in air-conditioned environment. *Building and Environment*, 45(10): 2177–2183.

Chung, T.M.M. & Tong, W.C.C. 1990. Thermal Comfort Study of Young Chinese People in Hong Kong. *Building and Environment*, 25(4): 317–328.

CIBSE. 2015. *Environmental design - CIBSE Guide A*. 8th ed. London: CIBSE (The Chartered Institution of Building Services Engineers).

Corgnati, S.P., Ansaldi, R. & Filippi, M. 2009. Thermal comfort in Italian classrooms under free running conditions during mid seasons: Assessment through objective and subjective approaches. *Building and Environment*, 44(4): 785–792.

Corgnati, S.P., Filippi, M. & Viazzo, S. 2007. Perception of the thermal environment in high school and university classrooms: Subjective preferences and thermal comfort. *Building and Environment*, 42(2): 951–959.

Costa, P.M. 2001. *Historic mosques and shrines of Oman*. Oxford: Archaeopress.

d'Ambrosio Alfano, F.R., Dell'Isola, M., Palella, B.I., Riccio, G. & Russi, A. 2013. On the measurement of the mean radiant temperature and its influence on the indoor thermal environment assessment. *Building and Environment*, 63: 79–88.

d'Ambrosio Alfano, F.R., Ianniello, E. & Palella, B.I. 2013. PMV–PPD and acceptability in naturally ventilated schools. *Building and Environment*, 67: 129–137.

d'Energia, I.C. 2004. *Sustainable building: Design manual - volume 2*. New Delhi: The Energy and Resources Institute.

Daneshvar, M., Bagherzadeh, A. & Tavousi, T. 2013. Assessment of bioclimatic comfort conditions based on Physiologically Equivalent Temperature (PET) using the RayMan Model in Iran. *Open Geosciences*, 5(1): 53–60.

de Dear, R., Brager, G. & Cooper, D. 1997. *Developing an adaptive model of thermal comfort and preference*. Atlanta.

de Dear, R., Kim, J., Candido, C. & Deuble, M. 2015. Adaptive thermal comfort in Australian school classrooms. *Building Research & Information*, 43(3): 383–398.

de Dear, R.J. & White, S. 2008. Residential air conditioning, thermal comfort and peak electricity demand management. In *5th Windsor Conference: Air Conditioning and the Low Carbon Cooling Challenge*. Windsor: NCEUB (Network for Comfort and Energy Use in Buildings): 1–11.

Dias Pereira, L., Raimondo, D., Corgnati, S.P. & Gameiro da Silva, M. 2014a. Assessment of indoor air quality and thermal comfort in Portuguese secondary classrooms: Methodology and results. *Building and Environment*, 81: 69–80.

Dias Pereira, L., Raimondo, D., Corgnati, S.P. & Gameiro da Silva, M. 2014b. Energy consumption in schools – A review paper. *Renewable and Sustainable Energy Reviews*, 40: 911–922.

Djamila, H. 2017. Indoor thermal comfort predictions: Selected issues and trends. *Renewable and Sustainable Energy Reviews*, 74: 569–580.

Djongyang, N., Tchinda, R. & Njomo, D. 2010. Thermal comfort: A review paper. *Renewable and Sustainable Energy Reviews*, 14(9): 2626–2640.

Dubai Municipality. 2014. *Green building regulations and specifications*.

Fabbri, K. 2013. Thermal comfort evaluation in kindergarten: PMV and PPD measurement through datalogger and questionnaire. *Building and Environment*, 68: 202–214.

Farghal, A. & Wagner, A. 2008. Studying the adaptive comfort approach within a hot dry climate: A case study in educational buildings in the Egyptian climate. In *5th Windsor Conference: Air Conditioning and the Low Carbon Cooling Challenge*. Windsor: NCEUB (Network for Comfort and Energy Use in Buildings): 1–15.

Feriadi, H. & Wong, N.H. 2004. Thermal comfort for naturally ventilated houses in Indonesia. *Energy and Buildings*, 36(7): 614–626.

Ferreira, A.M. da C. & Cardoso, M. 2014. Indoor air quality and health in schools. *Jornal Brasileiro de Pneumologia*, 40(3): 259–68.

Fountain, M.E., Arens, E., Xu, T., Bauman, F.S. & Oguru, M. 1999. An investigation of thermal comfort at high humidities. *ASHRAE Transactions Research*, 94: 94–103.

Frenken, K. 2009. *Irrigation in the Middle East region in figures: AQUASTAT Surevy - 2008*. Rome.

Frost, J. 2013a. Four tips on how to perform a regression analysis that avoids common problems. http://blog.minitab.com/blog/adventures-in-statistics-2/four-tips-on-how-to-perform-a-regression-analysis-that-avoids-common-problems 10 August 2017.

Frost, J. 2013b. Regression analysis: How do I interpret R-squared and assess the goodness-of-fit? http://blog.minitab.com/blog/adventures-in-statistics-2/regression-analysis-how-do-i-interpret-r-squared-and-assess-the-goodness-of-fit 10 August 2017.

Fuchs, X., Becker, S., Schakib-Ekbatan, K. & Schweiker, M. 2018. Subgroups holding different conceptions of scales rate room temperatures differently. *Building and Environment*, 128: 236–247.

La Gennusa, M., Nucara, A., Pietrafesa, M. & Rizzo, G. 2007. A model for managing and evaluating solar radiation for indoor thermal comfort. *Solar Energy*, 81(5): 594–606.

De Giuli, V., Da Pos, O. & De Carli, M. 2012. Indoor environmental quality and pupil perception in Italian primary schools. *Building and Environment*, 56: 335–345.

De Giuli, V., Zecchin, R., Corain, L. & Salmaso, L. 2014. Measured and perceived environmental comfort: Field monitoring in an Italian school. *Applied Ergonomics*, 45(4): 1035–1047.

Giusti, L. & Almoosawi, M. 2017. Impact of building characteristics and occupants' behaviour on the electricity consumption of households in Abu Dhabi (UAE). *Energy and Buildings*, 151: 534–547.

Givoni, B. 1998. *Climate considerations in building and urban design*. Danvers: John Wiley & Sons, Inc.

Givoni, B., Noguchi, M., Saaroni, H., Pochter, O., Yaacov, Y., Feller, N. & Becker, S. 2003. Outdoor comfort research issues. *Energy and Buildings*, 35(1): 77–86.

Global Footprint Network. 2018. Ecological footprint per person. http://data.footprintnetwork.org/#/ 30 May 2018.

Groat, L. & Wang, D. 2013. *Architectural Research Methods*. 2nd ed. New Jersey: John Wiely & Sons, Inc.

Halawa, E. & van Hoof, J. 2012. The adaptive approach to thermal comfort: A critical overview. *Energy and Buildings*, 51: 101–110.

Halawa, E., van Hoof, J. & Soebarto, V. 2014. The impacts of the thermal radiation field on thermal comfort, energy consumption and control—A critical overview. *Renewable and Sustainable Energy Reviews*, 37: 907–918.

Hamzah, B., Gou, Z., Mulyadi, R., Amin, S., Hamzah, B., Gou, Z., Mulyadi, R. & Amin, S. 2018. Thermal Comfort Analyses of Secondary School Students in the Tropics. *Buildings*, 8(56): 1–19.

Harrison, A. 1988. Arabic pain words. *Pain*, 32(2): 239–250.

Hasan, M.H., Alsaleem, F. & Rafaie, M. 2016. Sensitivity study for the PMV thermal comfort model and the use of wearable devices biometric data for metabolic rate estimation. *Building and Environment*, 110: 173–183.

Havenith, G., Holmér, I. & Parsons, K. 2002. Personal factors in thermal comfort assessment: clothing properties and metabolic heat production. *Energy and Buildings*, 34(6): 581–591.

Haverinen-Shaughnessy, U., Shaughnessy, R.J., Cole, E.C., Toyinbo, O. & Moschandreas, D.J. 2015. An assessment of indoor environmental quality in schools and its association with health and performance. *Building and Environment*, 93: 35–40.

Hensen, J.L.M. 1991. *On the thermal interaction of building structure and heating and ventilating system*. Eindhoven University of Technology.

Hodder, S. & Parsons, K. 2008. The effects of solar radiation and black body re-radiation on thermal comfort. *Ergonomics*, 51(4): 476–491.

Holes, C. 2004. *Modern Arabic: structures, functions, and varieties*. 2nd ed. Washington, D.C.: Georgetown University Press.

Höppe, P. 2002. Different aspects of assessing indoor and outdoor thermal comfort. *Energy and Buildings*, 34(6): 661–665.

Humphreys, M. & Nicol, F. 2018. Puzzles and paradoxes in adaptive comfort. In *10th Windsor Conference: Rethinking comfort*. Windsor: NCEUB (Network for Comfort and Energy Use in Buildings): 3–19.

Humphreys, M., Nicol, F. & Roaf, S. 2016. *Adaptive Thermal Comfort: Foundations and Analysis*. 1st ed. Oxon: Routledge.

Humphreys, M.A. 1977. A study of the thermal comfort of primary school children in summer. *Building and Environment*, 12(4): 231–239.

Humphreys, M.A. 1976. Field studies of thermal comfort compared and applied. *Journal of the Institution of Heating and Ventilating Engineers*, 44: 5–27.

Humphreys, M.A. 2008. 'Why did the piggy bark?' Some effects of language and context on the interpretation of words used in scales of warmth and thermal preference. In *5th Windsor Conference: Air Conditioning and the Low Carbon Cooling Challenge*. Windsor: NCEUB (Network for Comfort and Energy Use in Buildings): 1–14.

Humphreys, M.A. & Hancock, M. 2007. Do people like to feel 'neutral'?: Exploring the variation of the desired thermal sensation on the ASHRAE scale. *Energy and Buildings*, 39(7): 867–874.

Humphreys, M.A., Rijal, H.B. & Nicol, J.F. 2013. Updating the adaptive relation between climate and comfort indoors; new insights and an extended database. *Building and Environment*, 63: 40–55.

Hwang, R.-L., Lin, T.-P., Chen, C.-P. & Kuo, N.-J. 2009. Investigating the adaptive model of thermal comfort for naturally ventilated school buildings in Taiwan. *International Journal of Biometeorology*, 53(2): 189–200.

Hwang, R.-L., Lin, T.-P. & Kuo, N.-J. 2006. Field experiments on thermal comfort in campus classrooms in Taiwan. *Energy and Buildings*, 38(1): 53–62.

Indraganti, M. & Boussaa, D. 2018. Developing the adaptive model of thermal comfort for offices in the GCC region. In *10th Windsor Conference: Rethinking Comfort*. Windsor: NCEUB (Network for Comfort and Energy Use in Buildings): 533–554.

Indraganti, M., Ooka, R. & Rijal, H.B. 2015. Thermal comfort in offices in India: Behavioral adaptation and the effect of age and gender. *Energy and Buildings*, 103: 284–295.

Indraganti, M. & Rao, K.D. 2010. Effect of age, gender, economic group and tenure on thermal comfort: A field study in residential buildings in hot and dry climate with seasonal variations. *Energy and Buildings*, 42(3): 273–281.

Indurti, A.S., Mass, E.P., Ramadan, M., Deshpande, M.S., Soilam, M., Ranjith, A. & Abraham, T. 2009. *Oman's official guide and atlas*. Muscat: Ministry of Tourism.

Issa, M.H., Rankin, J.H., Attalla, M. & Christian, A.J. 2011. Absenteeism, Performance and Occupant Satisfaction with the Indoor Environment of Green Toronto Schools. *Indoor and Built Environment*, 20(5): 511–523.

Ja'abub, M.S. 2010. *Leading society towards change: Educational experience of the revolution of Dhofar (1969-1992)*. Beirut: Centre of Arab Unity Studies.

Jazizadeh, F., Marin, F.M. & Becerik-Gerber, B. 2013. A thermal preference scale for

personalized comfort profile identification via participatory sensing. *Building and Environment*, 68: 140–149.

Jing, S., Li, B., Tan, M. & Liu, H. 2013. Impact of Relative Humidity on Thermal Comfort in a Warm Environment. *Indoor and Built Environment*, 22(4): 598–607.

Jokl, M. V. 2002. Thermal Comfort and Optimum Humidity Part 1. *Acta Polytechnica*, 42(1): 12–24.

Jones, B.W., Hsieh, K. & Hashinaga, M. 1986. The effect of air velocity on thermal comfort at moderate activity levels. *ASHRAE Transactions*, 92(2B): 761–768.

Jones, J. & Ridout, N. 2015. *A History of Modern Oman*. New York: Cambrige University Press.

Karjalainen, S. 2007. Gender differences in thermal comfort and use of thermostats in everyday thermal environments. *Building and Environment*, 42(4): 1594–1603.

Karjalainen, S. 2012. Thermal comfort and gender: a literature review. *Indoor Air*, 22(2): 96–109.

Karyono, T.H. 2008. Bandung Thermal Comfort Study: Assessing the Applicability of an Adaptive Model in Indonesia. *Architectural Science Review*, 51(1): 60–65.

Katafygiotou, M.C. & Serghides, D.K. 2014a. Indoor comfort and energy performance of buildings in relation to occupants' satisfaction: investigation in secondary schools of Cyprus. *Advances in Building Energy Research*, 8(2): 216–240.

Katafygiotou, M.C. & Serghides, D.K. 2014b. Thermal comfort of a typical secondary school building in Cyprus. *Sustainable Cities and Society*, 13: 303–312.

Katodrytis, G. 2015. Performative Urbanism: An Emerging Model of the Gulf. *Architectural Design: UAE and The Gulf Architecture and Urbanism Now*: 121–127.

Khatun, A., Hasib, M.A., Nagano, H. & Taimura, A. 2017. Differences in reported linguistic thermal sensation between Bangla and Japanese speakers. *Journal of physiological Anthropology*, 36(23): 1–8.

Kim, H.-Y. 2017. Statistical notes for clinical researchers: Chi-squared test and Fisher's exact test. *Restorative dentistry & endodontics*, 42(2): 152–155.

Kim, J. & de Dear, R. 2018. Thermal comfort expectations and adaptive behavioural characteristics of primary and secondary school students. *Building and Environment*, 127: 13–22.

Kim, J., de Dear, R., Cândido, C., Zhang, H. & Arens, E. 2013. Gender differences in office occupant perception of indoor environmental quality (IEQ). *Building and Environment*, 70: 245–256.

Koch-Nielsen, H. 2007. *Stay cool: a design guide for the built environment in hot climates*. London: Earthscan.

Koelblen, B., Psikuta, A., Bogdan, A., Annaheim, S. & Rossi, R.M. 2017. Thermal sensation models: a systematic comparison. *Indoor Air*, 27(3): 680–689.

Konya, A. & Vandenberg, M. 2011. *Design primer for hot climates*. Reading: Archimedia Press Limited.

Korsavi, S.S. & Montazami, A. 2018. Adaptive behaviours and occupancy patterns in UK primary schools: Impacts on comfort and indoor quality. In *10th Windsor Conference: Rethinking comfort*. Windsor: NCEUB (Network for Comfort and Energy Use in Buildings): 610–622.

Krawczyk, D.A., Gładyszewska-Fiedoruk, K. & Rodero, A. 2017. The analysis of microclimate parameters in the classrooms located in different climate zones. *Applied Thermal Engineering*, 113: 1088–1096.

Krosnick, J.A. & Presser, S. 2010. Chapter 9: Question and Questionnaire Design. In J. D. Wright & P. V. Marsden, eds. *Handbook of Surevy Research*. Bingley:

Emerald Group Publishing Limited.

Kuru, M. & Calis, G. 2017. Understanding the Relationship between Indoor Environmental Parameters and Thermal Sensation of users Via Statistical Analysis. *Procedia Engineering*, 196: 808–815.

Kwok, A.G. & Chun, C. 2003. Thermal comfort in Japanese schools. *Solar Energy*, 74(3): 245–252.

Lan, L., Lian, Z., Liu, W. & Liu, Y. 2008. Investigation of gender difference in thermal comfort for Chinese people. *European Journal of Applied Physiology*, 102(4): 471–480.

Langsrud, O. Fisher's exact test. : [1] O. Langsrud, Fisher's exact test, (n.d.). http. http://www.langsrud.com/fisher.htm 30 April 2018.

Lee, J.-Y., Stone, E.A., Wakabayashi, H. & Tochihara, Y. 2010. Issues in combining the categorical and visual analog scale for the assessment of perceived thermal sensation: Methodological and conceptual considerations. *Applied Ergonomics*, 41(2): 282–290.

Lee, M.C., Mui, K.W., Wong, L.T., Chan, W.Y., Lee, E.W.M. & Cheung, C.T. 2012. Student learning performance and indoor environmental quality (IEQ) in air-conditioned university teaching rooms. *Building and Environment*, 49: 238–244.

Leon, A.C., Davis, L.L. & Kraemer, H.C. 2011. The role and interpretation of pilot studies in clinical research. *Journal of Psychiatric Research*, 45(5): 626–629.

Liang, H.-H., Lin, T.-P. & Hwang, R.-L. 2012. Linking occupants' thermal perception and building thermal performance in naturally ventilated school buildings. *Applied Energy*, 94: 355–363.

Liu, Y., Jiang, J., Wang, D. & Liu, J. 2017. The indoor thermal environment of rural school classrooms in Northwestern China. *Indoor and Built Environment*, 26(5): 662–679.

Loreti, L., Barbaresi, L., De Cesaris, S. & Garai, M. 2015. Overall Indoor Quality of a Non-renewed Secondary-school Building. *Energy Procedia*, 78: 3126–3131.

Luo, M., de Dear, R., Ji, W., Bin, C., Lin, B., Ouyang, Q. & Zhu, Y. 2016. The dynamics of thermal comfort expectations: The problem, challenge and impication. *Building and Environment*, 95: 322–329.

Luo, M., Zhou, X., Zhu, Y. & Sundell, J. 2016. Revisiting an overlooked parameter in thermal comfort studies, the metabolic rate. *Energy and Buildings*, 118: 152–159.

Majid, N.H.A., Takagi, N., Hokoi, S., Ekasiwi, S.N.N. & Uno, T. 2014. Field survey of air conditioner temperature settings in a hot, dry climate (Oman). *HVAC&R Research*, 20(7): 751–759.

Manu, S., Shukla, Y., Rawal, R., Thomas, L.E. & de Dear, R. 2016. Field studies of thermal comfort across multiple climate zones for the subcontinent: India Model for Adaptive Comfort (IMAC). *Building and Environment*, 98: 55–70.

Mayer, E. 1993. Objective criteria for thermal comfort. *Building and Environment*, 28(4): 399–403.

Maykot, J.K., Rupp, R.F. & Ghisi, E. 2018. A field study about gender and thermal comfort temperatures in office buildings. *Energy and Buildings*, 178: 254–264.

McCluskey, A. & Lalkhen, A.G. 2007. Statistics III: Probability and statistical tests. *Continuing Education in Anaesthesia Critical Care & Pain*, 7(5): 167–170.

McDonald, J.H. 2014. *Handbook of biological statistics*. 3rd ed. Baltimore: Sparky House Publishing.

Meier, A., Olofsson, T. & Lamberts, R. 2002. What Is an Energy-Efficient Building? In *IX Encontro Nacional de Tecnologia do Ambiente Construido*. Parana: ENTAC: 3–12.

Mendell, M.J. & Heath, G.A. 2005. Do indoor pollutants and thermal conditions in schools influence student performance? A critical review of the literature. *Indoor Air*, 15(1): 27–52.

Mendelsohn, R., Emanuel, K., Chonabayashi, S. & Bakkensen, L. 2012. The impact of climate change on global tropical cyclone damage. *Nature Climate Change*, 2(3): 205–209.

Messing, K. & Stellman, J.M. 2006. Sex, gender and women's occupational health: The importance of considering mechanism. *Environmental Research*, 101(2): 149–162.

Metje, N., Sterling, M. & Baker, C.J. 2008. Pedestrian comfort using clothing values and body temperatures. *Journal of Wind Engineering and Industrial Aerodynamics*, 96(4): 412–435.

Ministry of Education. 2013. *The annual educational statistics book 2012/2013*. Muscat: Ministry of Education.

Ministry of Tourism. 2013. Mountains in Oman. http://www.omantourism.gov.om/wps/portal/mot/tourism/oman/home/experiences/nature/mountains/!ut/p/a0/04_Sj9CPykssy0xPLMnMz0vMAfGjzOItvc1dg40MzAz8fZzMDTyDQz0Mg92djN29zPQLsh0VAQHIYF0!/ 5 August 2015.

Mishra, A.K. & Ramgopal, M. 2015. A thermal comfort field study of naturally ventilated classrooms in Kharagpur, India. *Building and Environment*, 92: 396–406.

Mishra, A.K. & Ramgopal, M. 2013. Field studies on human thermal comfort — An overview. *Building and Environment*, 64: 94–106.

Mollyee. 2013. Introduction to soil and water sciences field equipment. http://mooooooli92szeyee.blogspot.co.uk/2013/09/introduction-to-soil-and-water-sciences.html 26 July 2015.

Montazami, A., Gaterell, M. & Nicol, F. 2015. A comprehensive review of environmental design in UK schools: History, conflicts and solutions. *Renewable and Sustainable Energy Reviews*, 46: 249–264.

Montazami, A. & Nicol, F. 2013. Overheating in schools: comparing existing and new guidelines. *Building Research & Information*, 41(3): 317–329.

Moon, J.H., Lee, J.W., Jeong, C.H. & Lee, S.H. 2016. Thermal comfort analysis in a passenger compartment considering the solar radiation effect. *International Journal of Thermal Sciences*, 107: 77–88.

Mors, S. ter, Hensen, J.L.M., Loomans, M.G.L.C. & Boerstra, A.C. 2011. Adaptive thermal comfort in primary school classrooms: Creating and validating PMV-based comfort charts. *Building and Environment*, 46(12): 2454–2461.

Mumovic, D., Palmer, J., Davies, M., Orme, M., Ridley, I., Oreszczyn, T., Judd, C., Critchlow, R., Medina, H.A., Pilmoor, G., Pearson, C. & Way, P. 2009. Winter indoor air quality, thermal comfort and acoustic performance of newly built secondary schools in England. *Building and Environment*, 44(7): 1466–1477.

Nam, I., Yang, J., Lee, D., Park, E. & Sohn, J.-R. 2015. A study on the thermal comfort and clothing insulation characteristics of preschool children in Korea. *Building and Environment*, 92: 724–733.

NCSI. 2017. *2017 Statistical year book*. Muscat.

NCSI. 2018. *Population statistics*. Muscat.

Nematchoua, M.K., Tchinda, R. & Orosa, J.A. 2014. Thermal comfort and energy consumption in modern versus traditional buildings in Cameroon: A questionnaire-based statistical study. *Applied Energy*, 114: 687–699.

Nicol, F., Humphreys, M. & Roaf, S. 2012. *Adaptive thermal comfort: Principles and practice*. 1st ed. Oxon: Routledge.

Nicol, J.F. & Humphreys, M.A. 2002. Adaptive thermal comfort and sustainable thermal standards for buildings. *Energy and Buildings*, 34(6): 563–572.

Nicol, J.F. & Roaf, S. 2017. Rethinking thermal comfort. *Building Research & Information*, 45(7): 711–716.

Nikolopoulou, M., Baker, N. & Steemers, K. 2001. Thermal comfort in outdoor urban spaces: understanding the human parameter. *Solar Energy*, 70(3): 227–235.

Nikolopoulou, M., Lykoudis, S. & Kikira, M. 2004. Thermal Comfort Models for Open Urban Spaces. In M. Nikolopoulou, ed. *Designing open spaces in the urban environment: a bioclimatic approach*. CRES (Centre for Renewable Energy Sources): 2–6.

Nikolopoulou, M. & Steemers, K. 2003. Thermal comfort and psychological adaptation as a guide for designing urban spaces. *Energy and Buildings*, 35(1): 95–101.

Ning, H., Wang, Z. & Ji, Y. 2016. Thermal history and adaptation: Does a long-term indoor thermal exposure impact human thermal adaptability? *Applied Energy*, 183: 22–30.

On The World Map. 2018. Oman political map. http://ontheworldmap.com/oman/oman-political-map.html 7 March 2018.

Parsons, K. 2014. *Human Thermal Environments: The Effects of Hot, Moderate, and Cold Environments on Human Health, Comfort, and Performance*. 3rd ed. Boca Raton: CRC Press.

Parsons, K.C. 2002. The effects of gender, acclimation state, the opportunity to adjust clothing and physical disability on requirements for thermal comfort. *Energy and Buildings*, 34(6): 593–599.

Peeters, L., Dear, R. de, Hensen, J. & D'haeseleer, W. 2009. Thermal comfort in residential buildings: Comfort values and scales for building energy simulation. *Applied Energy*, 86(5): 772–780.

Pistore, L., Cappelletti, F., Romagnoni, P. & Zonta, A. 2015. Assessment of the IEQ in Two High Schools by Means of Monitoring, Surveys and Dynamic Simulation. *Energy Procedia*, 82: 519–525.

Pitts, A. 2006. The language and semantics of thermal comfort. In *4th Windsor Conference: Comfort and Energy Use in Buildings - getting them right*. Windsor: NCEUB (Network for Comfort and Energy Use in Buildings): 1–7.

Porta, M., Greenland, S., Hernan, M., Silva, I. dos S., Last, J.M. & Buron, A. 2014. *A dictionary of epidemiology*. 6th ed. Oxford: Oxford University Press.

Puteh, M., Ibrahim, M.H., Adnan, M., Che'Ahmad, C.N. & Noh, N.M. 2012. Thermal Comfort in Classroom: Constraints and Issues. *Procedia - Social and Behavioral Sciences*, 46: 1834–1838.

Qader, M.R. 2009. Electricity Consumption and GHG Emissions in GCC Countries. *Energies*, 2(4): 1201–1213.

Ragette, F. 2012. *Traditional Domestic Architecture of the Arab Region*. 1st ed. Zlin: American Univeristy of Sharjah.

Rijal, H.B., Omori, T., Humphreys, M.A. & Nicol, F.J. 2014. A field-comparison of thermal comfort with floor heating systems and air conditioning systems in Japanese homes. In *8th Windsor Conference: Counting the Cost of Comfort in a changing world*. Windsor: NCEUB (Network for Comfort and Energy Use in Buildings): 1–9.

Roaf, S., Crichton, D. & Nicol, F. 2005. *Adapting buildings and cities for climate change: A 21st century survival guide*. Oxford: Architectural Press.

Saiegh-Haddad, E. 2018. MAWRID: A Model of Arabic Word Reading in Development. *Journal of Learning Disabilities*, 51(5): 454–462.

Saleh, S.Y.H. 2011. *Evaluation and enhancement of environmental performance of refugee shelters in Palestine*. University of Nottingham.

Sawa, B.A. & Buhari, B. 2011. Temperature variability and outbreak of meningitis and measles in Zaria, northern Nigeria. *Research Journal of Applied Sciences, Engineering and Technology*, 3(5): 399–402.

Sayed, F. 2015. A few surprising facts about the Arabic language. https://www.britishcouncil.org/voices-magazine/surprising-facts-about-arabic-language 28 February 2018.

Schakib-Ekbatan, K., Becker, S., Cannistraro, A. & Schweiker, M. 2018. What do people associate with 'cold' or 'hot'? - Qualitative analyses of the ASHRAE-scales' labels. In L. Brotas, S. Roaf, F. Nicol, & M. Humphreys, eds. *10th Windsor Conference: Rethinking Comfort*. NCEUB (Network for Comfort and Energy Use in Buildings): 371–385.

Schellen, L., Loomans, M., de Wit, M. & van Marken Lichtenbelt, W. 2013. The influence of different cooling techniques and gender on thermal perception. *Building Research & Information*, 41(3): 330–341.

Schweiker, M., Fuchs, X., Becker, S., Shukuya, M., Dovjak, M., Hawighorst, M. & Kolarik, J. 2017. Challenging the assumptions for thermal sensation scales. *Building Research & Information*, 45(5): 572–589.

Shahzad, S., Brennan, J., Theodossopoulos, D., Calautit, J.K. & Hughes, B.R. 2018. Does a neutral thermal sensation determine thermal comfort? *Building Services Engineering Research and Technology*, 39(2): 183–195.

Shan, X., Zhou, J., Chang, V.W.-C. & Yang, E.-H. 2016. Comparing mixing and displacement ventilation in tutorial rooms: Students' thermal comfort, sick building syndromes, and short-term performance. *Building and Environment*, 102: 128–137.

Shohan, A.A.A. 2015. *Thermal comfort and energy demand of small and large mosque buildings in Saudi Arabia*. University of Nottingham.

Shooshtarian, S. & Ridley, I. 2016. The effect of individual and social environments on the users thermal perceptions of educational urban precincts. *Sustainable Cities and Society*, 26: 119–133.

Singh, M.K., Mahapatra, S. & Atreya, S.K. 2011. Adaptive thermal comfort model for different climatic zones of North-East India. *Applied Energy*, 88(7): 2420–2428.

Singh, M.K., Ooka, R. & Rijal, H.B. 2018. Thermal comfort in classrooms: A critical review. In *10th Windsor Conference: Rethinking Comfort*. Windsor: NCEUB (Network for Comfort and Energy Use in Buildings): 649–668.

Sufeljen, A.M.A. 2014. *Microclimate and thermal comfort of public enclosed courtyards in hot dry regions, with special reference to Tripoli, Libya*. University of Nottingham.

Szokolay, S. 2014. *Introduction to Architectural Science:The basis of sustainable design*. 3rd ed. Oxon: Architectural Press.

Teli, D., James, P.A.B. & Jentsch, M.F. 2013. Thermal comfort in naturally ventilated primary school classrooms. *Building Research & Information*, 41(3): 301–316.

Teli, D., Jentsch, M.F. & James, P.A.B. 2012. Naturally ventilated classrooms: An assessment of existing comfort models for predicting the thermal sensation and preference of primary school children. *Energy and Buildings*, 53: 166–182.

Thabane, L., Ma, J., Chu, R., Cheng, J., Ismaila, A., Rios, L.P., Robson, R., Thabane, M., Giangregorio, L. & Goldsmith, C.H. 2010. A tutorial on pilot studies: the what, why and how. *BMC Medical Research Methodology*, 10(1): 1.

Tham, K.W. & Fadeyi, M.O. 2015. Towards whom should indoor environmental quality control be sympathetic – Asthmatics or non-asthmatics? *Building and*

Environment, 88: 55–64.

Thapa, S., Bansal, A.K. & Panda, G.K. 2016. Adaptive thermal comfort in the two college campuses of Salesian College, Darjeeling – Effect of difference in altitude. *Building and Environment*, 109: 25–41.

Toyinbo, O., Shaughnessy, R., Turunen, M., Putus, T., Metsämuuronen, J., Kurnitski, J. & Haverinen-Shaughnessy, U. 2016. Building characteristics, indoor environmental quality, and mathematics achievement in Finnish elementary schools. *Building and Environment*, 104: 114–121.

Uğursal, A. & Culp, C.H. 2013a. The effect of temperature, metabolic rate and dynamic localized airflow on thermal comfort. *Applied Energy*, 111: 64–73.

Ugursal, A. & Culp, C. 2013b. Gender Differences of Thermal Comfort Perception Under Transient Envirnomental and Metabolic Conditions. *ASHRAE Transactions*, 119: 52–62.

Unesco. 1972. *Sultanate of Oman: Present situation of education*. Paris.

Wang, D., Jiang, J., Liu, Y., Wang, Y., Xu, Y. & Liu, J. 2017. Student responses to classroom thermal environments in rural primary and secondary schools in winter. *Building and Environment*, 115: 104–117.

Wang, J., Wang, Z., de Dear, R., Luo, M., Ghahramani, A. & Lin, B. 2018. The uncertainty of subjective thermal comfort measurement. *Energy and Buildings*, 181: 38–49.

Wang, Z. 2006a. A field study of the thermal comfort in residential buildings in Harbin. *Building and Environment*, 41(8): 1034–1039.

Wang, Z. 2006b. A field study of the thermal comfort in residential buildings in Harbin. *Building and Environment*, 41(8): 1034–1039.

Wang, Z., de Dear, R., Luo, M., Lin, B., He, Y., Ghahramani, A. & Zhu, Y. 2018. Individual difference in thermal comfort: A literature review. *Building and Environment*, 138: 181–193.

Wargocki, P. & Wyon, D.P. 2006. Research report on effects of HVAC on students performance. *ASHRAE Journal*, 48: 22–28.

Weather Online. 2015. Oman - Climate. http://www.weatheronline.co.uk/reports/climate/Oman.htm 24 October 2015.

Weatherbase. 2018. Muscat, Oman: Monthly - Weather averages summary. http://www.weatherbase.com/weather/weather.php3?s=65214&cityname=Muscat-Muhafazat-Masqat-Oman 7 March 2018.

Wong, N.H., Feriadi, H., Lim, P.., Tham, K.., Sekhar, C. & Cheong, K.. 2002. Thermal comfort evaluation of naturally ventilated public housing in Singapore. *Building and Environment*, 37(12): 1267–1277.

Wong, N.H. & Jan, W.L.S. 2003. Total building performance evaluation of academic institution in Singapore. *Building and Environment*, 38(1): 161–176.

Wong, N.H. & Khoo, S.S. 2003. Thermal comfort in classrooms in the tropics. *Energy and Buildings*, 35(4): 337–351.

Yan, H. & Yang, L. 2014. Indoor thermal conditinos and thermal comfort in residential buildings during the winter in Lhasa, China. In *8th Windsor Conference: Counting the Cost of Comfort in a changing world*. Windsor: NCEUB (Network for Comfort and Energy Use in Buildings): 1–19.

Yang, C., Yin, T. & Fu, M. 2016. Study on the allowable fluctuation ranges of human metabolic rate and thermal environment parameters under the condition of thermal comfort. *Building and Environment*, 103: 155–164.

Yang, L., Yan, H. & Lam, J.C. 2014. Thermal comfort and building energy consumption implications – A review. *Applied Energy*, 115: 164–173.

Yao, R., Liu, J. & Li, B. 2010. Occupants' adaptive responses and perception of thermal environment in naturally conditioned university classrooms. *Applied Energy*, 87(3): 1015–1022.

Yun, H., Nam, I., Kim, J., Yang, J., Lee, K. & Sohn, J. 2014. A field study of thermal comfort for kindergarten children in Korea: An assessment of existing models and preferences of children. *Building and Environment*, 75: 182–189.

Zeiler, W. & Boxem, G. 2009. Effects of thermal activated building systems in schools on thermal comfort in winter. *Building and Environment*, 44(11): 2308–2317.

Zhang, G., Zheng, C., Yang, W., Zhang, Q. & Moschandreas, D.J. 2007. Thermal Comfort Investigation of Naturally Ventilated Classrooms in a Subtropical Region. *Indoor and Built Environment*, 16(2): 148–158.

Zomorodian, Z.S., Tahsildoost, M. & Hafezi, M. 2016. Thermal comfort in educational buildings: A review article. *Renewable and Sustainable Energy Reviews*, 59: 895–906.

Zurigat, Y.H., Al-Hinai, H., Jubran, B.A. & Al-Masoudi, Y.S. 2003. Energy efficient building strategies for school buildings in Oman. *International Journal of Energy Research*, 27(3): 241–253.

Appendices

Appendix 1.1

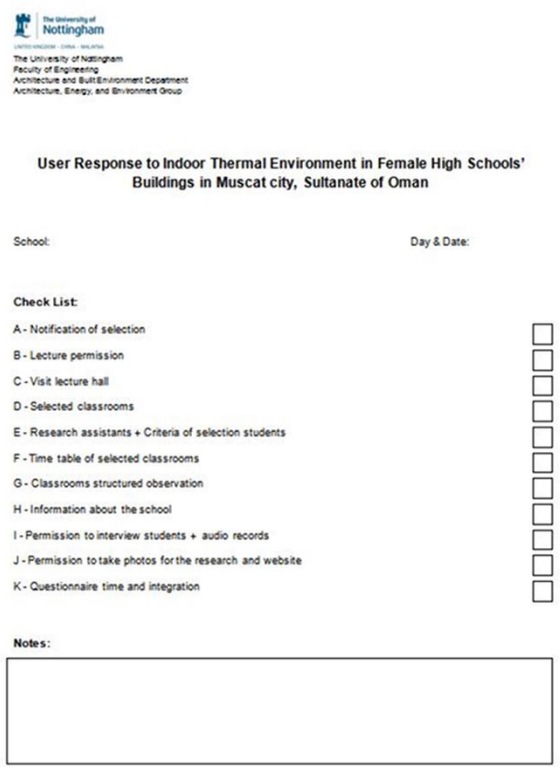
List of cyclones, storms, and depressions occurred in Oman since 1885 (Source: Omani General Directorate of Meteorology)

Date	Type	Affected areas	Rainfalls (mm)	Winds (Knots)
June 1885	Cyclone	Gulf of Adan	-	-
June 1890	Cyclone	Gulf of Oman	Muscat (285)	-
June 1903	Cyclone	Ras Al-Hed	-	-
June 1925	Cyclone	Moved to north Arabian sea	-	-
6th June 1946	Cyclone	Vanished before arriving Masirah	-	-
1st October 1948	Cyclone	Vanished before arriving Ras Al-Hed	-	-
25th October 1948	Storm	Cross Salalah from south east	Masirah (22.5), Salalah (156.8)	-
24th May 1959	Cyclone	Cross Salalah from south east	Masirah (6.3), Salalah (117.2)	-
18th October 1959	Cyclone	Cross Ras Madrakah from south east	Masirah (13.7)	-
18th May 1960	Cyclone	Southeast of Fertaq, Republic of Yemen	Salalah (4.1)	-
23rd November 1960	Storm	Gulf of Aden	Salalah (6.1)	-
30th May 1962	Storm	Vanished before arriving Ras Madrakah	Masirah (2.9)	-
26th May 1963	Cyclone	Southeast Salalah	Salalah (269.4)	-
13th May 1966	Cyclone	Southeast Salalah	Salalah (202.7)	-
July 1967	Depression	Southeast Salalah	Masirah (30.3)	-
July 1970	Depression	Southeast Salalah	Masirah (19.0)	-
August 1970	Depression	Southeast Salalah	Masirah (52.8)	-
December 1971	Storm	Southeast Salalah	Masirah (99.8)	-
July 1972	Depression	Southeast Salalah	Masirah (33.0)	-
July 1973	Depression	Southeast Salalah	Masirah (26.7)	-
September 1974	Depression	Approach Masirah and diverted to southeast Salalah coast	-	-
13th June 1977	Cyclone	Masirah	Masirah (430.6), Salalah (122.7)	-
9th November 1978	Cyclone	From India to Masirah then back to India	-	35
20th June 1979	Storm	Ras Madrakah	Salalah (54.2)	-
September 1979	Storm	South of Ras Madrakah	-	-
10th November 1979	Cyclone	Masirah	-	-
October 1981	Storm	Masirah	Masirah (45.6), Salalah (10.0), Thamrait (14.0), Sur (19.1), Seeb (Slightly)	-
10th August 1983	Storm	-	-	-
16th June 1986	Storm	-	-	-
July 1988	Depression	Between Masirah and Hallaniyat	-	Fuhud & Jibal (60)

11th–13th July 1989	Cyclone	Vanished before arriving 65 °E, went out to northern Arabian sea	-	-
3rd October 1992	Cyclone	Ras Madrakah	Um zamayam (56)	49
15th–16th November 1993	Cyclone	55 km from Oman coast	-	-
3rd November 1994	Depression	-	Seeb for two days (26.6), Sur (4.2)	Sur (28)
July 1995	Depression	Northern Oman	Over the mountains (300), Masirah (53.8)	-
10th–15th June 1996	Cyclone	Ras Madraka	Masirah (90), Salalah (37.02)	Estimated (60-65), one ship reported 45 knots about 120 km north
17th December 1998	Cyclone	Between Masirah and Salalah	Masirah (11.2), Saiq (6), Seeb (5.2)	Masirah (23), Ship reported (45)
17th – 20th May 1999	Cyclone	Gujarat / India & Pakistan	-	Pakistan & Indian coast (270 km/h), high waves in Oman coast
10th–16th October 1999	Depression	Ras Madrakah	Salalah (69.3), Thamrait (18.9)	Salalah (15-20), Thamrait (17-31)
10th May 2002	Storm	Salalah	Salalah (58.6), Qairoon (250.6)	Salalah (55-64), Thamrait (30), Qiroon (72)
29th-30th September 2004	Depression	Dhofar coast / Salalah	Salalah (89.4-116.2), Qairoon (96.6), Thamrait (7.8)	Salalah (20-25), Thamrait (62), Qiroon (37)
5th-6th June 2007	Cyclone (Gonu)	Arrived at Ras Al-Hed and then affected Al-Sharqia region and Muscat Governorate	Seeb (257), Sur (230), Qalhat (401), Ibra (60), Rustaq (78), Samail (83.2), Nizwa (4.8), Masirah (2.2), Al-Jabal Asfar (934), Al-Nahda city (293)	Adam (30.9 & 26), Bahla (35.8 & 44.3), Buraimi (26 & 27.4), Ibra (30.5 & 37.5), Majis (14.6 & 32.5), Masirah (34 & 37.9), Nizwa (31.1 & 35.4), Rustaq (18.5 & 39.3), Saiq (64.7 & -), Samail (36.5 & 50), Seeb (16.9 & 44.7), Sur (50.2 & -), Qalhat (55 & 95.1)
1st-6th June 2010	Cyclone (Phet)	Passed Al-Ashkhara coast, affected Al-Sharqia and Muscat Governorate, then Al-Dakhilia and Al-Batinah	Masirah (109), Qalhat (142.2), Sur (109.2), Port Sultan Qaboos (147), Muscat (81.6), Amrat (155.6), Rustaq (94), Samail (59.6), Ibra (38.8), Joba (49)	Samail (30 & 38), Nizwa (40 & 30), Bahla (32 & 37), Adam (33 & 36), Jabal Shams (105 & -)
8th-12th June 2015	Cyclone (Ashoba)	South Al-Sharqia coast, South Ras Al-Hed, Masirah Island, Ras Madrakah, and Al-Wusta	Qarn Alam (0, 0, 1.4, 0, & 3), Masirah (0, 0, 0, 26.6, & 212.6), Sur (0, 0, 4.4, 2.6 & 52.6)	Qarn Alam (24, 29, 70. 29 & 22), Masirah (26, 26, 26, 35 & 50), Sur (26, 23, 35, 39 & 32)

Appendix 5.1

Data collection sheet



The University of Nottingham
The University of Nottingham
Faculty of Engineering
Architecture and Built Environment Department
Architecture, Energy, and Environment Group

User Response to Indoor Thermal Environment in Female High Schools' Buildings in Muscat city, Sultanate of Oman

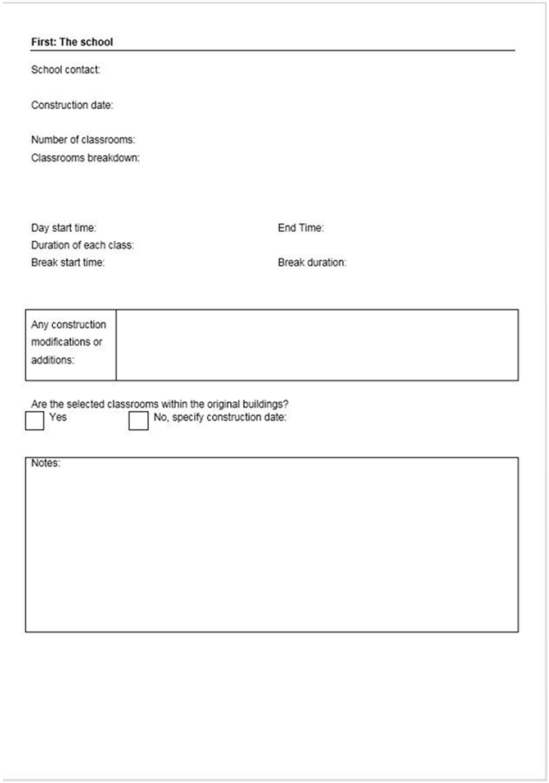
School: Day & Date:

Check List:

- A - Notification of selection ☐
- B - Lecture permission ☐
- C - Visit lecture hall ☐
- D - Selected classrooms ☐
- E - Research assistants + Criteria of selection students ☐
- F - Time table of selected classrooms ☐
- G - Classrooms structured observation ☐
- H - Information about the school ☐
- I - Permission to interview students + audio records ☐
- J - Permission to take photos for the research and website ☐
- K - Questionnaire time and integration ☐

Notes:

Page 1



First: The school

School contact:

Construction date:

Number of classrooms:
Classrooms breakdown:

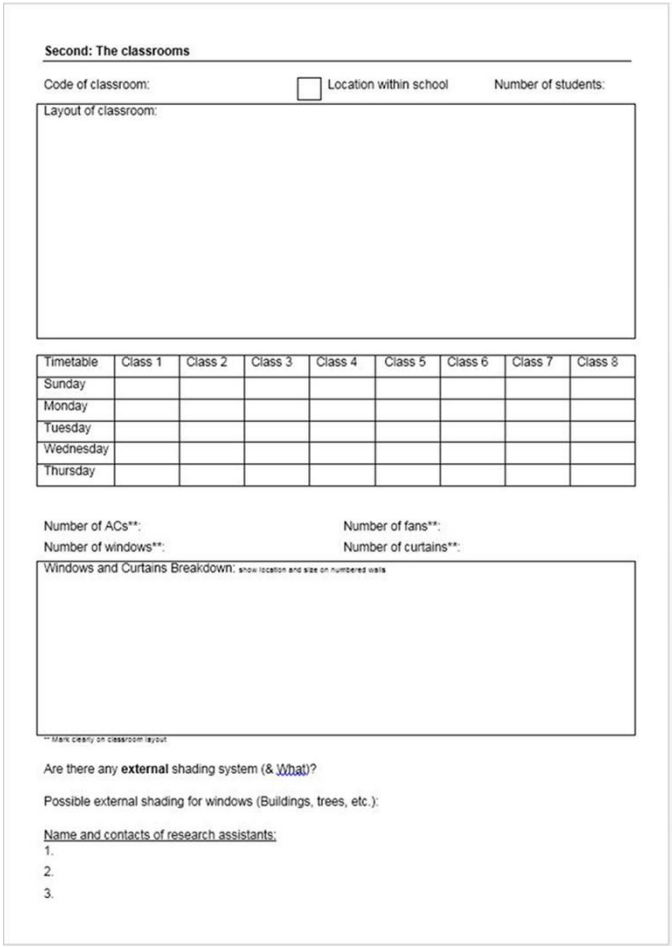
Day start time: End Time:
Duration of each class:
Break start time: Break duration:

Any construction modifications or additions:	

Are the selected classrooms within the original buildings?
☐ Yes ☐ No, specify construction date:

Notes:

Page 2



Second: The classrooms

Code of classroom: ☐ Location within school Number of students:

Layout of classroom:

Timetable	Class 1	Class 2	Class 3	Class 4	Class 5	Class 6	Class 7	Class 8
Sunday								
Monday								
Tuesday								
Wednesday								
Thursday								

Number of ACs**: Number of fans**:

Number of windows**: Number of curtains**:

Windows and Curtains Breakdown: show location and size on numbered walls

** Mark clearly on classroom layout

Are there any **external** shading system (& What)?

Possible external shading for windows (Buildings, trees, etc.):

Name and contacts of research assistants:

1.

2.

3.

Pages 3, 4, and 5



School Layout:

Page 6

Appendix 5.2

Surveyed companies' list

Company	Website
Campbell Scientific, Inc.	www.campbellsci.co.uk
Casella Measurement	www.casellameasurement.com
Davis Instruments Corporation	www.davisweather.co.uk
Environmental Measurements	www.emltd.net
Fairmount Weather Systems	www.fairmountweather.com
Gemini Data Loggers (UK) Ltd	www.geminidataloggers.com
Gill Instruments	www.gill.co.uk
Instromet Weather System Ltd	www.instromet.co.uk
Metrel UK Ltd.	www.metrel.co.uk
Metspec	www.metspec.net
OMEGA Engineering, Inc.	www.omega.co.uk
Oregon Scientific, Inc.	www.pregonscientific.co.uk
PCE Instruments UK Ltd.	www.industrial-needs.com
Richard Paul Russell Ltd (Official distributor of Nielsen-Kellerman products in UK)	www.r-p-r.co.uk
Prodata Weather Systems	www.weatherstations.co.uk
Russell Scientific Instruments Limited	www.russell-scientific.co.uk
Weather Front Ltd	www.weathershop.co.uk
Windspeed Limited (Vector Instruments)	www.windspeed.co.uk

Appendix 5.3

Comparison of the surveyed instruments

		Metrel MI6401 ST Poly Standard Set	Kestrel 4400 Heat Stress Tracker	WXT520 Vaisala Weather Transmitter
Model				
UK Seller		Metrel UK Ltd.	Richard Paul Russell Ltd	Campbell Scientific Ltd
Available sensors	T_a	Yes	Yes	Yes
	T_g	Yes[1]	Yes (25 mm)	No
	AV	Yes	Yes	Yes
	RH	Yes	Yes	Yes
Accuracy level	T_a	±0.2°C at ±25°C[2], ±0.5°C over working range[2], ±0.5°C[3]	±1.0°C	±0.3°C at +20°C
	T_g	±0.5°C at ±10.0°C to 49.9°C[3], ±1.0°C at ±50.0°C to 84.9°C [3], ±1.5°C at ±85.0°C to 120.0°C[3]	±1.4°C	-
	AV	±(0.5 m/s + 5% of reading) at 0.10 m/s to 9.99 m/s**, (±5% of reading) at 10.0 m/s to 20.0 m/s**	±0.1 m/s (±3%)	±0.3 m/s or ±3% whichever is greater (from 0 m/s to 35 m/s), ±5% m/s (from 36 m/s to 60 m/s)
	RH	*	±3%	±3% at 0% to 90%, ±5% at 90% to 100%,
Specification range	T_a	-20°C to +60°C	-29°C to +70°C	-52°C to +60°C
	T_g	10°C to 120°C ***	-29°C to +60°C	-
	AV	0.1 m/s to 20 m/s**	0.1 m/s to 20 m/s**	0 m/s to 60 m/s
	RH	0% to 100%	5% to 95%	0% to 100%
Datalogger integration		Yes	Yes	No
Sampling interval	T_a	*	*	*
	T_g	*	*	*
	AV	*	*	*
	RH	*	*	*
Logging interval	T_a	2 s to 1 hr	2 s to 12 hrs	-
	T_g	2 s to 1 hr	2 s to 12 hrs	-
	AV	2 s to 1 hour	2 s to 12 hrs	-
	RH	2 s to 1 hour	2 s to 12 hrs	-
Software		Yes	No	No
Mobility		Portable	Portable	Fixed
Dimensions (mm)		110 x 85 x 220	165 x 59 x 28	H: 238, D: 115
Weight		560g	125g	650g
Power source		6 x 1.2V rechargeable batteries, type AA	Batteries (2 AAA)	Input Voltage (5 to 30 Vdc)
Cost		From £1966.8	From £ 430.80	*

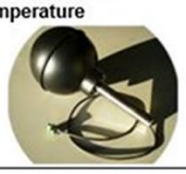
* missing
[1]Need to buy black globe thermometer A1131
[2]Using microclimatic probe A1091
[3]Using temperature and humidity probe A1127

		Tinytag View 2 Temperature/Relative Humidity Logger (TV-4500)	Tinytag Plus 2 Dual Channel Temperature/Relative Humidity (TGP-4500)	Handheld Hygro Thermometer Data Logger (RH318)
Model				
UK Seller		Gemini Data Loggers (UK) Ltd	Gemini Data Loggers (UK) Ltd	OMEGA Engineering, Inc.
Available sensors	T_a	Yes (Indoor only)	Yes (Outdoor only)	Yes
	T_g	No	No	No
	AV	No	No	No
	RH	Yes (Indoor only)	Yes (Outdoor only)	Yes
Accuracy level	T_a	0.4°C from 0°C to 50°C	Less than 0.5°C from 10°C to 40°C	±0.8°C from -20°C to +60°C
	T_g	-	-	-
	AV	-	-	-
	RH	±3.0% RH at 25°C	±3.0% RH at 25°C	±2.0% at 10% to 90%, other ±4.0%
Specification range	T_a	-25°C to +50°C	-25°C to +85°C	-20°C to +60°C
	T_g	-	-	-
	AV	-	-	-
	RH	0% to 100%	0% to 100%	0% to 100%
Datalogger integration		Yes	Yes	Yes
Sampling interval	T_a	10 minutes to 90% FSD in moving air	10 minutes to 90% FSD in moving air	10 s
	T_g	-	-	-
	AV	-	-	-
	RH	40 s to 90% FSD	40 s to 90% FSD	180 s
Logging interval	T_a	1 s to 10 days	1 s to 10 days	*
	T_g	-	-	-
	AV	-	-	-
	RH	1 s to 10 days	1 s to 10 days	*
Software		Yes	Yes	Yes
Mobility		Portable	Portable	Portable
Dimensions (mm)		90 x 656 x 35	34 x 57 x 80	Device: 185 x 65 x 36, Probe: L:94, D:15
Weight		85	110	285
Power source		Tekcell SBAA02P; SAFT LS14250 or LST14250	Tekcell SBAA02P; SAFT LS14250 or LST14250	9V Alkaline battery
Cost		From £165	From £150	From £200

* missing

		Standalone IN-Out Temperature Sensor	Precision RTD Handheld Data Logger Thermometer (HH376)	Extech HT30 Heat Stress WBGT Meter
Model				
UK Seller		Instromet Weather System Ltd	OMEGA Engineering, Inc.	Tester.co.uk (PASS Ltd)
Available sensors	T_a	Yes	Yes	Yes
	T_g	No	No	Yes
	AV	No	No	No
	RH	No	Yes	Yes
Accuracy level	T_a	±1.0°C	(±0.05% of reading + 0.1°C) from -100°C to 400°C	±1.0°C
	T_g	-	-	±2.0°C
	AV	-	-	-
	RH	-	(±0.05% of reading + 0.1°C) from -100°C to 400°C	±3%
Specification range	T_a	Indoor: -19.9°C to +69.9°C, Outdoor: -49.9°C to +69.9°C	-100°C to 400°C	0°C to 50°C
	T_g	-	-	0°C to 80°C
	AV	-	-	-
	RH	-	0% to 80%	0% to 100%
Datalogger integration		No	Yes	No
Sampling interval	T_a	*	2 times per second	*
	T_g	-	-	*
	AV	-	-	-
	RH	-	2 times per second	*
Logging interval	T_a	-	*	-
	T_g	-	-	-
	AV	-	-	-
	RH	-	*	-
Software		No	Yes	No
Mobility		Fixed	Portable	Portable
Dimensions (mm)		20x65x97	185x65x36	Meter: 254x48.7x29.4, Ball: H:35, D:40
Weight		100	Approx. 360	136
Power source		1.5 Volt equipment or AAA	9V Battery	2 AAA Batteries
Cost		X	From £220	From £123.60

* missing

		Data Logger PCE-WB 20SD	Heat Index Checker 8778	TB1 Black Globe Temperature
Model				
UK Seller		PCE Instruments UK Ltd.	ATG Stores (US)	Monitor Sensors (Australia)
Available sensors	T_a	Yes	Yes	No
	T_g	Yes	Yes	Yes
	AV	No	No	No
	RH	Yes	Yes	No
Accuracy level	T_a	±0.6°C	±0.6°C	-
	T_g	±0.6°C	Indoor: ±1°C at 15°C to 40°C, Other: ±1.5°C Outdoor: ±1.5°C at 15°C to 40°C, Other: ±2°C	±0.1°C at 0°C to 50°C, other: ±0.2°C
	AV	-	-	-
	RH	(±3% reading value + 1% RH) for readings >70% RH, ±3%RH for readings <70% RH	±3% (at 25°C and 10% to 90% RH), ±5% for other range	-
Specification range	T_a	0°C to 50°C	0°C to 50°C	-
	T_g	0°C to 80°C	0°C to 80°C	-40°C to 60°C
	AV	-	-	-
	RH	5% to 95%	0% to 100%	-
Datalogger integration		Yes	No	No
Sampling interval	T_a	*	*	-
	T_g	*	*	*
	AV	-	-	-
	RH	*	*	-
Logging interval	T_a	1 hour	-	-
	T_g	1 hour	-	-
	AV	-	-	-
	RH	1 hour	-	-
Software		No	No	No
Mobility		Portable	Portable	*
Dimensions (mm)		117 x 68 x 445, Diameter: 75	278 x 75 x 75	230 x 150 x 25
Weight		489	Approx. 140	650
Power source		6 x 1.5 V AA batteries or 9V Adapter	2 AAA Batteries	6-28 Vdc unregulated, some output options require > 12Vdc
Cost		From £150	From $165.93	*

* missing

		HHF2005HW Hot wire anemometer with real time data logger	HHF144B Handheld Rotating Vane Hygro-Thermo Anemometer	Windscribe - 0276 Ultrasonic Wind & Temperature Meter
Model				
UK Seller		OMEGA Engineering, Inc.	OMEGA Engineering, Inc.	Weather Shop
Available sensors	T_a	Yes	Yes	Yes
	T_g	No	No	No
	AV	Yes	Yes	Yes
	RH	No	Yes	No
Accuracy level	T_a	±0.8 °C	±0.3°C + 0.2% of reading in °C	±1°C
	T_g	-	-	-
	AV	±(10% + lsd[1]) full scale	±1% of reading ±1-digit	±3%
	RH	-	±2%	-
Specification range	T_a	0°C to 50°C	-20°C to 80°C[2]	-40°C to +65°C
	T_g	-	-	-
	AV	0.2 m/s to 20 m/s	0.2 m/s to 40 m/s	0.3 mph to 150 mph
	RH	-	5% to 95%	-
Datalogger integration		Yes	No	No
Sampling interval	T_a	*	Approx. 60 s in still air, Approx. 10 s in moving air streams	80 ms
	T_g	-	-	-
	AV	*	*	80 ms
	RH	-	Up to 90% of change in measured value in 15 seconds	-
Logging interval	T_a	2 s to 8hr, 59 min, 59s	-	-
	T_g	-	-	-
	AV	2 s to 8hr, 59 min, 59s	-	-
	RH	-	-	-
Software		Yes	No	No
Mobility		Portable	Portable	Portable
Dimensions (mm)		Instrument: 203 x 76 x 38, Telescopic probe: H: 280 to 940, D: 12	165 x 83 x 38, Diameter: 70	127 x 76 x 23
Weight		515	*	120
Power source		4 AA Batteries	3 AA Alkaline batteries	CR2032, 3 volt lithium cell
Cost		From £430	From £760	From £132

* missing
[1]lsd = Least significant digit
[2]Using standard combination temp/humidity probe

Appendix 5.4

Evaluation system of instruments (selected instruments are highlighted in bold)

			Technical			Physical		Logistical		General	
	Instruments		Accuracy	Datalogger	Measuring more factors	Compactness	Weight	Mobility	Availability in UK	Cost	Total (80)
1	Metrel MI6401 ST Poly Standard Set		5	10	10	10	5	5	10	0	55
2	Kestrel 4400 Heat Stress Tracker		0	10	5	10	10	10	5	5	55
3	WXT520 Vaisala Weather Transmitter		10	10	10	5	5	0	5	0	45
4	**Tinytag View 2 Temperature/Relative Humidity Logger (TV-4500)**		**10**	**10**	**5**	**10**	**10**	**10**	**10**	**10**	**75**
5	**Tinytag Plus 2 Dual Channel Temperature/Relative Humidity (TGP-4500)**		**10**	**10**	**5**	**10**	**10**	**10**	**10**	**10**	**75**
6	Handheld Hygro Thermometer Data Logger (RH318)		0	10	5	5	10	10	10	10	60
7	Standalone IN-Out Temperature Sensor		0	0	0	10	10	0	10	0	30
8	Precision RTD Handheld Data Logger Thermometer (HH376)		5	10	5	10	10	10	10	10	70
9	Extech HT30 Heat Stress WBGT Meter		0	0	5	10	10	10	5	10	50
10	**Data Logger PCE-WB 20SD**		**5**	**10**	**5**	**10**	**5**	**10**	**10**	**10**	**65**
11	Heat Index Checker 8778		0	0	5	5	10	10	0	5	35
12	TB1 Black Globe Temperature		10	0	0	5	0	0	0	0	15
13	**HHF2005HW Hot wire anemometer with real time data logger**		**10**	**10**	**5**	**10**	**5**	**10**	**10**	**5**	**65**
14	HHF144B Handheld Rotating Vane Hygro-Thermo Anemometer		10	0	10	10	0	10	10	0	60
15	Windscribe - 0276 Ultrasonic Wind & Temperature Meter		5	0	5	10	10	5	5	10	50

Appendix 5.5

First questionnaire



The University of Nottingham
The University of Nottingham
Faculty of Engineering
Architecture and Built Environment Department
Architecture, Energy, and Environment Group

The University of Nottingham
جامعة نوتنغهام
كلية الهندسة
قسم العمارة والبيئة المشيدة
مجموعة العمارة والطاقة والبيئة

Questionnaire about thermal conditions in schools' environemnt

استبيان عن الأحوال الحرارية في البيئة المدرسية

Dear student,

Thank you for participating in this questionnaire, which is essential for a PhD study at the University of Nottingham, UK. It aims to investigate the thermal conditions in educational buildings. At a larger scale, this will contributes towards reducing the consumed energy for air-conditioning purposes and designing energy-efficient buildings.

The researcher confirms the confidentiality of your answers and not passing them to a third party except in an anonymous way.

Should you require any assistant, kindly ask the researcher or contact her at:

e-mail: hanan.khatri@gmail.com

Your participation is highly appreciated.

عزيزي الطالبة:

شكرا لمشاركتكم في هذا الاستبيان، والذي يعتبر ضروريا لدراسة دكتوراة في جامعة نوتنجهام بالمملكة المتحدة. يهدف هذا الاستبيان إلى اكتشاف الأحوال الحرارية في المباني التعليمية، مما يساهم – على نطاق أوسع – في التقليل من استهلاك الطاقة لأغراض التبريد، ويسهم كذلك في تصميم مباني موفرة للطاقة.

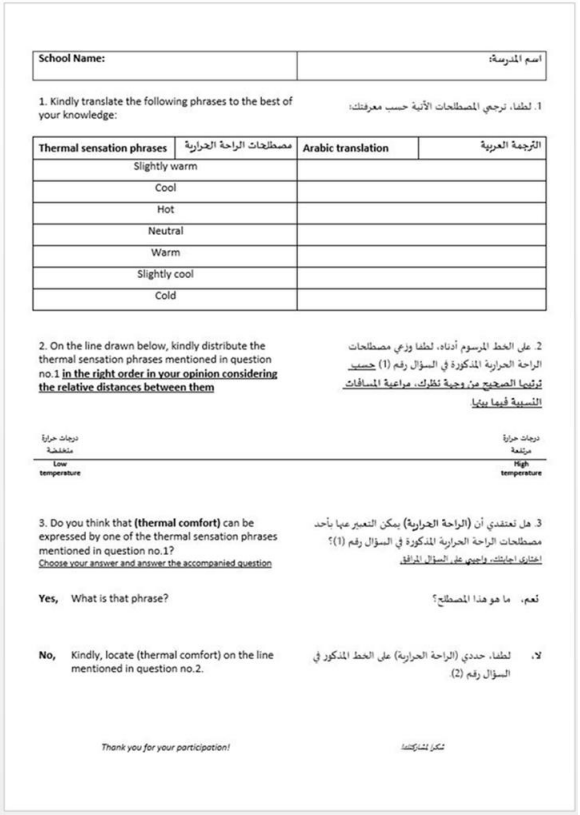
هذا وتتعهد الباحثة بالمحافظة على سرية بياناتكم، وعدم توفيرها لأي طرف ثالث إلا بما يضمن عدم الكشف عن هوياتكم.

في حال احتياجكم لأي مساعدة، الرجاء سؤال الباحثة أو التواصل معها على:

البريد الألكتروني: hanan.khatri@gmail.com

مشاركتكم محل تقديرنا.

Page 1



School Name:	اسم المدرسة:

1. Kindly translate the following phrases to the best of your knowledge:

1. لطفا، ترجي المصطلحات الآتية حسب معرفتك:

Thermal sensation phrases	مصطلحات الراحة الحرارية	**Arabic translation**	الترجمة العربية
Slightly warm			
Cool			
Hot			
Neutral			
Warm			
Slightly cool			
Cold			

2. On the line drawn below, kindly distribute the thermal sensation phrases mentioned in question no.1 **in the right order in your opinion considering the relative distances between them**

2. على الخط المرسوم أدناه، لطفا وزعي مصطلحات الراحة الحرارية المذكورة في السؤال رقم (1) حسب ترتيبها الصحيح من وجهة نظرك، مراعية المسافات النسبية فيما بينها

درجات حرارة منخفضة
Low temperature

درجات حرارة مرتفعة
High temperature

3. Do you think that **(thermal comfort)** can be expressed by one of the thermal sensation phrases mentioned in question no.1?
Choose your answer and answer the accompanied question

3. هل تعتقدي أن (الراحة الحرارية) يمكن التعبير عنها بأحد مصطلحات الراحة الحرارية المذكورة في السؤال رقم (1)؟
اختاري اجابتك، وأجبي على السؤال المرافق

Yes, What is that phrase?

نعم، ما هو هذا المصطلح؟

No, Kindly, locate (thermal comfort) on the line mentioned in question no.2.

لا، لطفا، حددي (الراحة الحرارية) على الخط المذكور في السؤال رقم (2).

Thank you for your participation!

شكرا لمشاركتنا

Page 2

Appendix 5.6

Second questionnaire



The University of Nottingham
UNITED KINGDOM · CHINA · MALAYSIA
جامعة نوتنجهام
كلية الهندسة
قسم العمارة والبيئة المشيدة
مجموعة العمارة، والطاقة، والبيئة

استبيان عن الأحوال الحرارية في البيئة المدرسية

عزيزتي الطالبة:

شكرا لمشاركتكم في هذا الاستبيان، والذي يعتبر ضروريا لدراسة دكتوراة في جامعة نوتنجهام بالمملكة المتحدة. يهدف هذا الاستبيان إلى اكتشاف الأحوال الحرارية في المباني التعليمية، مما يساهم – على نطاق أوسع – في التقليل من استهلاك الطاقة لأغراض التبريد، ويسهم كذلك في تصميم مباني موفرة للطاقة.

هذا وتتعهد الباحثة بالمحافظة على سرية بياناتكم، وعدم توفيرها لأي طرف ثالث إلا بما يضمن عدم الكشف عن هوياتكم.

في حال احتياجكم لأي مساعدة، الرجاء سؤال الباحثة أو التواصل معها على:

البريد الإلكتروني: hanan.khatri@gmail.com

مشاركتكم محل تقديرنا.

Page 1



اسم المدرسة:

لطفا، ضعي دائرة على إجابة واحدة فقط من البدائل المعطاة:

1. تترجم كلمة **Cold** إلى:
   بارد جدا　بارد　اجابة أخرى، هي:

2. تترجم كلمة **Cool** إلى:
   بارد　معتدل　اجابة أخرى، هي:

3. تترجم كلمة **Slightly cool** إلى:
   بارد قليلا　شديد البرودة　متوسط البرودة　اجابة أخرى، هي:

4. تترجم كلمة **Neutral** إلى:
   معتدل　طبيعي　اجابة أخرى، هي:

5. تترجم كلمة **Slightly warm** إلى:
   دافئ قليلا　دافئ　اجابة أخرى، هي:

6. تترجم كلمة **Warm** إلى:
   دافئ　ساخن　معتدل　اجابة أخرى، هي:

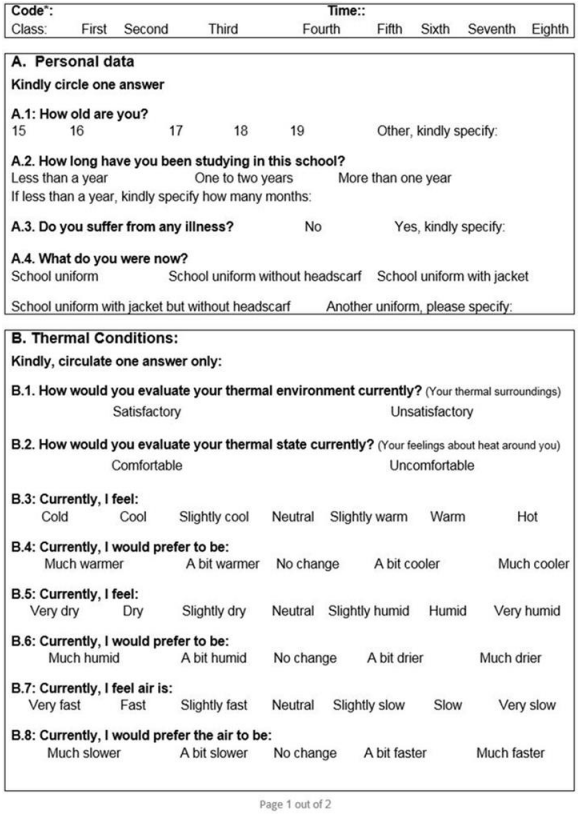
7. تترجم كلمة **Hot** إلى:
   ساخن　دافئ　حار　اجابة أخرى، هي:

شكرا لمشاركتك!

Page 2

Appendix 5.7

ASHRAE questionnaire



Code*: **Time::**

Class: First Second Third Fourth Fifth Sixth Seventh Eighth

A. Personal data

Kindly circle one answer

A.1: How old are you?

15 16 17 18 19 Other, kindly specify:

A.2. How long have you been studying in this school?

Less than a year One to two years More than one year

If less than a year, kindly specify how many months:

A.3. Do you suffer from any illness? No Yes, kindly specify:

A.4. What do you were now?

School uniform School uniform without headscarf School uniform with jacket

School uniform with jacket but without headscarf Another uniform, please specify:

B. Thermal Conditions:

Kindly, circulate one answer only:

B.1. How would you evaluate your thermal environment currently? (Your thermal surroundings)

Satisfactory Unsatisfactory

B.2. How would you evaluate your thermal state currently? (Your feelings about heat around you)

Comfortable Uncomfortable

B.3: Currently, I feel:

Cold Cool Slightly cool Neutral Slightly warm Warm Hot

B.4: Currently, I would prefer to be:

Much warmer A bit warmer No change A bit cooler Much cooler

B.5: Currently, I feel:

Very dry Dry Slightly dry Neutral Slightly humid Humid Very humid

B.6: Currently, I would prefer to be:

Much humid A bit humid No change A bit drier Much drier

B.7: Currently, I feel air is:

Very fast Fast Slightly fast Neutral Slightly slow Slow Very slow

B.8: Currently, I would prefer the air to be:

Much slower A bit slower No change A bit faster Much faster

Page 1 out of 2



الرمز*: **الوقت:**

رقم الحصة: الأولى الثانية الثالثة الرابعة الخامسة السادسة السابعة الثامنة

أ. البيانات الشخصية:

لطفا، ضعي دائرة على إجابة واحدة فقط:

أ.1: ما هو عمرك؟

15 16 17 18 19 غير ذلك، لطفا حددية:

أ.2: منذ متى وأنت تدرسي في هذه المدرسة؟ أكثر من عامين من عام إلى عامين أقل من عام

إذا **أقل من عام**، لطفا حددي **كم شهر:**

أ.3: هل تعاني من أي مرض؟ لا نعم، لطفا حددية:

أ.4: ماذا ترتدي في هذه اللحظة؟

الزي المدرسي الزي المدرسي من غير حجاب أو شيلة الزي المدرسي مع جاكيت

الزي المدرسي مع جاكيت ومن غير حجاب أو شيلة زي آخر، لطفا حددية:

ب. الأحوال الحرارية:

لطفا، ضعي دائرة على إجابة واحدة فقط:

ب.1: كيف تقيمي بيئتك الحرارية حاليا؟ (بيئتك الحرارية هي حرارة المكان من حولك)

مقبولة غير مقبولة

ب.2: كيف تقيمي حالتك الحرارية حاليا؟ (حالتك الحرارية هي شعورك عن الحرارة من حولك)

مرتاحة غير مرتاحة

ب.3: حاليا، أشعر بأنني:

ساخنة جدا ساخنة ساخنة قليلا معتدلة باردة قليلا باردة باردة جدا

ب.4: حاليا، أريد أن أكون:

أسخن كثيرا أسخن قليلا لا تغيير أبرد قليلا أبرد كثيرا

ب.5: حاليا، أشعر بأنني:

رطبة كثيرا رطبة رطبة قليلا معتدلة جافة قليلا جافة جافة كثيرا

ب.6: حاليا، أريد أن أكون:

أكثر رطوبة أقل رطوبة لا تغيير أقل جفافا أكثر جفافا

ب.7: حاليا، أشعر بأن الهواء:

بطيء كثيرا بطيء بطيء قليلا معتدل سريع قليلا سريع سريع كثيرا

ب.8: حاليا، أريد الهواء أن يكون:

أبطئ كثيرا أبطئ قليلا لا تغيير أسرع قليلا أسرع كثيرا

Page 1 out of 2

C. Activities

Kindly circle the appropriate answer:

C.1 Currently, you are:

Seated, reading, or writing | Walking | Other, kindly specify:

C.2 Before 15 minutes, you were:

Seated, reading, or writing | Walking | Eating or drinking
Other, kindly specify:

C.3 Where did you spent break time?

Not break time yet | Plaza | Classroom | Other, kindly specify:

D. Available adaptive opportunities:

Kindly circle all appropriate answers:

D.1: In these days, to change thermal conditions in your classroom (like air temperature or speed), you often:

Open windows	Close windows	Open curtains	Close curtains
Open door	Close door	Switch on or increase fans	Switch off or decrease fans
Take off clothing	Add on clothing	Switch on or increase AC	Switch off or decrease AC
Nothing	Other, kindly specify:		

D.2: In these days, when do you open windows in your classrooms?

Before break | After break | All the time | Not at all | No specific time

D.3: In these days, when do you switch on ACs in your classroom?

Before break | After break | All the time | Not at all | No specific time

D.4: In these days, when do you switch on fans in your classroom?

Before break | After break | All the time | Not at all | No specific time

D.5: Do you think you can concentrate in your classes if ACs in your classroom are not working or are switched off?

Yes | No

D.6: In your opinion, how many classes you can attend before losing your concentration if ACs are not working or are switched off in your classroom?

1 | 2 | 3 | 4 | 5 | 6 | 7 | 8

D.7: Assume ACs are not working in your classroom today, what would you do to keep yourself thermally comfortable?

Thank you for participating!

ج. الأنشطة:

لطفا اختاري جميع الاجابات الصحيحة:

ج.1: حاليا، أنت: | جالسة، أو تقرأي، أو تكتبي | تمشي | تقومي بشيء آخر، لطفا حدديه:

ج.2: قبل 15 دقيقة، كنتي: | جالسة، أو تقرأي، أو تكتبي | تمشي | تأكلي وتشربي | تقومي بشيء آخر، لطفا حدديه:

ج.3: أين قضيتي وقت الفسحة؟ | لم يحن وقت الفسحة بعد | في الساحة | في الصف | مكان آخر، لطفا حدديه:

د. فرص التكيف المتاحة:

لطفا اختاري جميع الاجابات الصحيحة:

د.1: في هذه الأيام، لتغيير البيئة الحرارية داخل غرفة فصلكم (مثلا درجة حرارة الهواء أو سرعته)، تقومين غالبا ب:

فتح نافذة	اغلاق نافذة	فتح ستائر	اسدال (اغلاق) ستائر
فتح باب	اغلاق باب	فتح أو زيادة مراوح	اغلاق أوتخفيض مراوح
فتح أو زيادة التكييف	اغلاق أوتخفيض التكييف	زيادة ملابسك	تقليل ملابسك
لا شيء	شيء آخر، لطفا حدديه:		

د.2: في هذه الأيام، متى تفتحون النوافذ في فصلكم؟

قبل الفسحة | بعد الفسحة | طوال الوقت | لا تفتح اطلاقا | لا يوجد وقت محدد

د.3: في هذه الأيام، متى تفتحون أجهزة التكييف في فصلكم؟

قبل الفسحة | بعد الفسحة | طوال الوقت | لا تفتح اطلاقا | لا يوجد وقت محدد

د.4: في هذه الأيام، متى تفتحون المراوح في فصلكم؟

قبل الفسحة | بعد الفسحة | طوال الوقت | لا تفتح اطلاقا | لا يوجد وقت محدد

د.5: هل تعتقدي أن بامكانك التركيز في حصصك الدراسية إذا كانت مكيفات الهواء في صفكم لا تعمل أو مطفأة؟

نعم | لا

د.6: في تقديرك، كم عدد الحصص التي تستطيعي حضورها قبل أن تفقدي تركيزك إذا كانت مكيفات الهواء في صفكم لا تعمل أو مطفأة؟

8 | 7 | 6 | 5 | 4 | 3 | 2 | 1

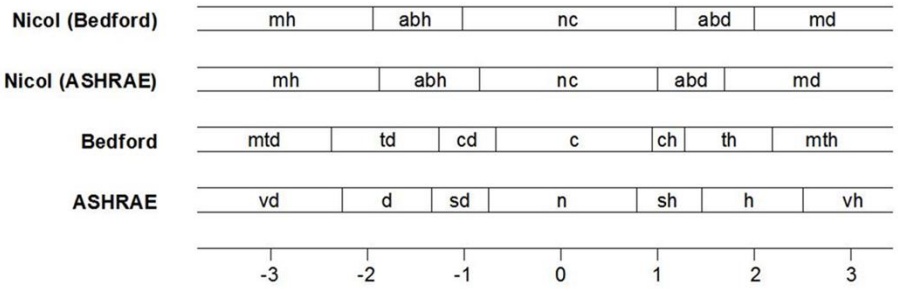
د.7: افترضي أن مكيفات الهواء لا تعمل في صفكم اليوم، ماذا ستفعلين لابقاء نفسك مرتاحة حراريا؟

شكرا لمشاركتك!

Appendix 8.1

Cumulative proportions, probits, and standard errors of humidity categories (summer)

	ASHRAE, N = 333			Bedford, N = 349		
Category	**Cum. Prop.**	**Probit**	**SE**	**Cum. Prop.**	**Probit**	**SE**
-3	0.012	- 2.26	0.159	0.009	- 2.38	0.172
-2	0.090	- 1.34	0.091	0.103	- 1.26	0.086
-1	0.225	- 0.75	0.074	0.252	- 0.67	0.071
0	0.784	0.79	0.079	0.828	0.95	0.082
+1	0.928	1.46	0.112	0.900	1.28	0.097
+2	0.994	2.51	0.404	0.986	2.19	0.222
+3	1.000	-	-	1.000	-	-
	Nicol (ASHRAE), N = 333			**Nicol (Bedford), N = 349**		
-2	0.030	- 1.88	0.122	0.026	- 1.95	0.125
-1	0.201	- 0.84	0.076	0.155	- 1.02	0.078
0	0.841	1.00	0.086	0.883	1.19	0.092
+1	0.955	1.69	0.134	0.977	2.00	0.176
+2	1.000	-	-	1.000	-	-



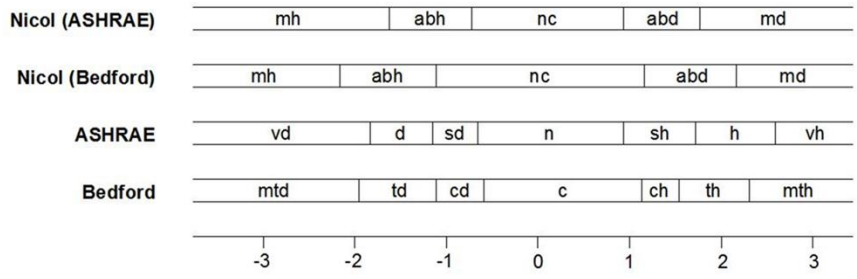
Key:

ASHRAE: vd = Very dry, d = Dry, sd = Slightly dry, n = Neutral, sh = Slightly humid, h = Humid, vh = Very humid
Bedford: mtd = Much too dry, td = Too dry, cd = Comfortably dry, c = Comfortable neither humid nor dry, ch = Comfortably humid, th = Too humid, mth = Much too humid
Nicol: mh = Much humid, abh = A bit humid, nc = no change, abd = A bit drier, md = Much drier

Comparing humidity categories' widths of ASHRAE, Bedford, and Nicol scales in summer

Cumulative proportions, probits, and standard errors of humidity categories (winter)

	Bedford, N = 194			ASHRAE, N = 209		
Category	**Cum. Prop.**	**Probit**	**SE**	**Cum. Prop.**	**Probit**	**SE**
-3	0.026	- 1.95	0.162	0.033	- 1.83	0.146
-2	0.134	- 1.11	0.107	0.124	- 1.15	0.105
-1	0.278	- 0.59	0.093	0.254	- 0.66	0.091
0	0.871	1.13	0.123	0.823	0.93	0.107
+1	0.938	1.54	0.161	0.957	1.72	0.179
+2	0.990	2.31	0.427	0.995	2.59	1.643
+3	1.000	-	-	1.000	-	-
	Nicol (Bedford), N = 194			**Nicol (ASHRAE), N = 209**		
-2	0.015	- 2.16	0.186	0.053	- 1.62	0.130
-1	0.134	- 1.11	0.107	0.234	- 0.72	0.092
0	0.876	1.16	0.125	0.823	0.93	0.107
+1	0.985	2.16	0.320	0.962	1.77	0.189
+2	1.000	-	-	1.000	-	-



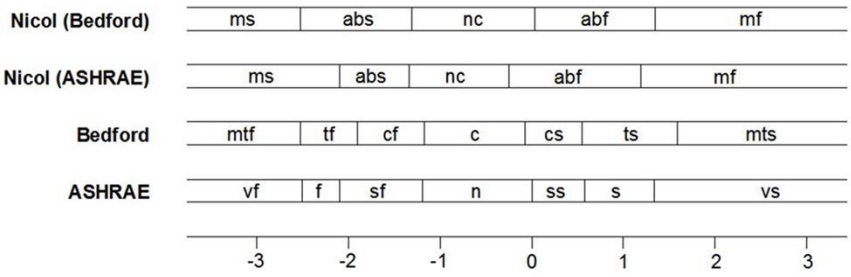
Key:

ASHRAE: vd = Very dry, d = Dry, sd = Slightly dry, n = Neutral, sh = Slightly humid, h = Humid, vh = Very humid
Bedford: mtd = Much too dry, td = Too dry, cd = Comfortably dry, c = Comfortable neither humid nor dry, ch = Comfortably humid, th = Too humid, mth = Much too humid
Nicol: mh = Much humid, abh = A bit humid, nc = no change, abd = A bit drier, md = Much drier

Comparing humidity categories' widths of ASHRAE, Bedford, and Nicol scales in winter

Cumulative proportions, probits, and standard errors of air velocity categories (summer)

	ASHRAE, N = 333			Bedford, N = 349		
Category	**Cum. Prop.**	**Probit**	**SE**	**Cum. Prop.**	**Probit**	**SE**
-3	0.006	- 2.51	0.194	0.006	- 2.53	0.193
-2	0.018	- 2.10	0.142	0.029	- 1.90	0.122
-1	0.117	- 1.19	0.085	0.120	- 1.17	0.083
0	0.502	0.00	0.069	0.473	- 0.07	0.067
+1	0.718	0.58	0.075	0.708	0.55	0.072
+2	0.910	1.34	0.104	0.951	1.66	0.127
+3	1.000	-	-	1.000	-	-
	Nicol (ASHRAE), N = 333			**Nicol (Bedford), N = 349**		
-2	0.018	- 2.10	0.142	0.006	- 2.53	0.193
-1	0.090	- 1.34	0.091	0.095	- 1.31	0.088
0	0.399	- 0.25	0.069	0.510	0.03	0.067
+1	0.883	1.19	0.095	0.911	1.35	0.101
+2	1.000	-	-	1.000	-	-



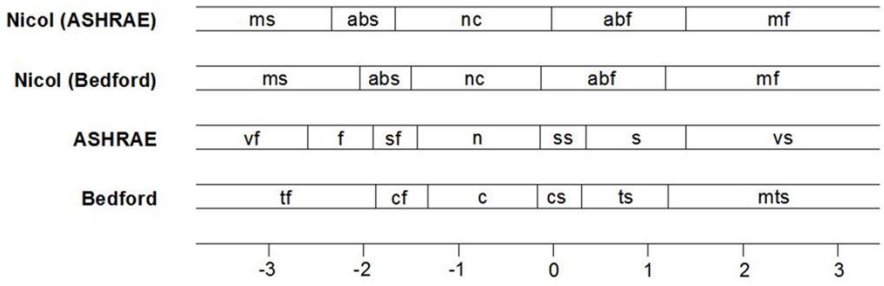
Key:

ASHRAE: vf = Very fast, f = Fast, sf = Slightly fast, n = Neutral, ss = Slightly slow, s = Slow, vs = Very slow
Bedford: mtf = Much too fast, tf = Too fast, cf = Comfortably fast, c = Comfortable neither slow nor fast, cs = Comfortably slow, ts = Too slow, mts = Much too slow
Nicol: ms = Much slower, abs = A bit slower, nc = no change, abf = A bit faster, mf = Much faster

Comparing air velocity categories' widths of ASHRAE, Bedford, and Nicol scales in summer

Cumulative proportions, probits, and standard errors of air velocity categories (winter)

	Bedford, N = 194			ASHRAE, N = 209		
Category	**Cum. Prop.**	**Probit**	**SE**	**Cum. Prop.**	**Probit**	**SE**
-3	0.000	-	-	0.005	- 2.59	0.248
-2	0.031	- 1.87	0.154	0.029	- 1.90	0.152
-1	0.093	- 1.32	0.116	0.077	- 1.43	0.118
0	0.433	- 0.17	0.090	0.445	- 0.14	0.087
+1	0.619	0.03	0.093	0.632	0.34	0.090
+2	0.887	1.21	0.128	0.919	1.40	0.139
+3	1.000	-	-	1.000	-	-
	Nicol (Bedford), N = 194			**Nicol (ASHRAE), N = 209**		
-2	0.021	- 2.04	0.172	0.010	- 2.34	0.206
-1	0.067	- 1.50	0.126	0.048	- 1.67	0.133
0	0.448	- 0.13	0.090	0.493	- 0.02	0.087
+1	0.881	1.18	0.126	0.919	1.40	0.139
+2	1.000	-	-	1.000	-	-



Key:

ASHRAE: vf = Very fast, f = Fast, sf = Slightly fast, n = Neutral, ss = Slightly slow, s = Slow, vs = Very slow
Bedford: mtf = Much too fast, tf = Too fast, cf = Comfortably fast, c = Comfortable neither slow nor fast, cs = Comfortably slow, ts = Too slow, mts = Much too slow
Nicol: ms = Much slower, abs = A bit slower, nc = no change, abf = A bit faster, mf = Much faster

Comparing air velocity categories' widths of ASHRAE, Bedford, and Nicol scales in winter

Appendix 9.1

$$T_{op} = H\,T_a + (1 - H)T_r$$

Where: $H = \dfrac{h_c}{h_c + h_r}$

And: $\dfrac{h_c}{h_r} = \sqrt{10\,v}$

So:

$$H = \frac{h_c}{h_c + h_r} = \frac{\frac{h_c}{h_r}}{1 + \frac{h_c}{h_r}} = \frac{\sqrt{10\,v}}{1 + \sqrt{10\,v}}$$

So:

$$T_{op} = \left(\frac{\sqrt{10\,v}}{1 + \sqrt{10\,v}}\right)T_a + \left(1 - \frac{\sqrt{10\,v}}{1 + \sqrt{10\,v}}\right)T_r$$

$$T_{op} = \left(\frac{\sqrt{10\,v}}{1 + \sqrt{10\,v}}\right)T_a + \left(\frac{1 + \sqrt{10\,v}}{1 + \sqrt{10\,v}} - \frac{\sqrt{10\,v}}{1 + \sqrt{10\,v}}\right)T_r$$

$$T_{op} = \left(\frac{\sqrt{10\,v}}{1 + \sqrt{10\,v}}\right)T_a + \left(\frac{1}{1 + \sqrt{10\,v}}\right)T_r$$

$$T_{op} = \frac{T_r + T_a\sqrt{10\,v}}{1 + \sqrt{10\,v}}$$

Appendix 9.2

Pearson's correlation coefficients of thermal votes and indoor globe temperature

	Summer-ASHRAE		Summer-Bedford		Winter-Bedford		Winter-ASHRAE	
	TSV, N = 333	TPV, N = 333	TSV, N = 349	TPV, N = 349	TSV, N = 194	TPV, N = 194	TSV, N = 209	TPV, N = 209
Instantaneous	**0.258**	0.160	0.213	0.103	0.196	0.146	0.144	0.027
Overall mean	0.093	- 0.004	0.095	0.068	- 0.037	- 0.029	0.098	0.000
Overall mean – instantaneous	- 0.191	- 0.179	- 0.211	- 0.078	- 0.206	- 0.154	0.149	0.037
Overall max.	- 0.109	- 0.176	- 0.015	- 0.006	0.174	0.222	0.121	0.051
Overall max. – instantaneous	**- 0.301**	**- 0.260**	- 0.223	- 0.107	- 0.164	- 0.104	- 0.119	- 0.010
Overall min.	0.001	- 0.030	0.056	0.077	0.055	0.027	0.084	0.036
Overall min. – instantaneous	- 0.179	- 0.136	- 0.185	- 0.032	- 0.136	- 0.112	- 0.109	- 0.005
Mean before	0.154	0.023	0.088	0.069	- 0.120	- 0.097	0.034	- 0.004
Mean before – instantaneous	- 0.133	- 0.161	- 0.196	- 0.066	- 0.219	- 0.166	- 0.149	- 0.032
Max. before	- 0.112	- 0.188	- 0.040	- 0.029	0.070	0.149	- 0.076	- 0.092
Max. before – instantaneous	**- 0.296**	**- 0.263**	**- 0.249**	- 0.128	- 0.177	- 0.109	- 0.172	- 0.060
Min. before	0.164	0.042	0.064	0.102	- 0.046	- 0.058	0.033	0.007
Min. before - instantaneous	- 0.052	- 0.091	- 0.169	0.004	- 0.165	- 0.137	- 0.144	- 0.026

Pearson's correlation coefficients of mean thermal votes and indoor globe temperature

	Annual		Summer		Winter	
	TSV, N = 45	TPV, N = 45	TSV, N = 28	TPV, N = 28	TSV, N = 17	TPV, N = 17
Instantaneous	**0.376**	0.234	**0.550**	**0.358**	**0.408**	0.227
Overall mean	0.071	- 0.004	0.216	0.061	0.190	0.080
Overall mean – instantaneous	**- 0.258**	**- 0.257**	**- 0.466**	**- 0.383**	- 0.069	- 0.137
Overall max.	- 0.066	- 0.120	- 0.147	- 0.261	**0.475**	**0.448**
Overall max. – instantaneous	**- 0.445**	**- 0.335**	**- 0.619**	**- 0.531**	- 0.238	- 0.058
Overall min.	0.015	0.012	0.020	0.011	0.234	0.165
Overall min. – instantaneous	**- 0.348**	- 0.214	**- 0.441**	**- 0.289**	- 0.206	- 0.085
Mean before	0.065	0.004	**0.294**	0.117	0.013	- 0.022
Mean before – instantaneous	**- 0.382**	**- 0.268**	**- 0.373**	**- 0.323**	**- 0.405**	- 0.237
Max. before	- 0.163	- 0.197	- 0.175	**- 0.310**	0.156	0.199
Max. before – instantaneous	**- 0.499**	**- 0.380**	**- 0.645**	**- 0.567**	**- 0.336**	- 0.144
Min. before	0.079	0.064	**0.288**	0.214	0.033	- 0.016
Min. before - instantaneous	**- 0.280**	- 0.160	- 0.224	- 0.118	**- 0.322**	- 0.203

Pearson's correlation coefficients of thermal votes and indoor operative temperature

	Summer-ASHRAE		Summer-Bedford		Winter-Bedford		Winter-ASHRAE	
	TSV, N = 333	TPV, N = 333	TSV, N = 349	TPV, N = 349	TSV, N = 194	TPV, N = 194	TSV, N = 209	TPV, N = 209
Instantaneous	**0.260**	0.161	0.206	0.102	0.202	0.152	0.144	0.027
Overall mean	0.095	0.003	0.091	0.053	- 0.037	- 0.029	0.079	- 0.021
Overall mean – instantaneous	- 0.189	- 0.174	- 0.204	- 0.092	- 0.214	- 0.162	- 0.159	- 0.048
Overall max.	- 0.112	- 0.183	- 0.007	- 0.049	0.162	0.207	0.128	0.060
Overall max. – instantaneous	**- 0.302**	**- 0.265**	- 0.198	- 0.138	- 0.169	- 0.109	- 0.114	- 0.005
Overall min.	0.012	- 0.014	0.083	0.065	0.061	0.034	0.070	0.013
Overall min. – instantaneous	- 0.167	- 0.122	- 0.117	- 0.028	- 0.140	- 0.116	- 0.115	- 0.021
Mean before	0.158	0.031	0.089*	0.067*	- 0.102	- 0.082	0.030	- 0.004
Mean before – instantaneous	- 0.127	- 0.154	- 0.208*	- 0.065*	- 0.223	- 0.170	- 0.150	- 0.032
Max. before	- 0.116	- 0.196	0.001*	0.019*	0.063	0.146	- 0.061	- 0.077
Max. before – instantaneous	**- 0.296**	**- 0.268**	- 0.212*	- 0.082*	- 0.185	- 0.118	- 0.169	- 0.056
Min. before	0.165	0.053	0.046*	0.055*	- 0.030	- 0.044	0.026	0.034
Min. before - instantaneous	- 0.043	- 0.077	- 0.191*	- 0.045*	- 0.166	- 0.138	- 0.136	- 0.004

* N = 325

Pearson's correlation coefficients of mean thermal votes and indoor operative temperature

	Annual		Summer		Winter	
	TSV, N = 45	TPV, N = 45	TSV, N = 28	TPV, N = 28	TSV, N = 17	TPV, N = 17
Instantaneous	**0.386**	**0.247**	**0.549**	**0.366**	**0.425**	**0.247**
Overall mean	0.073	- 0.005	**0.299**	0.071	0.158	0.042
Overall mean – instantaneous	**- 0.421**	**- 0.314**	**- 0.456**	**- 0.386**	**- 0.408**	**- 0.260**
Overall max.	- 0.035	- 0.137	- 0.106	**- 0.287**	**0.477**	**0.456**
Overall max. – instantaneous	**- 0.426**	**- 0.357**	**- 0.537**	**- 0.555**	**- 0.250**	- 0.072
Overall min.	0.019	- 0.006	0.036	- 0.007	0.226	0.146
Overall min. – instantaneous	**- 0.345**	- 0.239	**- 0.404**	**- 0.299**	- 0.227	- 0.119
Mean before	0.080*	0.013*	**0.308****	0.138**	0.024	- 0.008
Mean before – instantaneous	**- 0.391***	**- 0.275***	**- 0.375****	**- 0.321****	**- 0.421**	**- 0.254**
Max. before	- 0.132*	- 0.173*	- 0.127**	**- 0.252****	0.161	0.207
Max. before – instantaneous	**- 0.486***	**- 0.369***	**- 0.595****	**- 0.523****	**- 0.352**	- 0.162
Min. before	0.094*	0.067*	**0.266****	0.172**	0.062	0.054
Min. before - instantaneous	**- 0.277***	- 0.165*	- 0.240**	- 0.164**	**- 0.311**	- 0.168

* N = 44, ** N = 27

Pearson's correlation coefficients of thermal votes and outdoor air temperature

	Summer-ASHRAE		Summer-Bedford		Winter-Bedford		Winter-ASHRAE	
	TSV, N = 333	TPV, N = 333	TSV, N = 349	TPV, N = 349	TSV, N = 194	TPV, N = 194	TSV, N = 209	TPV, N = 209
Instantaneous	0.042	0.099	- 0.006	0.138	0.163	0.136	0.002	0.001
Overall mean	0.101	0.151	- 0.027	0.133	**0.298**	**0.262**	- 0.001	- 0.014
Overall mean – instantaneous	0.220	0.164	- 0.034	- 0.058	- 0.022	- 0.009	- 0.010	- 0.041
Overall max.	0.098	0.135	0.001	0.069	0.233	0.204	- 0.002	- 0.014
Overall max. – instantaneous	0.219	0.136	0.006	- 0.014	0.211	0.196	- 0.011	- 0.043
Overall min.	0.128	0.145	- 0.025	0.127	- 0.197	- 0.172	- 0.001	- 0.014
Overall min. – instantaneous	- 0.003	- 0.071	- 0.013	- 0.099	- 0.177	- 0.150	- 0.006	- 0.016
Mean before	0.072	0.129	0.045	0.077	0.102	0.038	- 0.034	- 0.047
Mean before – instantaneous	0.119	0.091	0.042	- 0.012	- 0.140	- 0.137	- 0.095	- 0.122
Max. before	0.058	0.108	0.081	0.198	0.172	0.128	- 0.047	- 0.051
Max. before – instantaneous	0.096	0.062	0.163	0.189	- 0.038	- 0.073	- 0.175	- 0.185
Min. before	0.128	0.145	- 0.039	0.127	- 0.197	- 0.172	- 0.001	- 0.014
Min. before - instantaneous	- 0.003	- 0.071	- 0.025	- 0.099	- 0.177	- 0.150	- 0.006	- 0.016

Pearson's correlation coefficients of mean thermal votes and outdoor air temperature

	Annual		Summer		Winter	
	TSV, N = 45	TPV, N = 45	TSV, N = 28	TPV, N = 28	TSV, N = 17	TPV, N = 17
Instantaneous	- 0.032	0.110	0.062	**0.319**	**0.315**	**0.301**
Overall mean	- 0.029	0.104	0.092	**0.358**	**0.326**	**0.301**
Overall mean – instantaneous	0.016	- 0.036	0.060	- 0.017	0.002	- 0.038
Overall max.	0.002	0.107	0.083	**0.246**	**0.340**	**0.315**
Overall max. – instantaneous	0.086	0.028	0.053	- 0.015	**0.281**	0.232
Overall min.	- 0.035	0.085	0.010	**0.273**	0.233	0.210
Overall min. – instantaneous	0.026	- 0.116	- 0.078	**- 0.280**	**- 0.328**	**- 0.332**
Mean before	0.023	0.118	0.206	**0.318**	**0.258**	0.220
Mean before – instantaneous	0.100	0.015	0.165	0.062	**- 0.277**	**- 0.351**
Max. before	0.006	0.149	0.179	**0.417**	**0.265**	0.235
Max. before – instantaneous	0.158	0.206	**0.309**	**0.358**	- 0.162	- 0.242
Min. before	- 0.035	0.090	0.006	**0.286**	0.233	0.210
Min. before - instantaneous	0.025	- 0.112	- 0.080	**- 0.273**	**- 0.328**	**- 0.332**

Pearson's correlation coefficients of humidity votes and indoor air temperature

	Summer-ASHRAE		Summer-Bedford		Winter-Bedford		Winter-ASHRAE	
	HSV, N = 333	HPV, N = 333	HSV, N = 349	HPV, N = 349	HSV, N = 194	HPV, N = 194	HSV, N = 209	HPV, N = 209
Instantaneous	0.200	- 0.127	0.086	- 0.126	0.025	0.075	- 0.106	0.091
Overall mean	0.108	- 0.024	0.043	- 0.028	- 0.052	0.042	- 0.168	0.080
Overall mean – instantaneous	0.116	- 0.124	0.083	- 0.161	0.044	0.063	- 0.048	0.082
Overall max.	0.054	- 0.024	0.022	0.066	- 0.139	0.054	- 0.162	0.056
Overall max. – instantaneous	0.152	- 0.105	0.070	- 0.189	0.053	0.065	- 0.046	0.086
Overall min.	0.019	0.060	0.040	- 0.046	- 0.115	0.007	- 0.077	- 0.000
Overall min. – instantaneous	0.132	- 0.157	0.055	- 0.096	0.129	0.064	- 0.049	0.099
Mean before	0.163	- 0.051	0.049	- 0.025	- 0.039	0.020	- 0.155	- 0.009
Mean before – instantaneous	0.047	- 0.097	0.070	- 0.156	0.036	0.066	- 0.044	0.110
Max. before	0.058	- 0.002	0.046	0.042	- 0.128	- 0.000	- 0.181	0.037
Max. before – instantaneous	0.143	- 0.118	0.056	- 0.170	0.050	0.074	- 0.033	0.082
Min. before	0.118	0.002	0.040	- 0.045	- 0.106	- 0.012	- 0.101	- 0.046
Min. before - instantaneous	0.041	- 0.118	0.044	- 0.082	0.088	0.064	- 0.029	0.123

Pearson's correlation coefficients of mean humidity votes and indoor air temperature

	Annual		Summer		Winter	
	HSV, N = 45	HPV, N = 45	HSV, N = 28	HPV, N = 28	HSV, N = 17	HPV, N = 17
Instantaneous	0.235	- 0.133	**0.383**	**- 0.464**	- 0.138	**0.364**
Overall mean	0.165	- 0.044	0.221	- 0.141	**- 0.436**	0.223
Overall mean – instantaneous	0.158	- 0.135	**0.268**	**- 0.466**	0.046	**0.318**
Overall max.	0.079	0.040	0.089	0.025	**- 0.434**	0.090
Overall max. – instantaneous	0.200	- 0.177	**0.304**	**- 0.477**	0.028	**0.359**
Overall min.	0.021	0.011	0.068	0.031	**- 0.378**	- 0.045
Overall min. – instantaneous	0.208	- 0.144	**0.274**	**- 0.453**	0.214	**0.391**
Mean before	0.238	- 0.134	**0.309**	- 0.198	**- 0.399**	- 0.052
Mean before – instantaneous	0.073	- 0.042	0.153	**- 0.397**	0.022	**0.401**
Max. before	0.120	0.005	0.146	0.003	**- 0.451**	- 0.022
Max. before – instantaneous	0.166	- 0.147	**0.273**	**- 0.472**	0.031	**0.377**
Min. before	0.107	- 0.108	0.224	- 0.102	**- 0.425**	- 0.176
Min. before - instantaneous	0.114	- 0.017	0.114	**- 0.343**	0.194	**0.522**

Pearson's correlation coefficients of air velocity votes and indoor air temperature

	Summer-ASHRAE		Summer-Bedford		Winter-Bedford		Winter-ASHRAE	
	AVSV, N = 333	AVPV, N = 333	AVSV, N = 349	AVPV, N = 349	AVSV, N = 194	AVPV, N = 194	AVSV, N = 209	AVPV, N = 209
Instantaneous	0.128	0.090	0.090	0.067	0.197	**0.258**	0.013	0.066
Overall mean	0.022	- 0.038	0.100	0.069	0.138	0.094	- 0.010	0.031
Overall mean – instantaneous	0.128	0.153	0.022	0.023	0.155	0.233	0.025	0.076
Overall max.	- 0.063	- 0.092	0.022	0.003	**0.316**	0.237	0.055	0.170
Overall max. – instantaneous	0.176	0.162	0.074	0.066	0.135	0.212	- 0.015	- 0.011
Overall min.	0.043	- 0.035	0.139	0.104	0.131	0.203	0.021	- 0.029
Overall min. – instantaneous	0.053	0.104	- 0.071	- 0.053	0.068	0.059	- 0.004	0.096
Mean before	0.014	- 0.036	0.095	0.068	0.068	0.012	- 0.024	0.027
Mean before – instantaneous	0.146	0.162	0.020	0.017	0.170	0.246	0.027	0.063
Max. before	- 0.067	- 0.105	- 0.003	- 0.009	0.231	0.172	- 0.018	0.063
Max. before – instantaneous	0.173	0.168	0.099	0.079	0.150	0.221	0.022	0.043
Min. before	0.040	- 0.026	0.136	0.099	0.073	0.095	0.033	0.041
Min. before - instantaneous	0.069	0.113	- 0.081	- 0.057	0.101	0.132	- 0.012	0.034

Pearson's correlation coefficients of mean air velocity votes and indoor air temperature

	Annual		Summer		Winter	
	AVSV, N = 45	AVPV, N = 45	AVSV, N = 28	AVPV, N = 28	AVSV, N = 17	AVPV, N = 17
Instantaneous	0.126	0.191	0.120	- 0.018	**0.332**	**0.438**
Overall mean	0.049	- 0.017	0.189	- 0.083	0.196	0.145
Overall mean – instantaneous	0.121	**0.267**	- 0.052	0.069	**0.294**	**0.441**
Overall max.	0.060	- 0.018	0.125	- 0.190	**0.388**	**0.388**
Overall max. – instantaneous	0.094	0.224	0.015	0.139	0.202	**0.317**
Overall min.	0.121	0.053	0.224	- 0.091	**0.265**	**0.267**
Overall min. – instantaneous	- 0.009	0.129	- 0.134	0.083	0.076	0.176
Mean before	- 0.002	- 0.041	0.164	- 0.072	0.064	0.040
Mean before – instantaneous	0.157	**0.272**	- 0.034	0.063	**0.319**	**0.439**
Max. before	- 0.036	- 0.081	0.074	- 0.205	0.167	0.157
Max. before – instantaneous	0.162	**0.263**	0.063	0.143	**0.273**	**0.383**
Min. before	0.096	0.054	0.195	- 0.042	0.209	0.216
Min. before - instantaneous	0.021	0.125	- 0.118	0.034	0.119	0.200

Appendix 9.3

Regression models of individual thermal sensation votes and concurrent indoor globe temperature based on schools

School	N	p-value	R^2	Intercept	Gradient	T_n	Temp. step
Summer - ASHRAE							
WK	67	Not sign.	-	-	-	-	-
SQ	83	0.000	0.195	-8.33	0.342	24.4	2.9
ZA	51	0.003	0.172	-17.1	0.657	26.0	1.5
NK	72	Not sign.	-	-	-	-	-
DA	60	Not sign.	-	-	-	-	-
Summer – Bedford							
WK	60	Not sign.	-	-	-	-	-
SQ	92	Not sign.	-	-	-	-	-
ZA	43	0.009	0.156	-51.2	1.90	26.9	0.53
NK	76	Not sign.	-	-	-	-	-
DA	78	0.000	0.143	-6.02	0.238	25.3	4.2
Winter – Bedford							
NK	74	Not sign.	-	-	-	-	-
DA	50	Not sign.	-	-	-	-	-
ZA	70	Not sign.	-	-	-	-	-
Winter – ASHRAE							
NK	67	Not sign.	-	-	-	-	-
DA	71	0.000	0.158	-8.11	0.359	22.6	2.8
ZA	71	Not sign.	-	-	-	-	-

Regression models of individual thermal sensation votes and concurrent indoor operative temperature based on schools

School	N	p-value	R^2	Intercept	Gradient	T_n	Temp. step
Summer - ASHRAE							
WK	67	Not sign.	-	-	-	-	-
SQ	83	0.000	0.195	-8.33	0.342	24.4	2.9
ZA	51	0.003	0.171	-17.1	0.657	26.0	1.5
NK	72	Not sign.	-	-	-	-	-
DA	60	Not sign.	-	-	-	-	-
Summer – Bedford							
WK	60	Not sign.	-	-	-	-	-
SQ	92	Not sign.	-	-	-	-	-
ZA	43	0.009	0.156	-51.2	1.90	26.9	0.53
NK	76	Not sign.	-	-	-	-	-
DA	78	0.000	0.141	-5.47	0.218	25.1	4.6
Winter – Bedford							
NK	74	Not sign.	-	-	-	-	-
DA	50	Not sign.	-	-	-	-	-
ZA	70	Not sign.	-	-	-	-	-
Winter – ASHRAE							
NK	67	Not sign.	-	-	-	-	-
DA	71	0.000	0.158	-8.11	0.359	22.6	2.8
ZA	71	Not sign.	-	-	-	-	-