Assessment of School Buildings' Physical Conditions and Indoor Environmental Quality in Relation to Teachers' Satisfaction and Well-Being

By

Abdul-Manan Sadick

A thesis submitted to the Faculty of Graduate Studies of
the University of Manitoba
in partial fulfillment of the requirements for the degree of

Doctor of Philosophy

Department of Civil Engineering
University of Manitoba
Winnipeg, Manitoba, Canada

DECLARATION

I, Abdul-Manan Sadick, declare this document to be my own unaided work, and where published sources are used, they are acknowledged.

____

Abdul-Manan Sadick

Abstract

Building indoor spaces are enclosed by elements including walls, windows, and floors; however, the physical conditions of these elements are generally not assessed in indoor environmental quality studies. Indoor environmental quality field observations have focused on recording the presence of elements like operable windows and building characteristics like floor finish type. Additionally, most existing building condition assessment instruments were not conceptualized with indoor environmental quality enhancement as prime objective. Therefore, there is limited empirical evidence on how physical conditions of these elements influence indoor environments and subsequently building occupants. However, there is compelling evidence supporting the thesis that improving buildings' indoor environment would positively impact occupants' well-being. Most indoor environmental quality studies in schools have focused on students, with limited focus on how schools' indoor environment affect teachers' well-being. Furthermore, most indoor environmental quality studies have restricted the definition of occupants' well-being to indoor environmental quality satisfaction. Additionally, most existing well-being measures in the social sciences literature are context-free and may overlook factors unique to teachers in school context.

This two-stage research, conducted in collaboration with the Government of Manitoba Public School Finance Board and two Manitoba school divisions, assessed the impact of school buildings' physical and indoor environmental conditions on teachers' indoor environmental quality satisfaction and well-being. Stage one of this research focused on developing an indoor environmental quality-related building condition assessment instrument to assess physical conditions of classroom space envelope elements, and an indoor environmental quality field measurement protocol for schools. Additionally, an existing indoor environmental quality satisfaction survey was adapted for teachers, and preliminary surveys were developed for assessing teachers' psychological, social, and physical well-being in school context only. Stage two included conducting indoor environmental quality-related building condition assessments and indoor environmental quality field measurements in 10 of the 32 schools that participated in this research. Additionally, the adapted indoor environmental quality satisfaction survey and the preliminary well-being surveys were administered to teachers in all 32 schools.

The results suggested that physical conditions of space enclosing elements were likely to influence classroom environments and teachers. For example, low and high concentrations of particulate matter were likely to have negative and positive effects respectively on teachers' indoor environmental quality satisfaction based on indoor environmental quality-related openings defects. The results found statistically significant differences in indoor environmental quality satisfaction only between both new and renovated schools and non-renovated schools. Therefore, the results suggested that renovating schools to improve their indoor environmental quality would likely enhance teachers' indoor environmental quality satisfaction. The validity of the well-being surveys developed in this research was supported; however, none of the differences in well-being scores between any two strata of schools were statistically significant. Nevertheless, an indirect impact of indoor environmental quality on teachers' well-being was suggested through their indoor environmental quality satisfaction. Findings of this exploratory research would contribute to developing school buildings' operation and maintenance strategies to improve indoor environmental quality and enhance occupants' satisfaction and well-being.

Acknowledgments

I thank God for the gift of life that led to the successful completion of this thesis.

I would like to take this opportunity to express my sincere gratitude to Dr. Mohamed H. Issa, my Ph.D. supervisor for his guidance and unflinching support. His in-depth reviews and constructive feedback were extremely helpful. I would also like to express my sincere thanks to my Ph.D. committee members, Dr. Dimos Polyzois and Dr. Robert Renaud whose invaluable support was essential towards the successful completion of this thesis.

This research would not have been possible without the support of our collaborators, the Government of Manitoba Public School Finance Board, the two school divisions that participated in this research, and the 32 schools in both divisions. I am grateful to the Government of Manitoba Public School Finance Board for access to the divisions, and to the school divisions for access to their schools. I would like to extend special thanks to the school divisions authorities, the staff, teachers, and students of all the schools for the wonderful reception during the field measurements. And to all the teachers who completed the online surveys, I will forever be grateful. I would like to thank Dr. Baafour Nyantekyi-Kwakye, Joshua Boateng Akom, Md Anamul Hasan, and Katia Cavalcanti Parpinelli for their assistance with data collection for this research. Additionally, I would also like to thank Bartholomew Ghanney (Wawanesa Insurance, Winnipeg) for his support with respect to the statistical analyses. Thanks, are also due to members of my research group (Mohamed Ouf, Rhoda Qauigrain, Ahmed Radwan, Joshua Akom Boateng, Bezalel Orogun, Hamid Afshari, and Jimmy Winter) for their support. I would like to acknowledge the financial support provided by the Natural Sciences and Engineering Research Council of Canada (Discovery

Grant; RGPIN 418532-2012) for this research. I am also grateful to the University of Manitoba's Research Ethics Board for reviewing and approving the protocols for this research.

To my parents, Abubakar Ibrahim Sadick and Halifatu Abdulai, I will forever be grateful for your unflinching love and support; I will forever be indebted to both of you. To my lovely siblings, Safuratu, Zulaiha, and Rukaiya, you are the best, "Nagode". I would like to thank Mubarak Usman, my Uncle and lifetime friend, for his support and encouragement towards the completion of my thesis. To Adama Tahiru and Rahinatu Abdul Hamid, I will forever be grateful for your support.

Lastly, I would like to thank the University of Manitoba Muslim Students' Association and all members of the Ghana Students' Union of Manitoba and the Ghana Union of Manitoba for their support in diverse ways.

Table of Content

Abstract iii
Acknowledgments v
Table of Content vii
List of Tables xii
List of Figures xiv
List of Abbreviations xvi
CHAPTER 1: Introduction 1
1.1 Background 1
1.2 Problem Statement 3
1.3 Goal, objectives, and hypotheses 5
1.4 Scope 6
1.5 Significance 7
1.6 Research outline 9
1.7 Summary of research methods 12
1.8 References 20
Connecting Section 23
CHAPTER 2: General literature 24
2.1 Building Condition Assessment 24
2.1.1 Definition of building condition assessment 24
2.1.2 Building condition assessment in IEQ research 26
2.1.3 Methods of building condition assessment 27
2.2 Indoor environmental quality 29
2.2.1 Definition and overview 29
2.2.2 Indoor environmental quality in schools 31
2.2.3 Evaluation of indoor environmental quality 32
2.2.3.1 IEQ Field measurement 32
2.2.3.2 Occupant survey 34
2.2.3.3 Field observations 35
2.3 Well-being 35
2.3.1 Definition of well-being 36
2.3.2 Psychological well-being 38

2.3.3 Social well-being 41
2.3.4 Physical well-being 43
2.3.5 Summary 44
2.3.6 Well-being in IEQ research 45
2.4 References 47
Connecting Section 55
CHAPTER 3: Assessing the Physical Conditions of Indoor Space Enclosing Elements in Schools in Relation to their Indoor Environmental Quality 57
3.1 Abstract 57
3.2 Introduction 58
3.3 Background information 60
3.4 Methods 63
3.4.1 Stage one 64
3.4.1.1 Study location and buildings 64
3.4.1.2 Sampling 67
3.4.1.3 Data collection 67
3.4.1.4 Development of the space level condition assessment 67
3.4.1.5 IEQ field measurement protocol 73
3.4.1.5.1 Thermal comfort data collection 74
3.4.1.5.2 Indoor air quality data collection 75
3.4.1.5.3 Acoustics data collection 76
3.4.1.5.4 Lighting data collection 79
3.4.2 Stage two 80
3.4.2.1 Sampling 80
3.4.2.2 Data collection 80
3.4.2.3 Data analysis 81
3.5 Results 82
3.5.1 Thermal comfort-related SLCA and IEQ field measurements 82
3.5.2 Indoor air quality-related SLCA and IEQ field measurements 86
3.5.3 Acoustics-related SLCA and IEQ field measurements 91
3.5.4 Lighting-related SLCA and IEQ field measurements 96
3.6 Discussion 99
3.7 Conclusion 104

3.8 Acknowledgments 105
3.9 References 105
Connecting Section 110
CHAPTER 4: Occupants' Indoor Environmental Quality Satisfaction Factors as Measures of School Teachers' Well-Being 111
4.1 Abstract 111
4.2 Introduction 112
4.3 Background information 114
4.3.1 Indoor environmental quality and its impact on building occupants 114
4.3.2 Well-being in the IEQ literature 116
4.3.3 Well-being in the social science literature 118
4.4 Methods 119
4.4.1 Stage one 120
4.4.1.1 Sampling 121
4.4.1.2 Data collection 122
4.4.1.3 Analysis 123
4.4.2 Stage two 125
4.4.2.1 Sampling 125
4.4.2.2 Data collection 126
4.4.2.3 Data analysis 128
4.5 Results 131
4.5.1 Factor structure of teachers' IEQ satisfaction survey 131
4.5.1.1 Exploratory factor analysis 131
4.5.2 Factor structures of teachers' well-being surveys 134
4.5.2.1 Exploratory factor analysis 134
4.5.2.2 Teachers' psychological well-being 134
4.5.2.3 Teachers' social well-being 135
4.5.2.4 Teachers' physical well-being 137
4.5.3 Validity and reliability of the final teachers' well-being surveys 138
4.5.4 Refined IEQ satisfaction factors as measures of teachers' well-being 138
4.6 Discussion 139
4.7 Conclusion 145
4.8 Acknowledgment 147

4.9 References 148
Connecting Section 153
CHAPTER 5: Differences in Teachers' Satisfaction with Indoor Environmental Quality and their Well-Being in New, Renovated, and Non-Renovated Schools 155
5.1 Abstract 155
5.2 Introduction 156
5.3 Background information 158
5.3.1 Renovated versus non-renovated 159
5.3.2 Pre-renovation versus post-renovation 160
5.3.3 Post-renovation 161
5.4 Methods 162
5.4.1 Study location and buildings 163
5.4.2 Study sample and online survey 164
5.4.3 Refining of occupants' satisfaction and well-being surveys 165
5.4.4 Data analysis 166
5.5 Results 167
5.5.1 Demographic information 167
5.5.2 Stratum level satisfaction with overall IEQ and its factors 168
5.5.3 Stratum level differences between IEQ satisfaction factors 172
5.5.4 Stratum level perception of the subdivisions of personal well-being 173
5.5.5 Stratum level differences between subdivisions of individual well-being 176
5.5.6 Associations between well-being and IEQ satisfaction factors 177
5.6 Discussion 177
5.7 Conclusion 181
5.8 Acknowledgment 183
5.9 References 183
Connecting Section 187
CHAPTER 6: Conditional Effects of Indoor Environmental Quality Parameters on Occupants' Satisfaction Based on Defects of School Building Envelope Elements 188
6.1 Abstract 188
6.2 Introduction 189
6.3 Background information 191
6.4 Methods 194

6.4.1 IEQ-related building condition assessment 194
6.4.2 Field measurements of IEQ 195
6.4.3 Occupants' survey 196
6.4.4 Data analysis 196
6.5 Results 198
6.5.1 Descriptive statistics 198
6.5.2 Moderation for ventilation and thermal comfort satisfaction 200
6.5.3 Moderation of lighting satisfaction 205
6.6 Discussion 208
6.7 Conclusion 213
6.8 Acknowledgments 214
6.9 References 215
Connecting Section 219
CHAPTER 7: Conclusion 220
7.1 Summary of research findings 220
7.2 Contributions to the body of knowledge and implications of this research 226
7.3 Limitations 229
7.4 Recommendations 233
7.5 Concluding remarks 236
Appendix A: Space level condition assessment instrument 238
Appendix B: Ethics approval certificate 1 242
Appendix C: Invitation email from Principal Investigator to Teachers 243
Appendix D: Open-ended interview questions 244
Appendix E: Informed Consent – stage one 245
Appendix F: Demographic information – stage one 249
Appendix G: Adapted teachers' IEQ satisfaction survey 250
Appendix H: Preliminary teachers' well-being surveys 252
Appendix I: Ethics approval certificate 2 255
Appendix J: Invitation letter from Principal Investigator to Principals – stage two 256
Appendix K: Occupants' survey invitation email – stage two 259
Appendix L: Informed consent – stage two 260

List of Tables

Table 1.1: Summary of research methods for stage one and two 14
Table 2.1: Satisfaction with Life Scale 39
Table 2.2: Ryff's Scale of Psychological Well-Being 40
Table 2.3: SWB-Related Dimensions of the SPWB and the PWBMS 42
Table 2.4: Physical Well-Being Components of RAND 36 45
Table 3.1: IEQ-related renovations executed in stratum 2 schools and their expected impact 65
Table 3.2: Strata of schools 66
Table 3.3: Thermal Comfort Parameters Field Measurement Protocol 74
Table 3.4: Indoor Air Quality Parameters Field Measurement Protocol 76
Table 3.5: Acoustics parameters field measurement protocol 77
Table 3.6: Room Index and Correspondingly Lighting Sampling Points 79
Table 3.7: Lighting Parameters Field Measurement Protocol 80
Table 3.8: Details of participating schools 81
Table 3.9: Leading level 2 SLCA scores for thermal comfort-related defects 84
Table 3.10: Leading level 2 SLCA scores for indoor air quality-related defects 87
Table 3.11: Leading level 2 SLCA scores for acoustics-related defects 92
Table 3.12: Leading level 2 SLCA scores for lighting-related defects 98
Table 4.1: Average values of selected IEQ parameters for a sample of 10 schools 119
Table 4.2: Online survey components 126
Table 4.3: 12 items three-factor solution for teachers' IEQ satisfaction survey 133
Table 4.4: 12 Items two-factor solution for the new final TPWB survey 135
Table 4.5: 12 items three-factor solution for the new final TSWB survey 136
Table 4.6: 11 items two-factor solution for the new final TPhWB survey 137
Table 4.7: Validity of teachers' final well-being surveys 138
Table 4.8: Associations of refined IEQ satisfaction factors with the existing well-being surveys and the final teachers' well-being surveys 139
Table 5.1. summary of renovated versus non-renovated buildings research studies 160
Table 5.2. Summary of pre-renovation versus post-renovation research studies 161
Table 5.3: Summary of post-renovation research studies 162
Table 5.4: Details of the study sample 164
Table 5.5. Demographic information 168

Table 5.6. Post hoc pairwise comparison of IEQ satisfaction variables 173
Table 5.7. Correlations between IEQ variables and well-being measures 177
Table 6.1: Descriptive statistics 199

List of Figures

Figure 1.1: Organization of the thesis 10
Figure 1.2: Components of two stage research process with related objectives 13
Figure 2.1: Structured Framework for Defining Well-Being 37
Figure 2.2: Definition of Well-Being 37
Figure 3.1: Flow Diagram for Exploratory Sequential Mixed-Method Design 64
Figure 3.2: Hierarchy of space level condition assessment components 69
Figure 3.3: Custom built temperature profile apparatus 75
Figure 3.4: Schematic diagram for reverberation time measurement 78
Figure 3.5: Schematic diagram for apparent sound transmission class measurement 78
Figure 3.6: Thermal comfort-related SLCA scores for level 4 components 83
Figure 3.7: Air temperature and relative humidity for new, renovated and non-renovated schools respectively 85
Figure 3.8: Indoor air quality-related SLCA scores for level 4 components 87
Figure 3.9: Carbon monoxide, carbon dioxide, total volatile organic compound, and particulate matter for new, renovated and non-renovated schools respectively 89
Figure 3.10: Acoustics-related SLCA scores for level 4 components 92
Figure 3.11: A and C-weighted background noise for the three strata of schools 94
Figure 3.12: Reverberation time and apparent sound transmission class for new, renovated and non-renovated schools 95
Figure 3.13: Lighting-related SLCA scores for level 4 components 97
Figure 3.14: Daylight factor for new, renovated and non-renovated schools 99
Figure 4.1: Outline of two stage research methodology 120
Figure 4.2: Development of Preliminary Well-Being Surveys 125
Figure 4.3: Hypothetical two stage impact of IEQ satisfaction factors on occupants' well-being 145
Figure 5.1. Stratum level distribution of overall IEQ satisfaction ratings 169
Figure 5.2. Stratum level teachers' satisfaction with IEQ factors. 170
Figure 5.3. Stratum level mean teacher ratings of VTC_{sat} items 171
Figure 5.4. Stratum level teachers' perception of the three subdivisions of personal well-being 174
Figure 5.5. Stratum level mean ratings of the factors of personal well-being subdivisions 175
Figure 6.1: Moderation models: (a) graphical model; (b) statistical model 197
Figure 6.2: Effect of $PM_{2.5}$ on VTC_{sat} moderated by indoor air quality-related finishes SLCA. 201

Figure 6.3: Conditional effect of $PM_{2.5}$ on VTC_{sat} as a function of indoor air quality-related finishes SLCA 202

Figure 6.4: Effect of PM_{10} on VTC_{sat} moderated by indoor air quality-related electrical SLCA 204

Figure 6.5: Conditional effect of PM10 on VTC_{sat} as a function of indoor air quality-related electrical SLCA........ 205

Figure 6.6: Effect of daylight factor on L_{sat} moderated by lighting-related openings SLCA..... 206

Figure 6.7: Conditional effect of daylight factor on L_{sat} based on lighting-related openings SLCA 208

List of Abbreviations

AP_{sat}	Acoustics and Privacy Satisfaction
ASHRAE	American Society for Heating, Refrigerating and Air-Conditioning Engineers
ASTM	American Society for Testing and Materials
ASTC	Apparent Sound Transmission Class
ATL	Apparent Transmission Loss
BASE	Building Assessment Survey and Evaluation
BCA	Building Condition Assessment
BUS	Building Use Studies
CO_2	Carbon Dioxide
CO	Carbon Monoxide
CDC	Center for Disease Control and Prevention
CBE	Centre for the Built Environment
CFA	Confirmatory Factor Analysis
COPE	Cost-effective Open-Plan Environments
α	Cronbach's Alpha
DF	Daylight Factor
EM	Expectation Maximization
EFA	Exploratory Factor Analysis
HOPE	Health Optimization Protocol for Energy Efficient Buildings
HRQL	Health Related Quality of Life
HVAC	Heating, Ventilation, And Air-Conditioning System
IAQ	Indoor Air Quality
IEQ	Indoor Environmental Quality
ISO	International Organization for Standardization
KMO	Kaiser-Meyer-Olkin
L_{sat}	Lighting Satisfaction
NRC	National Research Council Canada
N/A	Not Applicable

PPB	Parts Per Billion
PPM	Parts Per Million
PhWB	Physical Well-Being
PCA	Principal Component Analysis
PD	Psychological Distress
PWB	Psychological Well-Being
PWBMS	Psychological Well-Being Manifestation Scale
PHAS	Public Housing Assessment System
SWLS	Satisfaction With Life Scale
SPANE	Scale of Positive and Negative Experience
SPWB	Scale of Psychological Well-Being
SBS	Sick Building Syndromes
SWB	Social Well-Being
STC	Sound Transmission Class
SLCA	Space Level Condition Assessment
TPhWB	Teachers' Physical Well-being Survey
TPWB	Teachers' Psychological Well-being Survey
TSWB	Teachers' Social Well-being Survey
TVOC	Total Volatile Organic Compound
US	United States
VTC_{sat}	Ventilation and Thermal Comfort Satisfaction
VOC	Volatile Organic Compound
WHO	World Health Organization

CHAPTER 1: Introduction

This chapter starts with a summarized background information and proceeds to discuss the research problems investigated in this study. The goal, specific objectives, scope, significance, and a thesis outline are also presented in this chapter.

1.1 Background

People spend an estimated 90% of their time working and living indoors (Gill, Tierney, Pegg, & Allan, 2010), highlighting the need for research that investigates the impact of indoor spaces on building occupants. The indoor environmental quality (IEQ) literature supports the premise that improving buildings' indoor environment would have a positive impact on building occupants (Bakó-Biró, Clements-Croome, Kochhar, Awbi, & Williams, 2012; Kielb et al., 2015; Lan, Wargocki, & Lian, 2011). For example, Lan et al. (2011) estimated that IEQ improvement of office buildings would lead to at least 10% increase in office workers' productivity. Additionally, Bakó-Biró et al. (2012) reported a negative association between low ventilation rate and students' concentration in classrooms while Kielb et al. (2015) found a positive association between indoor air pollutants like dust and mold and the prevalence of asthma among teachers. The majority of IEQ studies have focused on office buildings and their occupants (e.g. Hodgson, 2008; Newsham et al., 2013; Nicol, Wilson, & Chiancarella, 2006) considering the likely economic outcomes. For school buildings, the majority of IEQ studies (Bradley & Sato, 2008; Noullett, Jackson, & Brauer, 2010; Zandvliet & Straker, 2001) have focused on exploring the impact on students' performance and well-being with a limited emphasis on teachers. However, Buckley, Schneider, and Shang

(2005) reported that improvement of schools' facilities was most likely to increase teacher retention compared to salary increment.

The assessment of IEQ in all building types is conducted through IEQ field measurement, occupants' IEQ satisfaction, and field observations (Newsham et al., 2013). IEQ field measurements, conducted with calibrated sensors, provide objective measurements of thermal comfort, indoor air quality, acoustics, and lighting parameters (Thomsen et al., 2016) that are compared to established benchmarks for human habitation and comfort (ASHRAE, 2010; WHO, 2006). Occupants' IEQ satisfaction, conducted mainly through a questionnaire survey, aims to evaluate occupants' satisfaction with thermal comfort, indoor air quality, lighting, and acoustics. Occupants' IEQ satisfaction is usually referred to as occupants' well-being in the IEQ literature (Kim, Candido, Thomas, & de Dear, 2016). The results of IEQ field measurement and occupants IEQ satisfaction are sometimes divergent probably due to differences in occupants' capacities to cope with adverse IEQ. For example, Ghita and Catalina (2015) found that students were satisfied with indoor air quality although carbon dioxide (CO_2) concentration in the classrooms exceeded recommended levels. During field observations, researchers record additional information that would be relevant in exploring observed trends in IEQ field measurements and potential causes of occupants' IEQ dissatisfaction (Aries, Veitch, & Newsham, 2010). This additional information includes building features (e.g. operable windows, thermostat, and floor finish type) and adaptation strategies (occupants' clothing, opening windows, and using portable fan) (Newsham et al., 2013). De Giuli, Da Pos, and De Carli (2012) attributed students dissatisfaction with indoor air quality to closed operable windows during class time, thus, demonstrating the usefulness of field observations.

1.2 Problem Statement

The environmental quality of indoor spaces in buildings would depend on the extent to which building space envelope elements including walls, windows, and floors meet their functional requirements during their service life. The efficiency and effectiveness of these space envelope elements depreciate with time due to defects and environmental exposure that may affect the quality of indoor environments. Consequently, the physical condition of these space envelope elements would influence the environmental quality of indoor spaces and subsequently affect occupants' well-being. IEQ studies that involved field measurement of parameters like air temperature and particulate matter (e.g. Muhič & Butala, 2004; Newsham et al., 2013) generally record additional information like the presence or absence of an operable window and whether it was opened or closed at the time of observation. Nevertheless, they do not account for the physical conditions of space envelope elements despite their potential impact on indoor environments. Therefore, there is limited empirical evidence on how the physical conditions of space envelope elements affect indoor environmental conditions and subsequently occupants' well-being. Additionally, building condition assessment (BCA) instruments found in the literature were not conceptualized with IEQ improvement as a primary objective and would therefore not be suitable for assessing the impact of buildings' physical conditions on IEQ.

A review of the concept of well-being in the social sciences literature suggests that the concept has not been sufficiently explored in IEQ research. Dodge, Daly, Huyton, and Sanders (2012, p. 230) defined well-being as "the balance point between an individual's resource pool (i.e. psychological, social, and physical) and the challenges faced (i.e. psychological, social, and physical)". The resources and challenges include individuals' acceptance of their strengths and weaknesses (i.e. psychological), their ability to collaborate with others (i.e. social), and their ability to undertake daily activities (i.e. physical) (Hays & Morales, 2001; Keyes, 1998; Ryff, 1989). A problem with the IEQ literature is that it generally uses the term occupants' well-being to refer to occupants' IEQ satisfaction (e.g. Bluyssen, Aries, & van Dommelen, 2011a; Bluyssen, Janssen, van den Brink, & de Kluizenaar, 2011b; Righi, Aggazzotti, Fantuzzi, Ciccarese, & Predieri, 2002; Turunen et al., 2014). This is problematic because occupants' IEQ satisfaction refers to occupants' satisfaction with thermal comfort (e.g. air temperature), indoor air quality (i.e. concentration of carbon dioxide), acoustics (i.e. background noise), and lighting parameters (amount of daylight indoors) (Bluyssen et al., 2011a). Occupants' IEQ satisfaction excludes other relevant aspects of occupants' well-being like psychological, social, and physical. Additionally, most IEQ studies in schools focused on students despite the potential impact of adverse IEQ on teachers' effectiveness and the reported association between teachers' effectiveness and students' performance (Harris & Sass, 2014b). Consequently, there is little empirical evidence on the extent to which teachers' IEQ satisfaction reflects their well-being in school. There is also little empirical evidence on the conditional effects of school buildings' physical conditions on the physical parameters of IEQ and subsequently the satisfaction and well-being of building occupants, particularly school teachers. In addition, most of the well-being surveys found in the social sciences (e.g. Satisfaction with Life Scale and Ryff's Scale of Psychological Well-being) are context-free (Dagenais-Desmarais & Savoie, 2012). These context-free surveys are likely to exclude some unique well-being dimensions relevant to teachers in school environments.

1.3 Goal, objectives, and hypotheses

The goal of this multidisciplinary research was to assess the impact of school buildings' physical and indoor environmental conditions on teachers' IEQ satisfaction and well-being. Therefore, the objectives of this research were to:

1. Assess the physical conditions of space envelope elements of school building types (i.e. new, renovated, and non-renovated) in relation to their IEQ
2. Determine the extent to which IEQ satisfaction factors are direct measures of occupants' well-being
3. Assess school teachers' IEQ satisfaction and their well-being in different school types (i.e. new, renovated, and non-renovated)
4. Assess the impact of the physical conditions of school building elements on IEQ parameters and subsequently on teachers' IEQ satisfaction and well-being

Achieving the objectives of this research involved assessing the following hypotheses:

1. School buildings' physical conditions and indoor environments will vary significantly between school types (i.e. new, renovated, and non-renovated) [chapter 3]
2. School buildings' physical conditions will significantly correlate with IEQ parameters [chapter 3]
3. Occupants' IEQ satisfaction factors (i.e. ventilation and thermal comfort, lighting, and acoustics and privacy) will not significantly correlate with occupants' well-being (i.e. psychological, social, physical) [chapter 4]

4. Occupants' IEQ satisfaction and well-being will vary significantly between school types (i.e. new, renovated, and non-renovated) [chapter 5]
5. The impact of school buildings' indoor environment on teachers' IEQ satisfaction and well-being will significantly depend on the physical conditions of space enclosing elements [chapter 6]

1.4 Scope

This research was conducted in collaboration with the Government of Manitoba Public School Finance Board and two school divisions in the province of Manitoba, Canada. The 32 schools under the two divisions are in the southeast region of the province. This research was limited to teachers working in the two school divisions from Kindergarten to Grade 12. The first stage of this research involved developing an IEQ-related BCA instrument after visiting 10 of the 32 schools during the preliminary stage in the fall of 2015. The IEQ-related BCA, named space level condition assessment (SLCA) includes the key space enclosing elements of classrooms given that teachers spend most of their school time in classrooms. Additionally, a comprehensive protocol was developed for field measurement of thermal comfort, indoor air quality, acoustics, and lighting parameters in classrooms. Furthermore, the IEQ satisfaction survey developed by the National Research Council Canada (NRC) for office workers was adapted with permission to assess teachers' IEQ satisfaction in schools. The first stage also involved developing preliminary surveys for assessing teachers' well-being (i.e. psychological, social, and physical) based on semi-structured interviews of 20 teachers. The well-being surveys were limited to teachers' experiences in school context only, thus, excluding other life domains like home and other factors like medical health and financial status. The second stage involved conducting SLCA and IEQ field measurements of 52 classrooms in 10 schools. The SLCA and IEQ field measurements were limited to classrooms given that teachers spend most of their work time in them. The IEQ field measurements were conducted for thermal comfort, indoor air quality, acoustics, and lighting using calibrated measurement equipment. This second stage also included administering the adapted IEQ satisfaction survey, the preliminary teachers' well-being surveys, and three other well-being surveys from the literature for validation purposes. The surveys were administered online and were open to teachers in all 32 schools. The second stage of this research was completed during the winter of 2016.

1.5 Significance

This research is significant on several fronts with respect to the IEQ literature. Firstly, although indoor space enclosing elements like walls, floors, and ceilings develop defects or deteriorate with time, IEQ research generally excludes the assessment of their physical conditions, focusing instead mainly on observing their presence or absence and their usage pattern. This is despite for example the ability of operable windows to control IEQ parameters being substantially compromised by defects like cracked window glazing and deteriorated seal. Using the newly-developed SLCA, this research provides empirical evidence of statistically significant associations between the physical conditions of space enclosing elements and IEQ parameters like daylight and particulate matter, justifying thus the need for SLCA.

Secondly, the IEQ literature makes no distinction between occupants' IEQ satisfaction and occupants' well-being, with occupants' IEQ satisfaction ratings used to assess the impact of adverse IEQ on building occupants. This research is the first to evaluate these two concepts independently and to investigate the extent to which occupants' IEQ satisfaction is a direct measure of occupants' well-being. The empirical evidence presented in this research leads to the conclusion that the two concepts are not the same. Additionally, this research suggests that occupants' IEQ satisfaction is potentially a component of occupants' well-being. This is significant because interpreting occupants' IEQ satisfaction as occupants' well-being could lead to developing IEQ improvement strategies that would not result in the expected impact on occupants' well-being.

Thirdly, this research is the first to provide empirical evidence on statistically significant interactions between IEQ parameters, occupants' IEQ satisfaction, and the physical conditions of building elements based on IEQ-related BCA. Investigating the interactions between these three components would result in linking occupants' IEQ satisfaction to the physical conditions of buildings and would thus aid building managers in making informed and strategic maintenance decisions. Additionally, routine investigation of these interactions would contribute to developing building maintenance strategies primarily focused on IEQ improvement and occupants' satisfaction.

Lastly, this research contributes two new data collection methods that would enrich the IEQ literature. It is the first to provide a comprehensive method, SLCA, to evaluate the physical conditions of classrooms' space envelope elements in relation to their IEQ. Although the instrument was developed for schools, it can be adapted for other building types. This research is also the first to provide occupants' well-being surveys to evaluate teachers' psychological, social, and physical well-being in school environments. These surveys address the lack of similar surveys addressing the unique needs of school teachers in the IEQ and social science literature and were instrumental in reaching the conclusion that occupants' IEQ satisfaction should not be interpreted as occupants' well-being. The overall methodology developed and applied in this research also adds to its significance. The methodology provides a simplified and cost-effective process for investigating the impact of the physical conditions of space envelope elements on IEQ parameters and subsequently on building occupants.

1.6 Research outline

Figure 1.1 presents the outline of this thesis. Chapter1 highlights the state of the art regarding the impact of IEQ on building occupants and the three main IEQ assessment methods (i.e. IEQ field measurements, occupants' survey, and IEQ field observations). The chapter also highlights the problems investigated in this research, the research goal, objectives, hypotheses, scope, and significance of this research. Chapter 1 ends with a summary of the methods employed in this research.

Chapter 2 presents the background information required to support the need for this research. Following the sandwich thesis format, chapters 3 to 6 respectively include specific background information related to the objective(s) addressed in those chapters. This background information section in each chapter complements the background in chapter 1 and the general literature in chapter 2. Chapters 3 to 6 respectively includes a detailed description of the research methodology relevant to each chapter.

Chapter 3 addresses objectives one of this research and describes the SLCA instrument developed and validated as part of this research. The chapter also includes a detailed description of the IEQ field measurement protocol employed in this research. Results of the SLCA and IEQ field measurements conducted in 10 schools, as well as their correlations, are presented in this chapter.

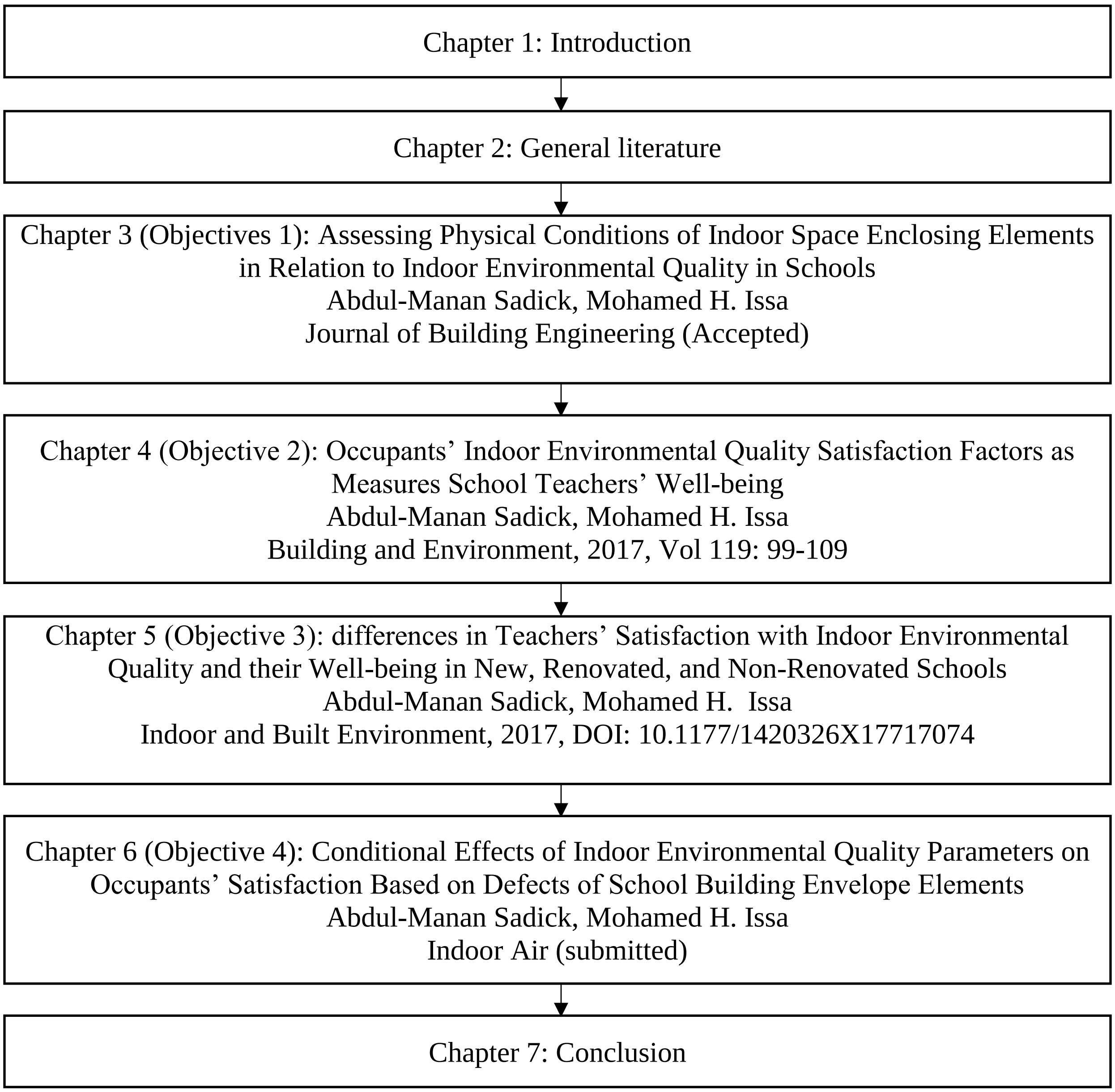

Figure 1.1: Organization of the thesis

Chapter 4 addresses objectives two of this research. This chapter describes in detail the methods used to develop and validate the psychological, social, and physical well-being surveys. Additionally, the chapter describes how the occupants' satisfaction survey developed by the National Research Council Canada for office workers (Newsham et al., 2013) was adapted for teachers in school context. The validity of the newly developed well-being surveys is demonstrated by showing how they correlate to their corresponding predominant surveys in literature. These predominant well-being surveys are context-free with supported construct validity from several studies. The chapter also proposes a path diagram for assessing the impact of IEQ satisfaction factors on teachers' well-being.

Chapter 5 relates to objective three and reports on the differences in teachers' IEQ satisfaction and well-being in new, renovated, and non-renovated schools. This chapter is a logical extension of chapter 4 given its focus on analyzing responses received for the IEQ satisfaction and well-being surveys presented and validated in chapter 4. The chapter does not account for the impact of defects on teachers IEQ satisfaction and well-being. The focus here is on the likely impact of IEQ-related renovations of school buildings on teachers' IEQ satisfaction and well-being.

Chapter 6 relates to the fourth objective of this research. This chapter uses data from the SLCA, IEQ field measurement, and IEQ satisfaction survey to assess the conditional effects of IEQ parameters on occupants based on the physical conditions of space envelope elements. Chapter 7, the concluding chapter, summarizes the findings in chapters 3 to 6. Additionally, it describes the contributions of this research and its implications as well as its limitations and recommendations for future research before providing final concluding remarks.

1.7 Summary of research methods

This research was conducted in two stages. Stage one involved the development of data collection instruments and measurement procedures for SLCA, IEQ field measurement, and occupants' surveys (i.e. IEQ satisfaction survey and well-being survey). Stage two involved the deployment of the instruments developed in stage one. The respective chapters include detailed descriptions of these methods. Figure 1.2 presents the major components of the two stages and the related objectives while Table 1.1 summarizes the methods employed.

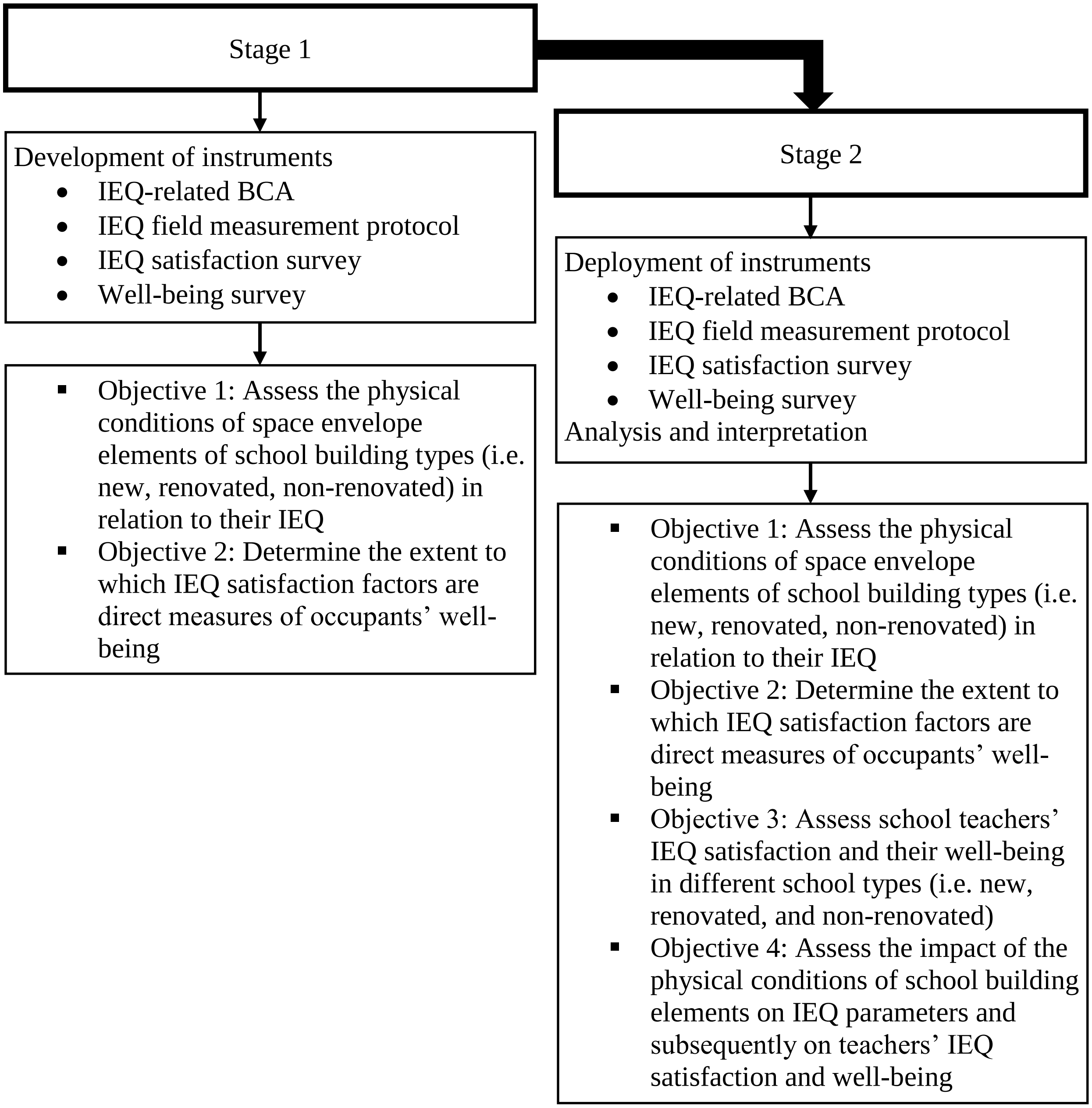

Figure 1.2: Components of two stage research process with related objectives

Table 1.1: Summary of research methods for stage one and two

Stages	Methods	Objectives
Stage one (Winter 2015 - fall 2015)	*Development of IEQ-related BCA* • Sampling ▪ Population of 32 schools stratified into three as follows: new (7), renovated (17), and non-renovated schools (8) ▪ Sample 10 schools consisting of new (4), renovated (3), and non-renovated schools (3) volunteered to participate • Data collection ▪ Written notes and photographs of physical conditions of classroom space enclosing elements ▪ Defects descriptions from the PHAS • Analyses ▪ Adapted and refined defects descriptions from PHAS based on field data ▪ Focused mainly on visually observable defects that are likely to influence IEQ ▪ Four severity levels developed for each defect	• Objective 1: Assess the physical conditions of space envelope elements of school building types (i.e. new, renovated, and non-renovated) in relation to their IEQ
	Development of IEQ field measurement protocol • Data collection ▪ Recognized standards and published journal articles including Thermal Environmental Conditions for Human Occupancy (ASHRAE 55), Acoustical Performance Criteria, Design Requirements, and Guidelines for Schools, Part 1: Permanent Schools, and Standard Test Method for Measurement of Airborne Sound Attenuation between Rooms in Buildings • Measurement protocols ▪ Developed protocols for thermal comfort, indoor air quality, acoustics, and lighting ▪ Thermal comfort parameters included air temperature, radiant temperature, and relative humidity ▪ Indoor air quality parameters included TVOC, CO_2, CO, $PM_{2.5}$, and PM_{10}	• Objective 1: Assess the physical conditions of space envelope elements of school building types (i.e. new, renovated, and non-renovated) in relation to their IEQ

	▪ Acoustics parameters included RT60, average background noise, and ASTC ▪ Lighting Included daylight factor	
	Development of occupants' surveys *IEQ satisfaction survey* • Data collection ▪ NRC's environmental features rating survey developed for office workers • Analysis ▪ Adapted NRC's environmental features rating survey for teachers *Well-being survey* • Sampling ▪ Selected 20 teachers from 25 who volunteered to participate from a population of 852 teachers using purposeful sampling ▪ Factors considered in selecting teachers included gender, years of teaching experience, school grade level, and number of teachers in each of the two school divisions • Data collection ▪ Conducted semi-structured interviews with open-ended questions for psychological, social, and physical well-being in school context ▪ Audio recorded interviews that ranged from about 30 minutes to one hour ▪ Selected existing validated psychological, social, and physical well-being surveys as benchmark surveys to validate the new well-being surveys • Analyses ▪ Extracted and labeled base codes from transcribed interviews ▪ Integrated base codes to form categories ▪ Conducted comparative analyses within and between categories, identified similarities and differences, and created subcategories (i.e. different dimensions of well-being manifestations) ▪ Number of well-being manifestations included in the preliminary psychological, social, and physical well-being surveys was based on the	• Objective 2: Determine the extent to which IEQ satisfaction factors are direct measures of occupants' well-being

	number of respondent who reported a specific manifestation and the ability of a manifestation to capture the meaning of other manifestations ▪ All non-school related manifestations were omitted ▪ Transcribed interview data were analyzed using QSR Nvivo version 10 software	
Stage two (winter 2016 – summer 2017)	*IEQ-related BCA* • Sampling ▪ Selected a sample of 10 schools consisting of three new, three renovated, and four non-renovated ▪ Selected a total of 52 classrooms with a minimum of 5 in each school given those classrooms were selected for IEQ field measurement • Data collection ▪ IEQ-related BCA of classrooms' space enclosing elements was conducted using customized Excel spreadsheet on a hand-held micro-computer • Analyses ▪ Assessed differences in IEQ-related BCA scores between new, renovated, and non-renovated schools using Kruskal-Wallis H test. Post hoc pairwise comparison with Bonferroni correction for multiple comparisons was conducted for statistically significant tests to identify pairs of schools that differed ▪ Statistical analyses were conducted using IBM SPSS version 23	• Objective 1: Assess the physical conditions of space envelope elements of school building types (i.e. new, renovated, and non-renovated) in relation to their IEQ
	IEQ field measurement • Sampling ▪ Selected a sample of 10 schools consisting of three new, three renovated, and four non-renovated ▪ Selected a total of 52 classrooms with a minimum of 5 in each school based on location, size, and being occupied at the time of field measurements • Data collection ▪ Short-term measurements of IEQ parameters for thermal comfort, indoor air quality, acoustics, and lighting were conducted using calibrated sensors	

	▪ Thermal comfort and indoor air quality parameters were measured when the classrooms were occupied, whereas lighting and acoustics parameters measured when the classrooms were unoccupied • Analyses ▪ Assessed differences in IEQ field measurements between new, renovated, and non-renovated schools using the Kruskal-Wallis H test. Post hoc pairwise comparison with Bonferroni correction for multiple comparisons was conducted for statistically significant tests to identify pairs of schools that differed ▪ Assessed associations between IEQ field measurements and IEQ-related BCA scores using Spearman's rho test ▪ Determined the proportion of variance in IEQ field measurements explained by IEQ-related BCA scores using the coefficient of determination ▪ Statistical analyses were conducted using IBM SPSS version 23	
	Occupants' surveys *IEQ satisfaction survey* • Sampling ▪ Target sample of 300 from population 852 teachers for 95% confidence level and 5% margin of error ▪ Survey was administered all teachers considering 25% average response rate for online surveys • Data collection ▪ Survey was administered online using the Qualtrics online survey platform • Analyses ▪ Assessed model fit between NRC survey's three-factor structure of IEQ satisfaction and teachers IEQ satisfaction data using confirmatory factor analysis ▪ Determined new factor structure for teachers IEQ satisfaction using exploratory factor analysis	• Objective 2: Determine the extent to which IEQ satisfaction factors are direct measures of occupants' well-being • Objective 3: Assess school teachers' IEQ satisfaction and their well-being in different school types (i.e. new, renovated, and non-renovated)

    - Determined internal consistency and reliability of survey using Cronbach's alpha
    - Assessed differences in teachers' IEQ satisfaction between new, renovated, and non-renovated schools using the Kruskal-Wallis H test. Post hoc pairwise comparison with Bonferroni correction for multiple comparisons was conducted for statistically significant tests to identify pairs of schools that differed
    - Statistical analyses were conducted using IBM SPSS version 23

Well-being survey

- Sampling
    - Target sample of 300 from population 852 teachers for 95% confidence level and 5% margin of error
    - Survey was administered all teachers considering 25% average response rate for online surveys
- Data collection
    - Survey was administered online using the Qualtrics online survey platform
    - Each respondent was randomly assigned either the psychological, social, or well-being component in addition to the IEQ satisfaction survey
- Analyses
    - Determined factor structure for teachers psychological, social, and physical well-being using exploratory factor analysis
    - Validity of the surveys was assessed using a two-tailed test of association with benchmark surveys
    - Determined internal consistency and reliability of surveys using Cronbach's alpha
    - Assessed associations between teachers' IEQ satisfaction factors, teachers' well-being surveys, and benchmark well-being surveys using two-tailed correlation test
    - Assessed differences in teachers' well-being between new, renovated, and non-renovated schools using the Kruskal-Wallis H test. Post hoc pairwise comparison with Bonferroni correction for multiple comparisons was

	conducted for statistically significant tests to identify pairs of schools that differed ▪ Statistical analyses were conducted using IBM SPSS version 23	
	IEQ related BCA, IEQ field measurement, and occupants survey • Analyses ▪ Determined how the physical conditions of space enclosing elements influenced the effect of IEQ parameters on teachers IEQ satisfaction using moderation analysis ▪ Moderation analyses were conducted using the "PROCESS" program version 2.16.3 for IBM SPSS	• Objective 4: Assess the impact of the physical conditions of school building elements on IEQ parameters and subsequently on teachers' IEQ satisfaction and well-being

1.8 References

Aries, M. B., Veitch, J. A., & Newsham, G. R. (2010). Windows, view, and office characteristics predict physical and psychological discomfort. *Journal of Environmental Psychology, 30*(4), 533-541.

ASHRAE. (2010). Thermal Environmental Conditons for Human Occupancy. Atlanta: the American Society of Heating, Refrigerating and Air-Conditioning Engineers.

Bakó-Biró, Z., Clements-Croome, D., Kochhar, N., Awbi, H., & Williams, M. (2012). Ventilation rates in schools and pupils' performance. *Building and Environment, 48*, 215-223.

Bluyssen, P. M., Aries, M., & van Dommelen, P. (2011a). Comfort of workers in office buildings: The European HOPE project. *Building and Environment, 46*(1), 280-288.

Bluyssen, P. M., Janssen, S., van den Brink, L. H., & de Kluizenaar, Y. (2011b). Assessment of wellbeing in an indoor office environment. *Building and Environment, 46*(12), 2632-2640.

Bradley, J. S., & Sato, H. (2008). The intelligibility of speech in elementary school classrooms. *The Journal of the Acoustical Society of America, 123*(4), 2078-2086. doi: doi:http://dx.doi.org/10.1121/1.2839285

Buckley, J., Schneider, M., & Shang, Y. (2005). Fix it and they might stay: School facility quality and teacher retention in Washington, DC. *The Teachers College Record, 107*(5), 1107-1123.

Dagenais-Desmarais, V., & Savoie, A. (2012). What is psychological well-being, really? A grassroots approach from the organizational sciences. *Journal of Happiness Studies, 13*(4), 659-684.

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.

Dodge, R., Daly, A. P., Huyton, J., & Sanders, L. D. (2012). The challenge of defining wellbeing. *International Journal of Wellbeing, 2*(3).

Ghita, S. A., & Catalina, T. (2015). Energy efficiency versus indoor environmental quality in different Romanian countryside schools. *Energy and Buildings, 92*, 140-154.

Gill, Z. M., Tierney, M. J., Pegg, I. M., & Allan, N. (2010). Low-energy dwellings: the contribution of behaviours to actual performance. *Building Research & Information, 38*(5), 491-508.

Harris, D. N., & Sass, T. R. (2014b). Skills, productivity and the evaluation of teacher performance. *Economics of Education Review, 40*, 183-204.

Hays, R. D., & Morales, L. S. (2001). The RAND-36 measure of health-related quality of life. *Annals of medicine, 33*(5), 350-357.

Hodgson, M. (2008). Acoustical Evaluation of Six 'Green' Office Buildings. *Journal of Green Building, 3*(4), 108-118. doi: 10.3992/jgb.3.4.108

Keyes, C. L. M. (1998). Social well-being. *Social psychology quarterly*, 121-140.

Kielb, C., Lin, S., Muscatiello, N., Hord, W., Rogers-Harrington, J., & Healy, J. (2015). Building-related health symptoms and classroom indoor air quality: a survey of school teachers in New York State. *Indoor air, 25*(4), 371-380.

Kim, J., Candido, C., Thomas, L., & de Dear, R. (2016). Desk ownership in the workplace: The effect of non-territorial working on employee workplace satisfaction, perceived productivity and health. *Building and Environment, 103*, 203-214. doi: http://dx.doi.org/10.1016/j.buildenv.2016.04.015

Lan, L., Wargocki, P., & Lian, Z. (2011). Quantitative measurement of productivity loss due to thermal discomfort. *Energy and Buildings, 43*(5), 1057-1062.

Muhič, S., & Butala, V. (2004). The influence of indoor environment in office buildings on their occupants: expected–unexpected. *Building and Environment, 39*(3), 289-296.

Newsham, G. R., Birt, B. J., Arsenault, C., Thompson, A. J., Veitch, J. A., Mancini, S., . . . Burns, G. J. (2013). Do 'green'buildings have better indoor environments? New evidence. *Building Research & Information, 41*(4), 415-434.

Nicol, F., Wilson, M., & Chiancarella, C. (2006). Using field measurements of desktop illuminance in European offices to investigate its dependence on outdoor conditions and its effect on occupant satisfaction, and the use of lights and blinds. *Energy and Buildings, 38*(7), 802-813.

Noullett, M., Jackson, P. L., & Brauer, M. (2010). Estimation and characterization of children's ambient generated exposure to PM2.5 using sulphate and elemental carbon as tracers. *Atmospheric Environment, 44*(36), 4629-4637. doi: http://dx.doi.org/10.1016/j.atmosenv.2010.08.004

Righi, E., Aggazzotti, G., Fantuzzi, G., Ciccarese, V., & Predieri, G. (2002). Air quality and well-being perception in subjects attending university libraries in Modena (Italy). *Science of The Total Environment, 286*(1), 41-50.

Ryff, C. D. (1989). Happiness is everything, or is it? Explorations on the meaning of psychological well-being. *Journal of personality and social psychology, 57*(6), 1069.

Thomsen, K. E., Rose, J., Mørck, O., Jensen, S. Ø., Østergaard, I., Knudsen, H. N., & Bergsøe, N. C. (2016). Energy consumption and indoor climate in a residential building before and after comprehensive energy retrofitting. *Energy and Buildings, 123*, 8-16. doi: http://dx.doi.org/10.1016/j.enbuild.2016.04.049

Turunen, M., Toyinbo, O., Putus, T., Nevalainen, A., Shaughnessy, R., & Haverinen-Shaughnessy, U. (2014). Indoor environmental quality in school buildings, and the health and wellbeing of students. *International Journal of Hygiene and Environmental Health*, *217*(7), 733-739.

WHO. (2006). *WHO Air quality guidelines for particulate matter, ozone, nitrogen dioxide and sulfur dioxide: Global update 2005 summary of risk assessment*. Geneva: World Health Organization

Zandvliet, D. B., & Straker, L. M. (2001). Physical and psychosocial aspects of the learning environment in information technology rich classrooms. *Ergonomics, 44*(9), 838-857. doi: 10.1080/00140130117116

Connecting Section

Chapter 1 highlighted the problems investigated in this research. The chapter also presented the goal, objectives, hypotheses, scope, and significance of this research. Additionally, the chapter also presented an outline of this thesis and ended with a summary of the methods employed in this research.

The next chapter, chapter 2, presents the key literature on building condition assessment, indoor environmental quality, and well-being to justify the goal and objectives of this research.

CHAPTER 2: General literature

This chapter presents the general background information that supports the problem statement, goal, and objectives of this research.

2.1 Building Condition Assessment

This subsection defines and describes the concept of building condition assessment. It also includes a discussion of the concept as it pertains to IEQ research particularly. This is followed by a discussion of the most important building condition assessment methods found in the literature.

2.1.1 Definition of building condition assessment

Eweda, Zayed, and Alkass (2013, p. 2) defined building condition assessment (BCA) as "a process of systematically evaluating an organization's capital assets in order to project repair, renewal, or replacement needs that will preserve their ability to support the mission or activities they were assigned to serve". The definition suggests that BCA is an essential process undertaken during the life of a building to ensure its efficient and effective operation and maintenance and for it to meet its functional requirements. Generally, asset management systems include the following: 1) current condition assessment, 2) prediction of future deterioration, 3) selection of improvement strategies, and 4) prioritization of funding allocation (Eweda et al., 2013). The allocation of infrastructure operation and maintenance funds would depend on the selected maintenance strategy and assessed conditions of infrastructure portfolio. Canadian cities currently spend an estimated 80% of their annual infrastructure maintenance and renewal budget (about $12 to $15 billion) on the repair of aging infrastructure because of its deterioration due to age and deferred maintenance (Langevine, Allouche, & AbouRizk, 2006b).

Adel-ElSamadony, ElHakeem, and Hussein (2013) proposed the following stages to conduct BCA:

1. Asset hierarchy: this involves classifying building components according to six descending criteria including the following: 1) building level (i.e. for different building types), 2) space level (i.e. for different space types with a building), and 3) category level (i.e. mechanical, electrical, architectural, and structural components) (António Costa Branco de Oliveira Pedro, Ângelo Vasconcelos de Paiva, & José Dâmaso Santos Matos Vilhena, 2008; Eweda et al., 2013).
2. Evaluation mechanism: the two general approaches used to evaluate a building component's condition are direct-condition rating and distress survey (Eweda et al., 2013). Direct-condition rating aims to identify the current condition of a component whiles distress survey identifies current problems and failures (Eweda et al., 2013). The choice will depend on the purpose of the evaluation. Direct-condition rating is based mainly on the evaluator's subjective opinion of a component's condition and can thus lead to substantial variations in ratings of similar components with similar conditions. Distress survey, on the other hand, involves identifying potential components' defects and checking them off during the actual evaluation. This enables similar components with similar defects to be ranked consistently.
3. Field inspection: this is the first step of the actual evaluation process for both direct-condition rating and distress survey (Eweda et al., 2013). The differences between the two are in the

evaluation mechanism and duration; with distress survey being more detailed and consistent but more expensive and lengthy than direct-condition rating.

4. Condition analysis: this involves the analysis of assessment data to reach component condition ratings that are aggregated to obtain a building-level condition score.

Several BCA instruments have been developed based on the stages described above. Key examples of these instruments are briefly discussed below.

2.1.2 Building condition assessment in IEQ research

Buildings aim to provide convenient indoor environments for people to live and work in (Aries et al., 2010). The effectiveness of building components such as double glazed windows depreciates with time due to defects including cracks (Ahluwalia, 2008). These defects will compromise the insulating properties of windows and affect the thermal comfort of indoor spaces and by extension occupants' satisfaction (Center for Disease Control and Prevention, 2013b; Huizenga, Abbaszadeh, Zagreus, & Arens, 2006). Existing IEQ studies (e.g. Aries et al., 2010; Newsham et al., 2013; Raja, Nicol, McCartney, & Humphreys, 2001) mostly record supplementary information such as floor, wall, and ceiling finish type, luminaire and lamp type, and window type to explore the intricate relationships between building occupants and their indoor environments. For example, Raja et al. (2001) found that office workers who were closer to an operable window reported less thermal discomfort than those who were not. Additionally, Brager and Baker (2009) investigated offices and educational buildings and concluded that respondents who had access to and control of operable windows were most satisfied with indoor air quality and thermal comfort. However, the supplementary information does not account for those building components' conditions even though a window, for instance, needs to be operable and in good working condition to be used by occupants to effectively control indoor temperature. Therefore, BCA could be essential in determining how the physical condition of building elements especially in schools relates to IEQ and teachers' well-being.

2.1.3 Methods of building condition assessment

António Costa Branco de Oliveira Pedro et al. (2008) developed a building condition assessment instrument conceptually based on the direct-condition rating mechanism. The condition of functional elements including "external windows and doors, stairs, and external walls" with predefined weightings were assessed on a five-point scale from minor (5) to critical (1) (António Costa Branco de Oliveira Pedro et al., 2008, p. 327). The assessment scale items were defined to minimize subjectivity; however, the combined rating of all defects for each functional element limit the usefulness of the instrument for decision-making. Both Langevine et al. (2006b) and Eweda et al. (2013) proposed direct-condition rating instruments that are conceptually similar to that of António Costa Branco de Oliveira Pedro et al. (2008) with combined assessment at the element level. However, Eweda et al. (2013) argued that building elements such as windows are found in multiple spaces and thus have varying importance in condition assessment depending on the function of the space. For example, glazed windows in spaces such as classrooms will not have the same level of importance in the condition assessment of a school building as glazed windows in washrooms. Therefore, Eweda et al. (2013) proposed a six-tier hierarchy for BCA with the first three tiers being building level, space level, and category level. The building elements, categorized into architectural, electrical, mechanical, and structural are assessed at the space level. These categories constitute the building space envelope that is assessed and amalgamated for space and building level ratings. Conducting BCA at the space level would be most relevant for IEQ improvement purposes given that building occupants interact with their indoor environment at the space level.

BUILDER and the public housing assessment system (PHAS) are examples of the predominant BCA instruments based on the distress survey mechanism. BUILDER is a Windows-based BCA instrument with capacity for both direct-condition rating and distress survey (CERL, 2014). It has a hierarchy with 12 building systems including plumbing, fire suppression, interior construction, and structural at the top level and their components at the second level. For example, the components of interior construction include floor surfaces and interior doors. Assessments are conducted at the subcomponent level and interior doors, for example, include frame and hardware as subcomponents. BUILDER has 20 generic condition assessment criteria including cracked, broken, missing, and deterioration which are used for assessing the conditions of subcomponents. The assessor has the option of recording measured distress quantities or using predefined densities to assess the conditions of subcomponents. For the PHAS, inspectable items including walls, windows, roofs, and lighting have predefined observable deficiencies that are assessed with three predefined severity levels from three (3) to one (1) in descending order of importance (HUD, 2012). The distress surveys will, therefore, provide more information for strategic operation and maintenance decision-making. The general observation is that most of the direct-condition and distress survey BCA instruments were developed to enable financial decisions related to buildings' repair and replacement needs. Therefore, existing instruments would not be the most suitable for assessing the impact of buildings' physical conditions on IEQ. For example, in the PHAS's scoring protocol, blocked or damaged fire escape is more important than a cracked window glazing. This is despite the likely impact of cracked window glazing on heat loses and on the indoor concentration or air pollutants in buildings including offices and schools.

2.2 Indoor environmental quality

This section starts with a general definition and overview of IEQ and followed with a focused discussion of IEQ in schools. The section ends with a discussion of the three main IEQ evaluation methods in the literature.

2.2.1 Definition and overview

The Center for Disease Control and Prevention (2013b) defines IEQ as "the quality of a building's environment in relation to the health and well-being of those who occupy space within it". The definition suggests an association between the variables that constitute a buildings' indoor environment and occupants' health and well-being. Additionally, the definition shows how IEQ can be evaluated objectively by measuring the physical variables of buildings' indoor environments and subjectively by assessing occupants' well-being. The literature shows how research studies have focused on measuring IEQ objectively (e.g. Jo & Sohn, 2009; Kropat et al., 2014), subjectively (e.g. Van Gaever, Jacobs, Diltoer, Peeters, & Vanlanduit, 2014; Zalejska-Jonsson, 2014), and both (e.g. Cakmak et al., 2014; De Giuli, Zecchin, Corain, & Salmaso, 2014); the choice depending on the aim of the particular study.

The four IEQ factors usually investigated in the literature are thermal comfort (e.g. air temperature), acoustics (e.g. background noise), indoor air quality (e.g. CO_2 concentration), and lighting (e.g. illuminance) (Newsham et al., 2013; Raja et al., 2001). Findings from the literature showed that these four factors can affect building occupants. For example, Witterseh, Wyon, and Clausen (2004) found that sick building syndromes (SBS) such as headaches and nose irritation worsened with increasing temperature (i.e. thermal comfort). Occupants perceived intelligible noise (i.e. acoustics) to be very distracting in Vischer (2007b). Wargocki, Wyon, Sundell, Clausen, and Fanger (2000) found higher ventilation rates to be associated with a significant reduction in throat dryness (i.e. indoor air quality). Bright light is believed to synchronize the internal human body clock with the daily morning and night cycle, ensuring that people sleep at night and awake during daytime (Van Bommel, 2006a) (i.e. lighting).

There is compelling evidence in the literature supporting the premise that improving buildings' indoor environments is likely to have a positive impact on occupants' well-being (Agha-Hossein, El-Jouzi, Elmualim, Ellis, & Williams, 2013; Aries et al., 2010; Kim & De Dear, 2012; Sisask et al., 2013; Vieira, Silva, & Souza, 2016). Most studies (e.g. Choi & Moon, 2017; Hodgson, 2008; Jensen & Arens, 2005; Lan et al., 2011; Muhič & Butala, 2004; Newsham et al., 2013; Nicol et al., 2006; Schreuder et al., 2015) that have investigated the impact of IEQ on occupants have focused on office buildings considering their likely economic benefits. Conservative estimates suggest that improving IEQ in offices can yield up to 10% increase in workers' productivity (Lan et al., 2011). In an earlier study, Djukanovic, Wargocki, and Fanger (2002a) predicted that improving the indoor air quality of an office building to achieve 10% occupants' satisfaction would result to annual productivity benefits equivalent to at least 10 times the annual increase in energy and maintenance cost due to improved indoor air quality.

2.2.2 Indoor environmental quality in schools

Although most IEQ research studies have focused on office buildings, some (e.g. Bakó-Biró et al., 2012; Issa, Rankin, Attalla, & Christian, 2011; Righi et al., 2002; Toyinbo et al., 2016; Wang & Zamri, 2013) focused on school buildings. Kruger and Fonseca (2011) showed how improvements in school buildings' IEQ including increased ventilation rates and increased indoor daylight reduced energy consumption and carbon emissions (Kruger & Fonseca, 2011). However, the most compelling research finding in schools is the relationship between school buildings' IEQ and students' performance. Bakó-Biró et al. (2012) studied ventilation rates in primary schools and concluded that low ventilation rates had a significant negative effect on students' concentration. Issa et al. (2011) noticed decreased absenteeism and increased student performance in green schools compared to conventional and energy-retrofitted schools. Sörqvist (2010) and Boman (2004) found that intelligible speech had a negative effect on student learning. Tanner (2008) reported a positive association between daylighting and students' academic achievement. These findings make a strong case for improving school buildings' indoor environments to enhance teaching and learning.

Historically, most IEQ research in schools (e.g. Allen & Marples, 1998; Bradley & Sato, 2008; Kranjc & Jamieson, 1998; Noullett et al., 2010; Pengelly, Kerigan, Goldsmith, & Inman, 1984; Yang & Bradley, 2009; Zandvliet & Straker, 2001) focused on students rather than teachers. This is despite the impact teachers have on students' performance (Uline & Tschannen-Moran, 2008) and the positive association between teachers' effectiveness and student test scores (Harris & Sass, 2014b). The few IEQ studies in the literature that focused on teachers (e.g. Buckley et al., 2005; Madureira et al., 2009; Sisask et al., 2013) linked improved IEQ to improved teachers' well-being. For example, Buckley et al. (2005) found that improvements in school facilities not only enhanced IEQ but also had a more significant impact on teacher retention than salary increases. Additionally, Madureira et al. (2009) found a significant association between the concentration of indoor air pollutants (e.g. CO_2 and total volatile organic compound (TVOC)) and the prevalence of fatigue, headaches, and thinking difficulties amongst elementary and secondary school teachers. These findings highlight the importance of studying the impact of school buildings' IEQ on teachers' well-being because of the limited understanding of that impact, particularly in the Canadian context.

2.2.3 Evaluation of indoor environmental quality

This subsection presents a brief review of the three main methods used to evaluate IEQ. These methods are IEQ field measurement, occupants survey, and field observations.

2.2.3.1 IEQ Field measurement

IEQ parameters such as air temperature and particulate matter are measured using electronic equipment manufactured to reference standards including ISO 7720 (i.e. Ergonomics of the Thermal Environment-Instruments for Measuring Physical Quantities) and ASHRAE Standard 70 (i.e. Method of Testing for Rating the Performance of Air Outlets and Inlets) (ASHRAE, 2004). These objectively measured values are compared to recommended values in reference standards including ASHRAE 55 (i.e. Thermal Environmental Conditions for Human Occupancy) (ASHRAE, 2004) to assess the suitability of indoor environments for human habitation and comfort. Additionally, these measurements are taken either in normal indoor environments (e.g. Newsham et al., 2012b; Paevere & Brown, 2008; Reynolds et al., 2001) or in mock environments as part of controlled IEQ experiments (e.g. Huang, Zhu, Ouyang, & Cao, 2012; Lan et al., 2011; Pellerin & Candas, 2004). The former is used to characterize the true state of indoor environments while the latter explicate complex relationships between IEQ parameters or between IEQ parameters and occupants. Some studies (e.g. Huang et al., 2012) used simple hand-held measurement equipment while others (e.g. Newsham et al., 2012b) used a custom-built automated apparatus by amalgamating different measurement equipment. While hand-held equipment are less expensive, they require considerable effort and time as respective parameters have to be measured in turn, thus making custom-built apparatuses most appropriate for larger studies with many buildings.

The IEQ literature stresses the importance of the measurement protocols used to evaluate IEQ parameters, particularly the sampling location of the instruments used to measure them (ASHRAE, 2004; ASTM, 2014; U.S. EPA, 2003). Thermal comfort parameters including air temperature, relative humidity (RH), and air velocity are perceived by the skin that covers the whole human body. Hence, key thermal comfort parameters including air temperature and air velocity are measured over a profile (at feet, chest, and head level) for a person either seated or standing (ASHRAE, 2004). Indoor air quality parameters like CO_2 concentration, TVOC, and particulate matter are measured in the head region for seated and standing building occupants considering the location of the human nose (U.S. EPA, 2003). Although the human eye is at the head level, lighting parameters are measured at the level of the essential plane of view. In offices, for example, illuminance is measured at the desktop level (working plane) for the purpose of vision (Newsham et al., 2013). The head level for seated students will be an essential plane of view for teachers in classrooms. Acoustics parameters including background noise and reverberation time are measured in the head region for either seated or standing occupants (Acoustical Society of America, 2010; ASTM, 2014). Parameters of indoor air quality and thermal comfort are preferably measured in occupied spaces. However, the American Society for Testing and Materials (ASTM) recommends measurement of room acoustic parameters including reverberation time in unoccupied spaces (ASTM, 2014). This may be due to the interruption of sound waves by occupants that is likely to decrease the true values of those acoustic parameters (Sato & Bradley, 2008).

2.2.3.2 Occupant survey

Although the field measurement of IEQ parameters provides reliable objective data, they are incapable alone of evaluating occupant comfort and well-being, thus the importance of occupants' IEQ satisfaction surveys. IEQ satisfaction surveys allow building occupants to assess the environmental quality of their indoor space through subjective assessment of their thermal comfort, indoor air quality, acoustics, and lighting satisfaction (Bluyssen et al., 2011a). They are the single most used IEQ data collection method due to the low cost of implementing them compared to the cost of conducting field measurements. Several IEQ surveys have been developed and validated over the years (Peretti & Schiavon, 2011). Examples include the Building Use Studies (BUS) Occupant Survey, the Building Assessment Survey and Evaluation (BASE), the Centre for the Built Environment (CBE) Survey, the Cost-effective Open-Plan Environments (COPE), and the Health Optimization Protocol for Energy Efficient Buildings (HOPE) (Peretti & Schiavon, 2011). The CBE survey has in excess of 60,000 responses from over 600 buildings, mostly offices, making it one of the most used IEQ satisfaction surveys globally (Peretti & Schiavon, 2011). Most recently, Newsham et al. (2012b) leveraged the strengths of existing surveys and developed their own to investigate the differences between green and conventional buildings in Canada. These surveys provide subjective data that complement the objective data derived from IEQ field measurements. Although most of these surveys were developed and used in office buildings, they have also been adapted and used in other contexts including homes and schools.

2.2.3.3 Field observations

Field observation is an essential aspect of IEQ evaluation (Bluyssen, 2013) that seeks to identify building occupants' adaptations like opening of window, use of portable fans or clothing adjustments to cope with adverse indoor environmental conditions (De Giuli et al., 2012; Newsham et al., 2012b). Additionally, field observation aims to document other building characteristics and environmental conditions like luminaires and lamp types used, air supply/return locations, window shade types used, and sky conditions on field measurement days (Newsham et al., 2013). This information is used to explain trends observed during data analyzes of field measurements and occupant surveys. Field observations are conducted by experienced observers who are knowledgeable of IEQ issues (Newsham et al., 2013). They rely mostly on the use of photographs and the filling-out of standard observation sheets (Newsham et al., 2013).

2.3 Well-being

This subsection includes a definition and description of the concept of well-being as found in the social sciences literature. It also includes definitions and descriptions of the three subdivisions of individual well-being considered in this research: psychological, social, and physical well-being, and a discussion of well-being within the context of IEQ research.

2.3.1 Definition of well-being

The World Health Organization (WHO) defines health as "a state of complete physical, mental and social well-being and not merely the absence of disease or infirmity" (Capio, Sit, & Abernethy, 2014, p. 4805). The WHO definition of health emphasizes that well-being is central to human health. Well-being, however, has no universally accepted definition (Dodge et al., 2012; Ryan & Deci, 2001). La Placa, McNaught, and Knight (2013) provided a structured framework for defining well-being as shown in Figure 2.1. Well-being, according to the framework is a broad concept with four main facets: societal, community, family, and individual wellbeing (La Placa et al., 2013). Individual well-being, the focus of this study is subdivided into four types: physical, psychological, social, and spiritual well-being. Furthermore, individual well-being may be affected by a multitude of factors including "ecology and the environment" as shown in Figure 2.1.

Dodge et al. (2012) proposed a definition of well-being based on an extensive review of the well-being literature. As shown in Figure 2.2, well-being is "the balance point between an individual's resource pool and the challenges faced" (Dodge et al., 2012, p. 230). Therefore, well-being is an equilibrium state that can be disturbed by the lack of balance between challenges and resources. For school teachers, these challenges would include being satisfied with themselves (i.e. psychological), caring about colleagues and students (i.e. social), and fatigue due to adverse indoor environmental conditions like high indoor air temperature (i.e. physical) (Rashid & Zimring, 2008; Uline & Tschannen-Moran, 2008). The resources needed to counter these challenges would include individual coping mechanisms and access to IEQ control features including thermostats for controlling air temperature (Huizenga et al., 2006; Rashid & Zimring, 2008). Dodge et al.'s

(2012) definition of well-being was adopted for this research because it was found to adequately capture the person-indoor environment interaction and how it affects well-being.

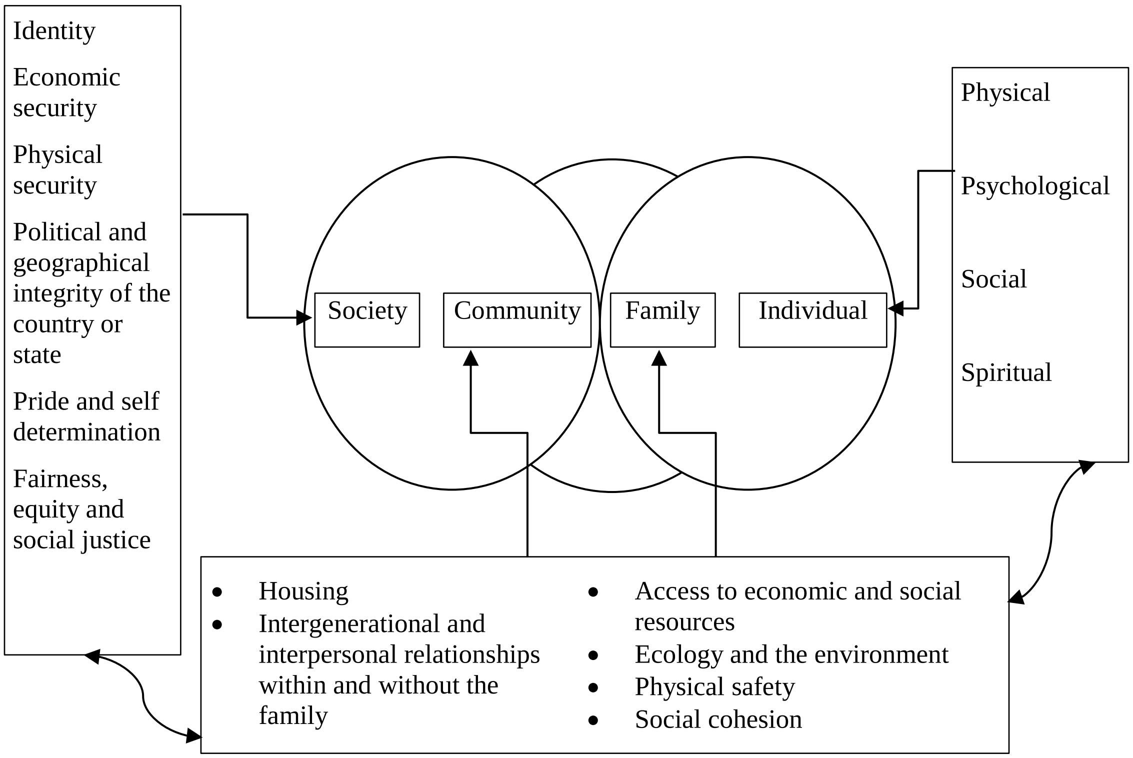

Figure 2.1: Structured Framework for Defining Well-Being

(La Placa et al., 2013, p. 118)

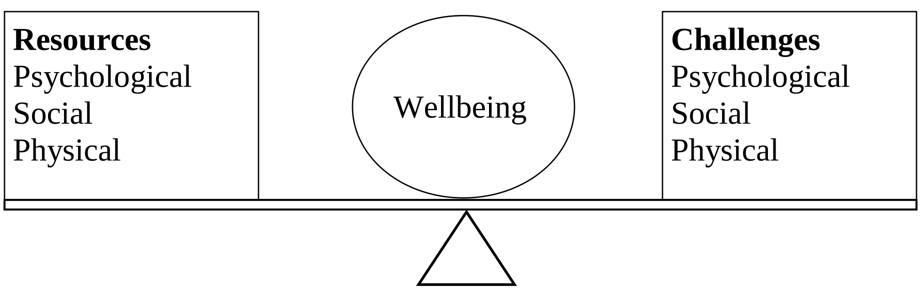

Figure 2.2: Definition of Well-Being

(Dodge et al., 2012, p. 230)

This research focused on psychological, social, and physical well-being because the dimensions of teachers' professionalism touch on these three subdivisions of well-being. Teachers' professionalism includes the dimensions of engagement in the teaching process (i.e. psychological and physical well-being) and willingness to corporate with one another (i.e. social well-being) (Uline & Tschannen-Moran, 2008). The dimensions also include enthusiasm (i.e. psychological and physical) and contribution to the overall school community (i.e. social) (Harris & Sass, 2014a). Research on schools has associated the prevalence of fatigue, headache, and thinking difficulties among teachers with adverse IEQ (Madureira et al., 2009). These health effects can influence the dimensions of teachers' professionalism and effectiveness. For example, a teacher suffering from fatigue will be less engaged in the teaching process and thus less likely to contribute to the school community. The three subdivisions of individual well-being (psychological, social, and physical well-being) that this research focuses on are discussed below.

2.3.2 Psychological well-being

The importance of psychological health to sustainable economic development cannot be overemphasized (Dagenais-Desmarais & Savoie, 2012). The cost of psychological health issues, including depression in the US is estimated to be in the region of $30 to $44 billion annually with an estimated 200 million workdays lost yearly (Dagenais-Desmarais & Savoie, 2012, p. 660). In Europe, occupational stress is estimated to cause 50 to 60% of workday loss (Dagenais-Desmarais & Savoie, 2012, p. 660). Researchers generally agree that psychological health is composed of psychological well-being (PWB) and psychological distress (PD) as its positive and negative dimensions respectively (Dagenais-Desmarais & Savoie, 2012; Massé et al., 1998). Although the two dimensions are related, they are distinct and do not stand on the extreme ends of the same continuum (Dagenais-Desmarais & Savoie, 2012; Massé et al., 1998). Hence, Massé et al. (1998) asserted that a low level of PD does not automatically imply the presence of high PWB. Winefield, Gill, Taylor, and Pilkington (2012) supported the findings of Massé et al. (1998) regarding the relationship between PWB and PD. Sisask et al. (2013) found that improving teachers' psychological well-being is likely to enhance their willingness to help students improve their performance, thus the decision to focus on PWD instead of PD in this research.

There is no consensus on the definition and dimensions of PWB; however, the literature points to three schools of thought (Dagenais-Desmarais & Savoie, 2012; Diener, Emmons, Larsen, & Griffin, 1985; Ryff, 1989). The hedonic perspective focuses on highly abstract dimensions of PWB such as affective states (e.g. moods, feelings) and life satisfaction (Dagenais-Desmarais & Savoie, 2012; Winefield et al., 2012). Essentially, PWB is described in relation to the achievement of pleasure (Ryan & Deci, 2001). The five-item satisfaction with life scale (SWLS) shown in Table 2.1 and developed by Diener et al. (1985) represents the hedonic perspective.

Table 2.1: Satisfaction with Life Scale

In most ways, my life is close to my ideal.
The conditions of my life are excellent.
I am satisfied with my life.
So far, I have gotten the important things I want in life.
If I could live my life over, I will change almost nothing.

(Diener et al., 1985, p. 72)

The eudaimonic perspective is oriented towards human development and focuses on dimensions such as "self-actualization" and "optimal functioning" of people (Dagenais-Desmarais & Savoie, 2012, p. 661; Winefield et al., 2012). It reflects the extent to which an individual is able to fully function (e.g. at work, home, or school) (Ryan & Deci, 2001). This perspective essentially focuses on the most obvious manifestation of human PWB. Ryff's (1989) six-factor scale of PWB summarized in Table 2.2 represents the eudaimonic perspective. The obvious distinction between the hedonic and eudaimonic perspective is in their focus, with the former focusing on an individual's personal experiences and excluding the influence of external factors such as the individual's relationship with others, and the latter considering both (Massé et al., 1998).

Table 2.2: Ryff's Scale of Psychological Well-Being

Self-acceptance

- Extent of satisfaction or dissatisfaction with the self
- Extent to which both good and bad personal qualities are accepted

Positive relations with others

- Extent to which a person is able to have a warm, trusting, and satisfying relationship with others
- Extent to which a person is able of showing empathy and affection

Autonomy

- Extent to which a person is able to self-regulate behavior from within and resist external pressure to conform

Environmental mastery

- Extent to which a person is able to control a multitude of complex external activities
- Extent to which a person is able to influence his surrounding context to meet his needs and values

Purpose in life

- Extent to which a person has goals in life which provide a sense of direction and purpose for living

Personal growth

- Extent to which a person has a feeling of continued development, opens to new experiences, and changes in ways that suggest increasing self-knowledge and effectiveness

(Ryff, 1989, p. 1072)

The third perspective involves the integration of both the hedonic and eudaimonic perspectives (Dagenais-Desmarais & Savoie, 2012; Ryan & Deci, 2001). Although attractive, the integrated approach has been criticized for being shallow given that the proponents simply combine hedonic and eudaimonic instruments without reporting the results of their construct validity (Dagenais-Desmarais & Savoie, 2012). Therefore, this perspective was considered conceptually inappropriate for evaluating teachers' PWB in a school context and thus for this research. Dagenais-Desmarais and Savoie (2012) developed a PWB instrument for office workers using an inductive approach. Despite its effectiveness, Dagenais-Desmarais and Savoie (2012) instrument was also inappropriate for this research given its focus on offices. Therefore, this research employed an inductive approach to explore teachers' PWB in a school context.

2.3.3 Social well-being

The concept of Social Well-Being (SWB) is a subject of debate amongst researchers (Cicognani, 2014). The debate centers on whether SWB should be studied as a component of overall personal well-being or a dimension of other well-being facades (Cicognani, 2014; Huppert et al., 2009; Keyes, 1998). Cicognani (2014) identified two research traditions that evaluate SWB at the individual level. First is the health-related quality of life (HRQL) tradition that conceptualizes social well-being, with social adjustment or functioning and social support as its components (Cicognani, 2014). Social adjustment refers to individuals' perceived satisfaction with relationships or performance of social roles (Cicognani, 2014). Social support is the number and quality of mutually trusting relationships that an individual has and the extent to which one matters to others and society (Cicognani, 2014). Consequently, the HRQL tradition advances a mutual theory of SWB where individuals are active in their society and feel valued. The second tradition is the PWB component of psychological health (Cicognani, 2014). Measures of PWB inclined to the eudaimonic perspective mostly include SWB-related dimensions (Cicognani, 2014; Dagenais-Desmarais & Savoie, 2012; Massé et al., 1998; Ryff, 1989). For example, Ryff's Scale of

Psychological Well-Being (SPWB) includes the SWB-related dimension of "positive relations with others" (Ryff, 1989, p. 1072). Additionally, the Psychological Well-Being Manifestation Scale (PWBMS) also includes dimensions such as "social involvement" (Massé et al., 1998, P. 499). However, a critical look at the items associated with these dimensions and shown in Table 2.3 suggests an intrapersonal and not an interpersonal focus as posited by Cicognani (2014). This intrapersonal focus of the second research tradition is contrary to the first.

Table 2.3: SWB-Related Dimensions of the SPWB and the PWBMS

Instrument	Dimensions
Scale of Psychological Well-Being (SPWB)	Positive relations with others • People would describe me as a giving person, willing to share my time with others • Maintaining close relationships has been difficult and frustrating for me
Psychological Well-being Manifestation Scale (PWBMS)	Social involvement • I felt like having fun, doing sports and participating in all my favourite activities and past-times • I had goals and ambitions

(Massé et al., 1998, p. 499; Springer & Hauser, 2006, pp. 1087,1088)

Keyes (1998) proposed a five-factor SWB model that leans towards the HRQL research tradition with respect to SWB. The dimensions of Keyes' (1998) model are "social integration", "social acceptance", "social actualization", and "social coherence" (Keyes, 1998, pp. 138, 139). Items of these dimensions not shown due to permission restrictions. Keyes (1998) model characterizes SWB as a construct with mutualism at its core. The notion of reciprocity in SWB is also evident in the European Social Survey Well-being Model which includes "inter-personal feelings" and "inter-personal functioning" as dimensions (Huppert et al., 2009, p. 305). Keyes' model supported by the European Social Survey Well-being Model depicts SWB as a subset of overall personal well-being and not a subset of PWB. Teachers in school environments are engaged in a complex social web where they interact with students, colleagues, and superiors, thus the benefit of studying SWB as a standalone concept. For this research, SWB will be defined "as an individual's appraisal of their social relationships": how they relate to others, their community and vice versa (Cicognani, 2014, p. 6194).

2.3.4 Physical well-being

A review of the literature shows that physical well-being (PhWB) has mainly been studied from a medical science perspective. The concept of HRQL conceptualized in medical science includes dimensions such as physical functioning, psychological functioning, social functioning, and health perceptions (Capio et al., 2014). The physical health components of HRQL are the most employed measures of PhWB (Capio et al., 2014; Hays, Marshall, Wang, & Sherbourne, 1994; Hays & Morales, 2001). These components are defined by an individuals' ability to perform physical activities, problems in performing social roles as a result of physical health, and experiences of bodily pain and general health (Capio et al., 2014, p. 4805). The most common operationalization of PhWB is the physical health component of the RAND 36-item health survey (RAND 36), also known as the SF-36 health survey (SF-36) (Hays & Morales, 2001; Sheikh, Yagoub, Elsatouhy, Al Sanosi, & Mohamud, 2013; Silva, Pais-Ribeiro, & Cardoso, 2008). RAND 36 is a 2-factor generic model of HRQL that consists of 36 items and eight scales (Hays & Morales, 2001).

Table 2.4 presents the scales, definitions, and examples of items for the PhWB component of RAND 36. It shows that PhWB is essentially the extent to which people can go about their daily activities subject to their physical health. The PhWB component of RAND 36 contains very generic items that are applicable to different life domains. For example, the “Role limitations due to physical health” and “Energy/fatigue” scales can be used to evaluate teachers’ PhWB in a school context. However, because of the generic nature of the items making up RAND 36, it will likely not include contextual issues specific to the PhWB of teachers in a school context.

2.3.5 Summary

The above discussion on well-being suggests that it is a broad and complex concept that is relevant in all domains of life. PWB from the eudaimonic perspective is characterized by dimensions such as “personal growth”, “environmental mastery”, and “autonomy”. Hence, for a given life domain such as work, PWB would be derived from personal experiences in the workplace that leads to the acquisition of new job-related knowledge, skills, and opportunities to make job-related decisions. SWB, as a subdivision of overall well-being, has dimensions including “social integration” and “social contribution”. In the context of work, SWB will relate to personal experiences that make people feel that they belong to a community and have something valuable to contribute to its advancement. PhWB is depicted by dimensions including “physical functioning” and “energy/fatigue”. Hence, the ability of people to go about their daily work activities such as walking, lifting, and typing without feeling worn out or tired would be manifestations of PhWB. Therefore, the dimensions of PWB, SWB, and PhWB would be influenced by a multitude of factors subject to the life domain in question. In a school context, these would be affected by the conditions of the indoor environment, with dire consequences on teaching and learning.

Table 2.4: Physical Well-Being Components of RAND 36

Scale	Definition	Example
Physical functioning	Limitations in activities due to health	Does your health now limit you in these activities? • Lifting and carrying groceries
Role limitations due to physical health	Extent to which physical health interferes with doing work or other regular daily activities	Have you had any of the following problems with your work or other regular daily activities as a result of your health? • Cut down on the amount of time you spent on work or other activities
Pain	Pain frequency and extent of role interference	How much bodily pain have you had during the past four weeks?
General health perceptions	Perception of health in general, such as feeling well or ill	How true or false is each of the following statements for you? • I expect my health to get worse
Energy/fatigue	Feeling energetic versus tired and worn out	How much of the time during the past four weeks • Did you feel tired
Social functioning	Extent to which health interferes with social activities with family, friends, neighbors, or groups	During the past four weeks, to what extent has your physical health or emotional problems interfered with your normal social activities with family, friends, neighbors, or groups?

(Hays et al., 1994, p. 443; RAND Corporation, 2016)

2.3.6 Well-being in IEQ research

Unlike the social sciences literature, the IEQ literature restricts occupants' well-being to occupants' satisfaction with IEQ factors like thermal comfort, indoor air quality, acoustics, and lighting or the prevalence of sick building syndromes (SBS) like headache and watery eyes (Bluyssen et al., 2011a; Bluyssen et al., 2011b; Righi et al., 2002; Turunen et al., 2014). Hence, most IEQ studies usually use assessment items related to occupants' satisfaction with IEQ parameters (e.g. temperature and CO_2 concentration) to assess occupants' IEQ satisfaction (Huizenga et al., 2006). Examples of IEQ satisfaction assessment items in the literature include "How satisfied are you with temperature in your workspace?" (i.e. thermal comfort) (Huizenga et al., 2006, p. 393); "Please rate your satisfaction with the lighting comfort of your normal work area (e.g. amount of light, glare, reflections, contrast)?" (lighting) (Kim et al., 2016, pp., p. 205); "How would you describe typical working conditions in the office … Noise from building systems (e.g. heating, plumbing, ventilation, air conditioning) in winter" (acoustics) (Building Research Establishment, 2002); and "Please rate your satisfaction with the overall air quality in your work area" (indoor air quality) (Kim et al., 2016). The focus on these IEQ satisfaction items raises concerns about using the term "well-being" to describe them in the IEQ literature. This is because the other items of PWB, SWB, and PhWB described earlier are usually ignored in the IEQ literature. Questions on the prevalence of SBS suggest that well-being in the IEQ literature is defined by the absence of sickness alone: a suggestion that does not hold given the above discussion and the WHO's definition of health. These observations raise concerns about the suitability of SBS and occupants' IEQ satisfaction for assessing occupants' well-being and particularly teachers' in school environments.

Newsham et al. (2013) departed from the norm in the IEQ literature and evaluated occupants' well-being in green and conventional buildings using a number of instruments including the Scale of Positive and Negative Experience (SPANE) developed by Diener et al. (2010). SPANE is a 12-item scale composed of a positive section (consisting of six items) that measure well-being and a negative section (consisting of six items) that measure ill-being (Diener et al., 2010). The former (i.e. well-being) includes items like "Good" and "Pleasant" whiles the latter (i.e. ill-being) includes "Bad" and "Unpleasant" (Diener et al., 2010, p. 154). The 12 items of SPANE suggest an inclination towards the hedonic perspective of PWB. Hence, SPANE will overlook eudaimonic dimensions that are relevant to teachers' well-being in a school context such as personal growth. In addition, SPANE and other predominant well-being instruments like Ryff's Scale of PWB and Keyes' Five Factors SWB model are context-free instruments that overlook the characteristics of specific contexts. This reinforces the need for context-specific instruments that address the unique characteristics of school teachers.

2.4 References

Acoustical Society of America. (2010). *Acoustical Performance Criteria, Design Requirements, and Guidelines for Schools, Part 1: Permanent Schools*. (ANSI/ASA S12.60-2010/Part 1). Melville, New York: Acoustical Society of America.

Adel-ElSamadony, O. H., ElHakeem, A., & Hussein, D. (2013). An asset management system for maintenance and repair of educational buildings. *International Journal of Scientific and Engineering Research, 4*(6), 2053-2064.

Agha-Hossein, M. M., El-Jouzi, S., Elmualim, A. A., Ellis, J., & Williams, M. (2013). Post-occupancy studies of an office environment: Energy performance and occupants' satisfaction. *Building and Environment, 69*(0), 121-130. doi: http://dx.doi.org/10.1016/j.buildenv.2013.08.003

Ahluwalia, S. S. (2008). *A framework for efficient condition assessment of the building infrastructure.* (PhD thesis), University of Waterloo, Waterloo, ON.

Allen, P., & Marples, C. L. (1998). Notched-noise and quiet detection thresholds as early indicators of auditory system damage in school-aged children. *Canadian Acoustics - Acoustique Canadienne, 26*(3), 62-63.

António Costa Branco de Oliveira Pedro, J., Ângelo Vasconcelos de Paiva, J., & José Dâmaso Santos Matos Vilhena, A. (2008). Portuguese method for building condition assessment. *Structural Survey, 26*(4), 322-335. doi: doi:10.1108/02630800810906566

Aries, M. B., Veitch, J. A., & Newsham, G. R. (2010). Windows, view, and office characteristics predict physical and psychological discomfort. *Journal of Environmental Psychology, 30*(4), 533-541.

ASHRAE. (2004). Thermal Environmental Conditons for Human Occupancy. Atlanta, GA: American Society of Heating, Refrigerating, and Air-Conditioning Engineers.

ASTM. (2014). *Standard test method for measurement of airborne sound attenuation between rooms in buildings*. (E336−14). West Conshohocken, PA: American Society for Testing and Materials. Retrieved from http://compass.astm.org.proxy1.lib.umanitoba.ca/download/E336.22070.pdf.

Bakó-Biró, Z., Clements-Croome, D., Kochhar, N., Awbi, H., & Williams, M. (2012). Ventilation rates in schools and pupils' performance. *Building and Environment, 48*, 215-223.

Bluyssen, P. M. (2013). *The Healthy Indoor Environment: How to Assess Occupants' Wellbeing in Buildings*: Routledge.

Bluyssen, P. M., Aries, M., & van Dommelen, P. (2011a). Comfort of workers in office buildings: The European HOPE project. *Building and Environment, 46*(1), 280-288.

Bluyssen, P. M., Janssen, S., van den Brink, L. H., & de Kluizenaar, Y. (2011b). Assessment of wellbeing in an indoor office environment. *Building and Environment, 46*(12), 2632-2640.

Boman, E. V. A. (2004). The effects of noise and gender on children's episodic and semantic memory. *Scandinavian Journal of Psychology, 45*(5), 407-416.

Bradley, J. S., & Sato, H. (2008). The intelligibility of speech in elementary school classrooms. *The Journal of the Acoustical Society of America, 123*(4), 2078-2086. doi: doi:http://dx.doi.org/10.1121/1.2839285

Brager, G., & Baker, L. (2009). Occupant satisfaction in mixed-mode buildings. *Building Research & Information, 37*(4), 369-380. doi: 10.1080/09613210902899785

Buckley, J., Schneider, M., & Shang, Y. (2005). Fix it and they might stay: School facility quality and teacher retention in Washington, DC. *The Teachers College Record, 107*(5), 1107-1123.

Building Research Establishment. (2002) HOPE office environment survey.

Cakmak, S., Dales, R. E., Liu, L., Kauri, L. M., Lemieux, C. L., Hebbern, C., & Zhu, J. (2014). Residential exposure to volatile organic compounds and lung function: Results from a population-based cross-sectional survey. *Environmental Pollution, 194*, 145-151.

Capio, C., Sit, C. P., & Abernethy, B. (2014). Physical Well-Being. In A. Michalos (Ed.), *Encyclopedia of Quality of Life and Well-Being Research* (pp. 4805-4807): Springer Netherlands.

Center for Disease Control and Prevention. (2013b). Workplace safety and health topics: indoor environmental quality. Retrieved June 4, 2015, from http://www.cdc.gov/niosh/topics/indoorenv/

CERL. (2014). BUILDER® Knowledge-based condition assessment manual for building component-sections (version 3.1.1) (Vol. 2015). Champaign, Illinois: U.S. Army Engineer Research and Development Center.

Choi, J.-H., & Moon, J. (2017). Impacts of human and spatial factors on user satisfaction in office environments. *Building and Environment, 114*, 23-35. doi: http://dx.doi.org/10.1016/j.buildenv.2016.12.003

Cicognani, E. (2014). Social Well-Being. In A. Michalos (Ed.), *Encyclopedia of Quality of Life and Well-Being Research* (pp. 6193-6197): Springer Netherlands.

Dagenais-Desmarais, V., & Savoie, A. (2012). What is psychological well-being, really? A grassroots approach from the organizational sciences. *Journal of Happiness Studies, 13*(4), 659-684.

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. doi: http://dx.doi.org/10.1016/j.apergo.2014.01.004

Diener, E., Emmons, R. A., Larsen, R. J., & Griffin, S. (1985). The Satisfaction With Life Scale. *Journal of Personality Assessment, 49*(1), 71.

Diener, E., Wirtz, D., Tov, W., Kim-Prieto, C., Choi, D.-w., Oishi, S., & Biswas-Diener, R. (2010). New well-being measures: Short scales to assess flourishing and positive and negative feelings. *Social Indicators Research, 97*(2), 143-156.

Djukanovic, R., Wargocki, P., & Fanger, P. O. (2002a). *Cost-benefit analysis of improved air quality in an office building.* Paper presented at the Indoor Air 2002.

Dodge, R., Daly, A. P., Huyton, J., & Sanders, L. D. (2012). The challenge of defining wellbeing. *International Journal of Wellbeing, 2*(3).

Eweda, A., Zayed, T., & Alkass, S. (2013). Space-Based Condition Assessment Model for Buildings: Case Study of Educational Buildings. *Journal of Performance of Constructed Facilities, 29*(1).

Harris, D. N., & Sass, T. R. (2014a). Skills, productivity and the evaluation of teacher performance. *Economics of Education Review, 40*(0), 183-204. doi: http://dx.doi.org/10.1016/j.econedurev.2014.03.002

Harris, D. N., & Sass, T. R. (2014b). Skills, productivity and the evaluation of teacher performance. *Economics of Education Review, 40*, 183-204.

Hays, R. D., Marshall, G. N., Wang, E. Y. I., & Sherbourne, C. D. (1994). Four-year cross-lagged associations between physical and mental health in the Medical Outcomes Study. *Journal of consulting and clinical psychology, 62*(3), 441.

Hays, R. D., & Morales, L. S. (2001). The RAND-36 measure of health-related quality of life. *Annals of medicine, 33*(5), 350-357.

Hodgson, M. (2008). Acoustical Evaluation of Six 'Green' Office Buildings. *Journal of Green Building, 3*(4), 108-118. doi: 10.3992/jgb.3.4.108

Huang, L., Zhu, Y., Ouyang, Q., & Cao, B. (2012). A study on the effects of thermal, luminous, and acoustic environments on indoor environmental comfort in offices. *Building and Environment, 49*(Journal Article), 304. doi: 10.1016/j.buildenv.2011.07.022

HUD. (2012). Public housing assessment system (PHAS): physical condition scoring notice and revised dictionary of deficiency definitions. In Department of Housing and Urban Development (Ed.), (Vol. 2015). Washington: Federal Register.

Huizenga, C., Abbaszadeh, S., Zagreus, L., & Arens, E. (2006). *Air quality and thermal comfort in office buildings: Results of a large indoor environmental quality survey*. Paper presented at the Healthy Buildings: Creating a Healthy Indoor Environment for People, HB 2006, Lisboa.

Huppert, F. A., Marks, N., Clark, A., Siegrist, J., Stutzer, A., Vittersø, J., & Wahrendorf, M. (2009). Measuring well-being across Europe: Description of the ESS well-being module and preliminary findings. *Social Indicators Research, 91*(3), 301-315.

Issa, M., Rankin, J., Attalla, M., & Christian, A. (2011). Absenteeism, performance and occupant satisfaction with the indoor environment of green Toronto schools. *Indoor and Built Environment, 20*(5), 511-523.

Jensen, K., & Arens, E. (2005). Acoustical quality in office workstations, as assessed by occupant surveys. Retrieved from UC Berkeley: Center for the Built Environment website: http://www.escholarship.org/uc/item/0zm2z3jg

Jo, W.-J., & Sohn, J.-Y. (2009). The effect of environmental and structural factors on indoor air quality of apartments in Korea. *Building and Environment, 44*(9), 1794-1802. doi: http://dx.doi.org/10.1016/j.buildenv.2008.12.003

Keyes, C. L. M. (1998). Social well-being. *Social psychology quarterly*, 121-140.

Kim, J., Candido, C., Thomas, L., & de Dear, R. (2016). Desk ownership in the workplace: The effect of non-territorial working on employee workplace satisfaction, perceived productivity and health. *Building and Environment, 103*, 203-214. doi: http://dx.doi.org/10.1016/j.buildenv.2016.04.015

Kim, J., & De Dear, R. (2012). Nonlinear relationships between individual IEQ factors and overall workspace satisfaction. *Building and Environment, 49*, 33-40.

Kranjc, G., & Jamieson, D. G. (1998). Intelligibility in classroom noise for young school aged children. *Canadian Acoustics - Acoustique Canadienne, 26*(3), 98-99.

Kropat, G., Bochud, F., Jaboyedoff, M., Laedermann, J. P., Murith, C., Palacios, M., & Baechler, S. (2014). Major influencing factors of indoor radon concentrations in Switzerland. *Journal of Environmental Radioactivity, 129*, 7-22.

Kruger, E. L., & Fonseca, S. D. (2011). Evaluating daylighting potential and energy efficiency in a classroom building. *Journal of Renewable and Sustainable Energy, 3*(6). doi: 10.1063/1.3670407

La Placa, V., McNaught, A., & Knight, A. (2013). Discourse on wellbeing in research and practice. *International Journal of Wellbeing, 3*(1).

Lan, L., Wargocki, P., & Lian, Z. (2011). Quantitative measurement of productivity loss due to thermal discomfort. *Energy and Buildings, 43*(5), 1057-1062.

Langevine, R., Allouche, M., & AbouRizk, S. (2006b). *Decision support tool for the maintenance management of buildings*. Paper presented at the Joint International Conference on Computing and Decision Making in Civil and Building Engineering, Montréal, Canada.

Madureira, J., Alvim-Ferraz, M. C. M., Rodrigues, S., Gonçalves, C., Azevedo, M. C., Pinto, E., & Mayan, O. (2009). Indoor Air Quality in Schools and Health Symptoms among Portuguese Teachers. *Human and Ecological Risk Assessment: An International Journal, 15*(1), 159-169.

Massé, R., Poulin, C., Dassa, C., Lambert, J., Bélair, S., & Battaglini, A. (1998). The structure of mental health: Higher-order confirmatory factor analyses of psychological distress and well-being measures. *Social Indicators Research, 45*(1-3), 475-504.

Muhič, S., & Butala, V. (2004). The influence of indoor environment in office buildings on their occupants: expected–unexpected. *Building and Environment, 39*(3), 289-296.

Newsham, G., Birt, B., Arsenault, C., Thompson, L., Veitch, J., Mancini, S., . . . Burns, G. (2012b). Do green buildings outperform conventional buildings? Indoor environment and energy performance in North American offices Retrived from

Newsham, G. R., Birt, B. J., Arsenault, C., Thompson, A. J., Veitch, J. A., Mancini, S., . . . Burns, G. J. (2013). Do ‘green’buildings have better indoor environments? New evidence. *Building Research & Information, 41*(4), 415-434.

Nicol, F., Wilson, M., & Chiancarella, C. (2006). Using field measurements of desktop illuminance in European offices to investigate its dependence on outdoor conditions and its effect on occupant satisfaction, and the use of lights and blinds. *Energy and Buildings, 38*(7), 802-813.

Noullett, M., Jackson, P. L., & Brauer, M. (2010). Estimation and characterization of children's ambient generated exposure to PM2.5 using sulphate and elemental carbon as tracers. *Atmospheric Environment, 44*(36), 4629-4637. doi: http://dx.doi.org/10.1016/j.atmosenv.2010.08.004

Paevere, P., & Brown, S. (2008). Indoor environment quality and occupant productivity in the CH2 building: post-occupancy summary (USP2007/23). Retrived from https://www.melbourne.vic.gov.au/Sustainability/CH2/Evaluation/Documents/CH2_Post_Occupancy_Summary.doc

Pellerin, N., & Candas, V. (2004). Effects of steady-state noise and temperature conditions on environmental perception and acceptability. *Indoor air, 14*(2), 129-136. doi: 10.1046/j.1600-0668.2003.00221.x

Pengelly, L. D., Kerigan, A. T., Goldsmith, C. H., & Inman, E. M. (1984). The Hamilton Study: Distribution of factors confounding the relationship between air quality and respiratory health. *Journal of the Air Pollution Control Association, 34*(10), 1039-1043.

Peretti, C., & Schiavon, S. (2011). Indoor environmental quality surveys. A brief literature review. Retrieved from UC Berkeley: Center for the Built Environment website: http://www.escholarship.org/uc/item/0wb1v0ss

Raja, I. A., Nicol, J. F., McCartney, K. J., & Humphreys, M. A. (2001). Thermal comfort: use of controls in naturally ventilated buildings. *Energy and Buildings, 33*(3), 235-244.

RAND Corporation. (2016). 36-Item Short Form Survey Instrument (SF-36): RAND 36-Item Health Survey 1.0 Questionnaire Items. Retrieved 19 February, 2016, from https://www.rand.org/health/surveys_tools/mos/36-item-short-form/survey-instrument.html

Rashid, M., & Zimring, C. (2008). A Review of the Empirical Literature on the Relationships Between Indoor Environment and Stress in Health Care and Office Settings: Problems and Prospects of Sharing Evidence. *Environment and Behavior, 40*(2), 151-190. doi: 10.1177/0013916507311550

Reynolds, S. J., Black, D. W., Borin, S. S., Breuer, G., Burmeister, L. F., Fuortes, L. J., . . . Thorne, P. S. (2001). Indoor environmental quality in six commercial office buildings in the midwest United States. *Applied occupational and environmental hygiene, 16*(11), 1065-1077.

Righi, E., Aggazzotti, G., Fantuzzi, G., Ciccarese, V., & Predieri, G. (2002). Air quality and well-being perception in subjects attending university libraries in Modena (Italy). *Science of The Total Environment, 286*(1), 41-50.

Ryan, R. M., & Deci, E. L. (2001). On happiness and human potentials: A review of research on hedonic and eudaimonic well-being. *Annual review of psychology, 52*(1), 141-166.

Ryff, C. D. (1989). Happiness is everything, or is it? Explorations on the meaning of psychological well-being. *Journal of personality and social psychology, 57*(6), 1069.

Sato, H., & Bradley, J. S. (2008). Evaluation of acoustical conditions for speech communication in working elementary school classrooms. *The Journal of the Acoustical Society of America, 123*(4), 2064-2077. doi: doi:http://dx.doi.org/10.1121/1.2839283

Schreuder, E., van Heel, L., Goedhart, R., Dusseldorp, E., Schraagen, J. M., & Burdorf, A. (2015). Effects of newly designed hospital buildings on staff perceptions: A pre-post study to validate design decisions. *Health Environments Research and Design Journal, 8*(4), 77-97. doi: 10.1177/1937586715573736

Sheikh, K., Yagoub, U., Elsatouhy, M., Al Sanosi, R., & Mohamud, S. (2013). Reliability and Validity of the Arabic Version of the SF-36 Health Survey Questionnaire in Population of Khat Chewers—Jazan Region-Kingdom of Saudi Arabia. *Applied Research in Quality of Life*, 1-13. doi: 10.1007/s11482-013-9291-1

Silva, I., Pais-Ribeiro, J., & Cardoso, H. (2008). Quality of Life and General Health Perception in Women with Obesity. *Applied Research in Quality of Life, 3*(2), 127-136. doi: 10.1007/s11482-008-9050-x

Sisask, M., Värnik, P., Värnik, A., Apter, A., Balazs, J., Balint, M., . . . Cosman, D. (2013). Teacher satisfaction with school and psychological well-being affects their readiness to help children with mental health problems. *Health Education Journal*, 0017896913485742.

Sörqvist, P. (2010). Effects of aircraft noise and speech on prose memory: What role for working memory capacity? *Journal of Environmental Psychology, 30*(1), 112-118.

Springer, K. W., & Hauser, R. M. (2006). An assessment of the construct validity of Ryff's scales of psychological well-being: Method, mode, and measurement effects. *Social science research*, *35*(4), 1080-1102.

Tanner, C. K. (2008). Explaining relationships among student outcomes and the school's physical environment. *Journal of Advanced Academics, 19*(3), 444-471.

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.

Turunen, M., Toyinbo, O., Putus, T., Nevalainen, A., Shaughnessy, R., & Haverinen-Shaughnessy, U. (2014). Indoor environmental quality in school buildings, and the health and wellbeing of students. *International Journal of Hygiene and Environmental Health, 217*(7), 733-739.

U.S. EPA. (2003). A standardized EPA protocol for characterizing indoor environmental quality Retrived from http://www.epa.gov/iaq/base/pdfs/2003_base_protocol.pdf

Uline, C., & Tschannen-Moran, M. (2008). The walls speak: the interplay of quality facilities, school climate, and student achievement. *Journal of Educational Administration, 46*(1), 55-73. doi: doi:10.1108/09578230810849817

Van Bommel, W. J. (2006a). Non-visual biological effect of lighting and the practical meaning for lighting for work. *Applied Ergonomics, 37*(4), 461-466.

Van Gaever, R., Jacobs, V. A., Diltoer, M., Peeters, L., & Vanlanduit, S. (2014). Thermal comfort of the surgical staff in the operating room. *Building and Environment, 81*, 37-41.

Vieira, E. M. d. A., Silva, L. B. d., & Souza, E. L. d. (2016). The influence of the workplace indoor environmental quality on the incidence of psychological and physical symptoms in intensive care units. *Building and Environment, 109*, 12-24.

Vischer, J. C. (2007b). The effects of the physical environment on job performance: towards a theoretical model of workspace stress. *Stress and Health, 23*(3), 175-184.

Wang, C., & Zamri, M. (2013). *Effect of IEQ on Occupant Satisfaction and Study/Work Performance in a Green Educational Building: A Case Study*. Paper presented at the ICCREM 2013: Construction and Operation in the Context of Sustainability, Karlsruhe, Germany.

Wargocki, P., Wyon, D. P., Sundell, J., Clausen, G., & Fanger, P. (2000). The effects of outdoor air supply rate in an office on perceived air quality, sick building syndrome (SBS) symptoms and productivity. *Indoor air, 10*(4), 222-236.

Winefield, H. R., Gill, T. K., Taylor, A. W., & Pilkington, R. M. (2012). Psychological well-being and psychological distress: is it necessary to measure both? *Psychology of Well-Being, 2*(1), 1-14.

Witterseh, T., Wyon, D. P., & Clausen, G. (2004). The effects of moderate heat stress and open-plan office noise distraction on SBS symptoms and on the performance of office work. *Indoor air, 14*(s8), 30-40.

Yang, W., & Bradley, J. S. (2009). Effects of room acoustics on the intelligibility of speech in classrooms for young children. *The Journal of the Acoustical Society of America, 125*(2), 922-933. doi: doi:http://dx.doi.org/10.1121/1.3058900

Zalejska-Jonsson, A. (2014). Parameters contributing to occupants' satisfaction. *Facilities, 32*(7/8), 411-437. doi: doi:10.1108/F-03-2013-0021

Zandvliet, D. B., & Straker, L. M. (2001). Physical and psychosocial aspects of the learning environment in information technology rich classrooms. *Ergonomics, 44*(9), 838-857. doi: 10.1080/00140130117116

Connecting Section

Chapter 2 presented the key literature on building condition assessment, indoor environmental quality, and well-being that justified the need for this research. The literature showed that the physical conditions of space enclosing elements like walls, windows, and ceilings were not generally accounted for in IEQ research. Given that these elements are responsible for enclosing indoor spaces, their physical conditions are likely to have a substantial impact on the quality of building indoor environments and subsequently occupants' satisfaction and well-being. The IEQ literature also showed that the concepts of occupants' IEQ satisfaction and occupants' well-being are generally used interchangeably. However, the social science literature on well-being indicated that the two concepts are likely not the same. Therefore, there is limited empirical evidence on how the physical conditions of key space enclosing elements influences IEQ and by extension occupants' satisfaction and well-being, especially teachers in schools given that most schools' IEQ studies have focused on students.

The next chapter, chapter 3 focuses on the physical conditions of school buildings' space enclosing elements by proposing an IEQ-related BCA instrument for schools. The instrument, space level condition assessment (SLCA) focused key classroom space enclosing elements given that teachers spend most of their school time in classrooms. The chapter also includes a detailed description of the IEQ field measurement protocol developed for this research. The SLCA and IEQ field measurements were conducted in new, renovated, and non-renovated schools. Chapter 3 presents the results of statistical analysis on the differences in SLCA scores and IEQ field measurements between the three strata of school. Additionally, the chapter also presents the results of association analyses between the SLCA scores and IEQ field measurements to determine the potential impact of the physical conditions of space enclosing elements on IEQ parameters. Chapter 3, therefore, addresses objective one of this thesis.

CHAPTER 3: Assessing the Physical Conditions of Indoor Space Enclosing Elements in Schools in Relation to their Indoor Environmental Quality

A version of this chapter was accepted for publication in the "Journal of Building Engineering".

Sadick, A.-M., & Issa, M. H. (2018). Occupants' indoor environmental quality satisfaction factors as measures of school teachers' well-being. Journal of Building Engineering (accepted).

The first author was responsible for the conception and design of the work, the data collection, data analysis and the drafting of the journal paper. The second author supervised the work and critically revised the paper.

3.1 Abstract

Field observations conducted during indoor environmental quality studies generally capture relevant building characteristics and occupants' discomfort coping strategies but do not capture the physical conditions of indoor space enclosing elements including walls, floor, and windows despite their likelihood to influence indoor environmental quality. Hence, there is limited empirical evidence on the extent to which the conditions of building elements influence indoor environmental quality. This research investigated the usefulness of the newly developed space level condition assessment instrument for assessing the impact of building elements' physical conditions on indoor environmental quality particularly in schools. This research involved assessing the physical condition of building elements using the newly developed instrument and conducting field measurements of indoor environmental quality parameters in 52 classrooms in new, renovated, and non-renovated schools. Variance analyses of the space level condition assessment data found the most number of statistically significant differences between new and non-renovated schools, and the least between renovated and non-renovated schools. Association analyses found theoretically relevant associations between space level condition assessment scores and indoor environmental quality field measurements, the most significant association was between the main envelope space level condition assessment score and relative humidity in non-renovated schools. Findings of this research should be of interest to school divisions looking to improve the indoor environmental quality of their existing schools.

Keywords: building condition assessment, indoor environmental quality, field observations, schools

3.2 Introduction

Most IEQ studies include field observations during which researchers record additional IEQ related information not captured by IEQ field measurements and occupants' IEQ satisfaction survey (e.g. Fan, Xie, Liu, & Yoshino, 2016; Newsham et al., 2013). These relevant information includes building characteristics (i.e. floor finish type, ceiling type, and window type) and occupants' adaptations (i.e. window opened or closed and use of portable fan) (Newsham et al., 2013) that are employed to explain observed trends in IEQ field measurements and causes of occupants' discomfort. For example, Fan et al. (2016) found CO_2 concentrations above recommended limits in houses because doors and windows were mostly closed in winter. Building indoor spaces are enclosed by elements including walls, floors, ceilings, and windows, hence their physical conditions would most likely influence IEQ. However, physical conditions of building elements are generally not assessed during IEQ field measurements and observations. Eweda et al. (2013) defined BCA as "a process of systematically evaluating an organization's capital assets in order to project repair, renewal, or replacement needs …". Hence, assessing physical conditions of key building elements (e.g. walls, floors, and windows) that are most likely to influence IEQ would be essential for maintenance planning to continuously enhance IEQ and ultimately occupants' well-being.

Most of the existing BCA instruments including public housing assessment system (PHAS) (HUD, 2012) and BUILDER^{TM} (CERL, 2014) were conceptualized without IEQ enhancement as a primary objective, hence, their defect severities and criticalities would not logically be most suitable for IEQ related BCA. Considering the potential health benefits of IEQ enhancements (Bluyssen, 2016) to occupants of existing buildings, the importance of IEQ related BCA cannot be overemphasized. This research was conducted in collaboration with the Government of Manitoba Public School Finance Board and two school divisions in Manitoba, Canada. Its goal was to assess the physical conditions of space envelope elements of school building types (i.e. new, renovated, non-renovated) in relation to their IEQ. This research, therefore, proposes a new BCA (i.e. SLCA) developed based on existing BCA's but with IEQ enhancement as a primary objective. The SLCA conceptualized based on classroom environments in schools, was deployed in 10 schools consisting of new, renovated, and non-renovated school. IEQ field measurements were also conducted in the 10 schools to assess the usefulness of the SLCA for IEQ-related BCA. Differences in SLCA and IEQ field measurements were assessed between school building types (i.e. new, renovated, and non-renovated) to determine the likely impact of IEQ-related renovations on school buildings' indoor environments. The SLCA is intended to provide a quick and cost-effective means of conducting IEQ-related BCA for multiple school buildings. Findings of this research should be of interest to school divisions and managers looking to renovate existing schools or develop a maintenance plan focused on IEQ enhancement. Additionally, the findings of this study would interest designers and engineers working on remodeling existing schools or planning new school projects. Finally, this research will be of interest to researchers investigating IEQ in schools or other building types. This chapter addresses objective one of this research presented in chapter 1.

3.3 Background information

There is growing interest in the IEQ literature about the impact of renovations on buildings' IEQ performance; however, most of these studies focused on homes and offices (Sadick & Issa, 2017b). For homes, Wells et al. (2015) conducted a post-renovation study of homes following deep energy retrofitting and energy star retrofitting and found that relative humidity, air temperature, and CO_2 concentrations were within recommended ranges or below the minimum threshold. In another post renovation study in homes, Thomsen et al. (2016) found that the average ventilation rate, air temperature, and CO_2 concentrations were within recommended thresholds of the Danish building code. Using a pre-post renovation approach, Noris et al. (2013) found improvement in CO_2, TVOC, and particulate matter ($PM_{2.5}$) concentrations in homes following their renovation. For offices, Hongisto, Haapakangas, Varjo, Helenius, and Koskela (2016) employed a pre-post research design and found no change in air temperature, insignificant improvement in CO_2 concentration, and significant improvement in sound pressure level of speech after refurbishment. For schools, Ghita and Catalina (2015) investigated the IEQ of a new, renovated, and old school and found that air temperature in all three schools was below the minimum recommended threshold of 20 ^oC in Romania. Nevertheless, the air temperature was highest in the renovated school and lowest in the old school. Classroom CO_2 concentration in all three schools was high (approximately 2000 ppm to 3000 ppm) and was attributed to the classrooms being naturally ventilated. A pre-post renovation study by Zinzi, Agnoli, Battistini, and Bernabini (2016) found improvements in both air temperature and CO_2 concentration following deep energy retrofitting of schools. Findings from these studies generally support the thesis that targeted renovations can enhance IEQ. However, these studies account for the impact of the implemented renovations on IEQ and not the impact of the defects prior to renovation.

Field observations are frequently used in IEQ research to identify potential sources of discomfort and poor IEQ performance. For instance, Newsham et al. (2013, pp., p. 417) used field observations to record space characteristics including "… ceiling height; floor, ceiling and wall finishes; lighting type; window orientation, … whether the window was open …" and found that a substantial number of offices without windows in both green and conventional buildings had lighting below recommended limits. Additionally, De Giuli et al. (2012) found that students were dissatisfied with classroom indoor air quality because windows were closed during class time. A review of the literature shows that although IEQ field observations monitor the availability of building elements, they generally do not account for the physical conditions of these elements and their likely influence on IEQ performance. This is important given that an operable window with damaged glazing, for example, can cause thermal discomfort in winter and also increase the concentration of indoor air pollutants.

ASTM International (2008) standard E2018-08 for building condition assessment provides guidelines for baseline BCA. The recommendation for assessing a building's envelope entails observing its elements including curtain wall system, glazing system, and doors. These recommendations are operationalized by BCA instruments including PHAS (HUD, 2012), BUILDER^{TM} (CERL, 2014), and Eweda et al. (2013) direct-condition rating. BUILDER^{TM} is a generic computer-based BCA that requires setting up a building components' model from an inventory and offers both distress survey and direct condition rating (CERL, 2014). Distress survey involves identifying defects and recording their severity and quantity, with standardized distresses assessed using densities ranging from 0 to 100. Direct-condition rating is an omnibus assessment based on the evaluator's subjective judgment and guided by color codes ranging from Green (+) (i.e. a building component has no visible defect) to Red (–) (i.e. a building component is completely degraded).

The PHAS developed by the US Department of Housing and Urban Development is based on the distress survey evaluation mechanism and has predefined building items and deficiencies (HUD, 2012). It also has predefined levels of criticality for deficiencies ranging from critical (i.e. 5) to slight contribution (i.e. 1). One limitation of this instrument is that there may not be consensus on the predefined levels of criticality. For example, an inoperable window is only rated at 3 and is thus not a critical deficiency in PHAS although research (Brager, Paliaga, & De Dear, 2004; De Giuli et al., 2012; Huizenga et al., 2006) suggests that operable windows are critical to occupants' IEQ satisfaction. Additionally, "cracked/broken/missing panes" and "damaged/missing screens" in windows are not critical deficiencies in PHAS despite their potential significant impact on IEQ and occupants' well-being (HUD, 2012).

Eweda et al. (2013) proposed a direct condition rating with six generalized condition descriptions rated using letter grades from A (excellent) to F (failure) and converted to index values ranging from 100 to 0 respectively. For example, an F rating is used for building elements that are "no longer functioning" or are a "complete failure" and are thus in "Poor" condition. These condition descriptions seek to minimize the level of subjectivity associated with direct condition ratings. Nevertheless, their value may be limited when making renovation decisions with respect to IEQ. For example, a glazed window with deteriorated caulking as the only defect may be rated as fair using this rating system given that the other parts of the glazed window are intact. Nevertheless, deteriorated caulking will most likely compromise a space envelope's integrity and influence relative humidity and air temperature. The generic nature of these BCA instruments makes them most suitable for projecting repairs and replacements for general maintenance purposes; however, the logic of their defect severity and critically makes them less suitable for IEQ-related BCA.

3.4 Methods

Based on the objectives of this thesis, an "exploratory sequential mixed-method design" (Creswell, 2014, p. 220) was used as depicted in Figure 3.1. This two-stage design starts with qualitative data collection and analysis that builds to quantitative data collection and analysis (Creswell, 2014). The qualitative stage is mostly for developing the instruments that will be used during the quantitative stage (Creswell, 2014). The qualitative stage (i.e. stage one) in this research included developing the SLCA instrument for school buildings, developing IEQ field measurement protocol, and adapting an existing IEQ satisfaction survey for teachers. Additionally, this stage included semi-structured interviews of teachers to identify manifestations of PWB, SWB, and PhWB that resulted in developing the preliminary well-being surveys. The quantitative stage (i.e. stage two) entailed conducting SLCA and IEQ field measurements along with deploying, refining, and validating the surveys developed in stage one. This chapter focuses on reporting stages one and two of the SLCA and IEQ field measurements only.

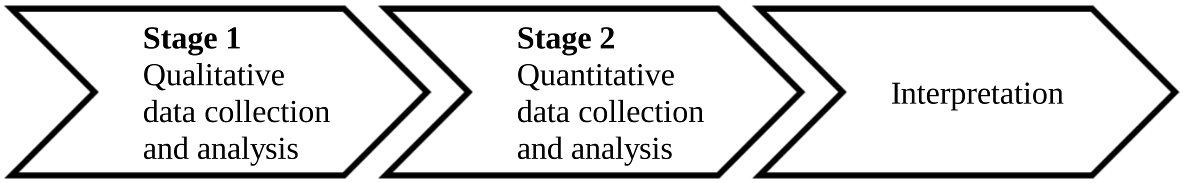

Figure 3.1: Flow Diagram for Exploratory Sequential Mixed-Method Design
(Creswell, 2014, p. 220)

3.4.1 Stage one

This subsection presents details of the study location and building, sampling, and data collection strategies employed. Additionally, detailed descriptions of the SLCA and IEQ field measurement protocol developed as part of this research are presented.

3.4.1.1 Study location and buildings

The two school divisions that participated in this research included a total of 32 elementary to secondary schools, mainly in rural Manitoba, southeast of Winnipeg. A two-stage classification strategy was employed to stratify these 32 schools for analysis purposes. The first stage involved classifying them based on their start date of operation that ranged from 1950 to 2012, representing a period of 62 years. This period was divided into three approximate 20-year periods, resulting in three school strata as follows: new schools from 1992 to 2012 (seven in number), middle age schools from 1971 to 1991 (six in number) and old schools from 1950 to 1970 (19 in number). The 20-year period seemed logical given that the National Building Code of Canada (NCB) had historically been revised nearly every five to 10 years from 1941 to 2015. Given that the 32 schools were constructed to different versions of the NCB, and that successive versions of the NBC are expected to improve the performance of buildings, it is logical to expect a substantial performance gap between these three school strata. The second stage of the classification was based on the schools' renovation records supplied by the two school divisions. From 2007 to 2014, five middle age and 12 old schools underwent substantial IEQ-related renovations to improve their IEQ performance. Table 3.1 summarizes the nature of these renovations and their potential impacts.

Table 3.1: IEQ-related renovations executed in stratum 2 schools and their expected impact

Renovations	Expected impact on IEQ	Number of schools
Building envelope		
• Partially replacing existing walls • Partially or completely reinsulating building envelopes • Completely replacing existing glazed windows with new low U-value and high visible light transmittance glazed windows	• Minimize thermal loss of building envelope to avoid rapid fluctuations in indoor air temperature levels • Increase the amount of daylight indoors • New walls would likely increase attenuation of sound from adjoining classrooms and outdoors • Tightening of building envelope will likely decrease exfiltration of indoor air pollutants	17
Finishes		
• Using low volatile organic compound (VOC) materials for painting, flooring, and ceiling • Replacing existing sound absorbing finishes and fixtures (e.g. acoustics ceiling)	• Decrease the concentration of VOCs in classrooms • Enhance the decay of sound indoors to minimize reverberation	13
HVAC		4
• Refurbishing or replacing existing HVAC systems	• Enhance ventilation and decrease the concentration of indoor air contaminants • Provide the required heating and cooling indoors	
Lighting		13
• Replacing lighting fixtures	• Enhance the quality of vision indoors	

Based on the IEQ-related renovations, the schools were reclassified by merging the 17 old and middle age schools that were renovated into one stratum (i.e. renovated) and the remaining eight old and middle age schools that were not renovated (i.e. not-renovated) into another stratum. The new school stratum from the first stage remained unchanged. Table 3.2 summarizes these three school strata.

Table 3.2: Strata of schools

Name of stratum	Abbreviated stratum name	Start date of operation	Number of schools	Number of students	Number of teachers
New schools	New	1992 – 2012	7	2520	172
Old/middle age recently renovated	Renovated	1971 – 1950	17	7892	557
Old/middle age not recently renovated	Non-renovated	1971 – 1950	8	3322	123

Schools in stratum 1 (i.e. new) were constructed in accordance with the NBC versions 1985 to 2010. Three of the oldest new schools were substantially upgraded within the last 10 years to enhance their IEQ while the rest only experienced routine maintenance such as replacing broken items (e.g. damaged window glazing). Schools in stratum 2 (i.e. renovated) were a mix of old and middle age schools constructed to NBC versions 1950 to 1980. All 17 schools in this stratum experienced substantial IEQ-related renovations as shown in Table 3.1. Stratum 3 schools (i.e. non-renovated) were also a mix of old and middle age schools constructed to NBC versions 1950 to 1980. However, they did not undergo the substantial IEQ-related renovations experienced by stratum 2 schools from the year 2007 to 2014. The new schools were expected to have the best IEQ conditions with the renovated schools being similar or second best to the new schools given the substantial IEQ-related renovations implemented in them. The non-renovated schools were expected to have the worst IEQ conditions relative to the new and renovated schools.

3.4.1.2 Sampling

Due to ethics restrictions, all the 32 schools in the two school divisions that participated in this research were invited in stage one, however, only 10 positive responses were received. The 10 schools included elementary, middle, and high schools. Additionally, the 10 schools comprised four new schools, three renovated schools, and three non-renovated schools.

3.4.1.3 Data collection

The data used for developing the SLCA included written notes and photographs of the physical conditions of key classroom space enclosing elements for the 10 schools that were visited in stage one during the fall of 2015. Almost all the classrooms in each of the 10 schools were inspected to record existing conditions. The elements and defects included in the SLCA were mainly adapted from the PHAS and refined using data collected from the 10 schools visited. Data for the IEQ field measurement protocol were established measurement standards and procedures in the literature

3.4.1.4 Development of the space level condition assessment

Eweda et al. (2013) proposed a six-tier hierarchy for BCA with the first three tiers being the building level, the space level, and the category level. Humans live and work indoors and thus experience IEQ at the space level. Defective building elements, for example, cracked window glazing, would compromise IEQ aspects including thermal comfort and indoor air quality and by extension occupants' well-being (Ahluwalia, 2008; CDC, 2013; Huizenga et al., 2006). Leveraging the strengths and weaknesses of the existing BCA, SLCA based on the distress survey method is proposed for quick condition assessment in schools. Given that teachers spend most of their school time in classrooms, the SLCA developed in this research focused on the classroom level. The SLCA consists of the key school building envelope elements found mainly in classrooms and their visually observable defects that are most likely to impact IEQ. The reasoning behind the conception of the SLCA is to move beyond observing the presence or absence of these building components to assessing their physical conditions with respect to IEQ enhancement. Figure 3.2 shows the SLCA hierarchy with level 4 representing the major elements of indoor spaces, level 3 depicting the sub-elements of level 4, level 2 listing key defects of level 3 elements, and level 1 describing the four severities of level 2 defects. The defect severities in level 1 are in ascending order of expected impact on IEQ. By focusing on visible defects of indoor space enclosing elements, the SLCA would enable a quick, less costly and objective assessment of school buildings' space enclosing elements. Levels 2 and 1 shown in Figure 3.2 are for windows only. The full SLCA including defects and severities for all elements are included in Appendix A.

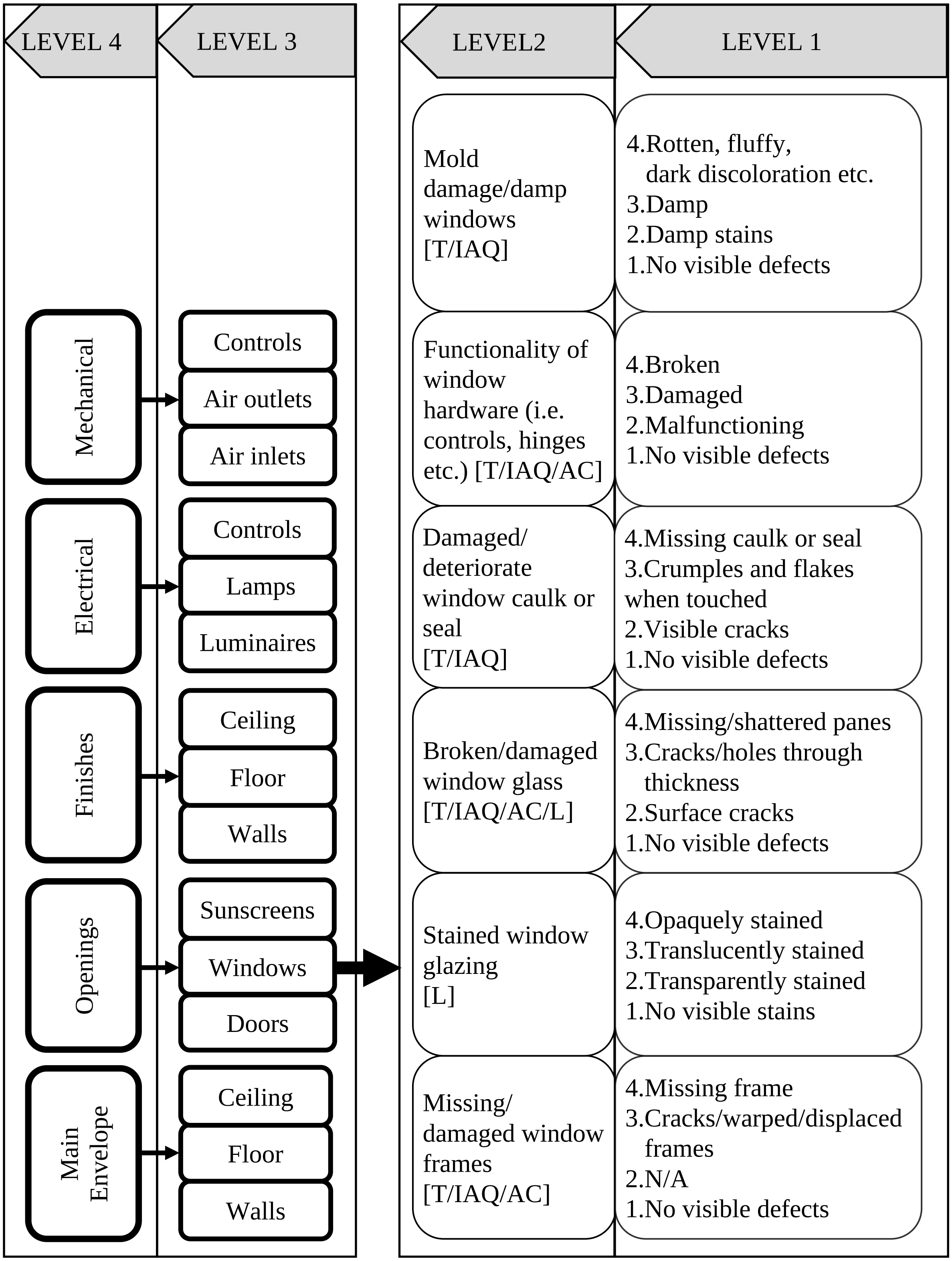

Figure 3.2: Hierarchy of space level condition assessment components

The “Main Envelope” category consisting of walls, floors, and ceilings focuses on defects of the core space enclosing elements excluding their surface finishes. Defects of the walls component include “damaged internal walls” and “damaged external walls” assessed based on cracks, missing units, holes, and separations, and whether these defects traverse the thickness of walls or not. Additionally, the floor component defect includes “damaged floor” that focuses on cracks and holes in floors. These defects in walls and floors would likely lead to substantial fluctuations in thermal comfort parameters like air temperature and relative humidity. For both finished walls and floors, only defects that are visually observable beyond the surface finishes are assessed. The ceiling component includes the defects “damaged concrete ceiling” and “damaged suspended ceiling” for single and multi-story school buildings. Assessment of “damaged concrete ceiling” is based on cracks, holes, and spalling of suspended concrete floor soffits of multi-story schools, and “damaged suspended ceiling” is based on cracks, missing units, and holes in suspended ceilings of either single or multi-story school buildings. Concrete ceilings that are invisible due to suspended ceilings are not assessed.

The “Openings” category includes doors, windows, and sunscreen. The doors component has specific defects for subcomponents of doors as follows: “damaged door frame”, “damaged door leaves”, “broken/damaged door glazing”, “functionality of door hardware”, and “mold damage/damp doors”. Similarly, the windows component has specific defects for the major components of glazed windows as shown in Figure 3.2. Although doors and windows are categorized under openings, they form an integral part of the main envelope, hence, their defects (especially windows) would have a noteworthy impact on the four main factors of IEQ. The sunscreen component of openings includes the defects “damaged screen/blinds” and “functionality of screen/blind control" that are directly related to the amount of daylight indoors. The last sunscreen defect, "appearance of sunscreen/blinds" relates to indoor air quality due to dust.

The "Finishes" category includes finishes to wall surface, floor, and ceiling. The wall surface finishes defects include "damaged render/stucco", "deteriorated/damaged painting", "painting appearance", "mold damage/damp wall surfaces", and "coverage of sound absorbing items". "Painting appearance" refers mainly to dust on painted wall surfaces and "coverage of sound absorbing items" refers to the proportion wall surfaces that are covered by sound absorbing materials like fiberboard. These sound absorbing items could be the primary wall surface finish or otherwise. Besides "damaged render/stucco" that would likely affect thermal comfort, indoor air quality, and acoustics, the other wall surface finishes defects would likely affect either indoor air quality, acoustics or both. While "damaged render/stucco" due to deep cracks and holes will affect the thermal resistance of walls, spalling of render/stucco would increase suspended airborne particles (i.e. indoor air quality) and reduce the impedance of sound (i.e. acoustics). Both floor and ceiling finishes have level 2 defects like wall surface finishes defects. The ceiling finishes defects include "damaged ceiling finish (render/stucco)" due to spalling, deep crack and holes. This ceiling finish defect is for render/stucco only to soffits of suspended concrete floors. However, the "damaged suspended ceiling" defect under the ceiling component of main envelope refers to cracks, missing units, and holes in other types of suspended ceilings (like acoustic tile ceiling) beside soffit of suspended concrete floors. Therefore, for each space, either "damaged ceiling finish (render/stucco)" under finishes or "damaged suspended ceiling" under main envelope may be applicable or both.

The “Electrical” category focused on lamps and luminaries and had two defects as follows: “functionality of lamps” and “appearance of luminaires/lamps”. The “functionality of lamps” was assessed as “lamps are functioning” or “Not functioning” with the switch turned on. The root cause of lamps not functioning may be an unobservable electrical defect that would not directly impact IEQ. Therefore, “functionality of lamps” focused on the primary function of lamps in illuminating indoor spaces that is easily observable by turning on or off a switch. The defect “Appearance of luminaires/lamps” focused on dust that would likely affect the concentration of suspended air particles (i.e. indoor air quality) and the quality of light emitted by lamps.

The “Mechanical” category focused on air inlets within indoor spaces that let in the conditioned air (warm or cool) from HVAC systems to control thermal comfort and indoor air quality. The air inlet defects were “functionality of air inlets” and “appearance of air inlets”. “Functionality of air inlets” focused on whether inlets were operational or not. Other noteworthy HVAC defects including dampness and mold in ducts would have a substantial impact on indoor air quality but are not account for by the SLCA given that they are not visually observable. The “appearance of air inlets” may have a substantial impact on indoor air quality as dust particles on inlets are carried along by incoming conditioned air. The mechanical category also includes a subjective assessment of HVAC noise as being either normal or otherwise. HVAC was observed to be the most noteworthy source of background noise in the schools visited, therefore, abnormal background noise may affect speech intelligibility.

The assessment of each level 2 defect is conducted using four defect severities (i.e. level 1) increasing from 1 to 4 as shown in Figure 3.2, while the intensity of a defect severity is judged using an intensity scale including 4 (76 – 100% of elements), 3 (51 – 75% of elements), 2 (26 – 50% of elements) and 1 (25% and below). These intensities are judged with respect to the surface area or length and are subject to the nature of the level 2 defect. Multiple severities can be assessed for each level 2 defect. Window glazing, for example, may be both opaquely and transparently stained; the intensities, however, are assigned to attain 100% summation. Hence, when a single defect severity is assigned an intensity of 4, the remaining severities are not assessed. Additionally, severity level 1 is only assessed when none of the other severities are observed. The SLCA scores for level 2 defects are calculated by summing the products of defect severities and defect intensities. The scores range from 1 to 16 and are divided into four regions as $1 \leq SLCA \leq 4$ (low), $4 < SLCA \leq 8$ (medium), $8 < SLCA \leq 12$ (high), and $12 < SLCA \leq 16$ (very high), thus suggesting expected levels of negative impact on IEQ. The level 2 defects are categorized into thermal comfort (T), air quality (AQ), acoustics (AC), and lighting (L) related defects (as shown in Figure 3.2 for windows) and their scores averaged to obtain IEQ-related SLCA scores for levels 3. Level 4 IEQ-related SLCA scores are calculated by averaging the scores of level 3 elements.

3.4.1.5 IEQ field measurement protocol

This subsection describes the methods used for the field measurement of school buildings' IEQ. Additionally, the subsection describes the study sample, the parameters measured, the instruments used to measure them, and the measurement procedures used to acquire data for parameters of thermal comfort, indoor air quality, acoustics, and lighting.

3.4.1.5.1 Thermal comfort data collection

Table 3.3 shows the thermal comfort parameters that were measured, the equipment used, and measurement protocols employed in this study. Only one sample was taken per sampling location to minimize class disruptions. The sampling location was generally the center of the area in front of classrooms (i.e. between the front role seats and white/blackboard) where teachers spend most of their time in class. Only the last ten (10) minutes of the 15 minutes sampled data were analyzed to avoid the variability in values due to effects such as the lagging response of sensors. All mounting heights were adopted from ASHRAE 55 (ASHRAE, 2010). The air temperature profile at the heights of 0.1 m (feet level), 1.1 m (chest level), and 1.7 m (head level) were measured using a customized apparatus designed for this study as shown in Figure 3.3. The customized thermal comfort apparatus has swivel wheels with brakes for ease of mobility and a data logger that automatically stores measurements.

Table 3.3: Thermal Comfort Parameters Field Measurement Protocol

Parameter	Unit	Measurement	Equipment
Air temperature	Degree Celsius (°C)	• Sample for 15 minutes at mounting heights of 0.1, 1.1, and 1.7 above floor level1 • Air temperature is the average of profile values	Campbell Scientific 109-L; -50 – 70 °C range; ±6 °C accuracy[2]
Relative humidity	Percentage (%)	Sample for 15 minutes at a mounting height of 1.1 m above floor[1]	GrayWolf IQ-604; 0 – 100% range; ±3% accuracy[3]

[1](ASHRAE, 2004, p. 12-13), [2](Campbell Scientific, 2015), [3](GrayWolf Sensing Solutions, 2014a)

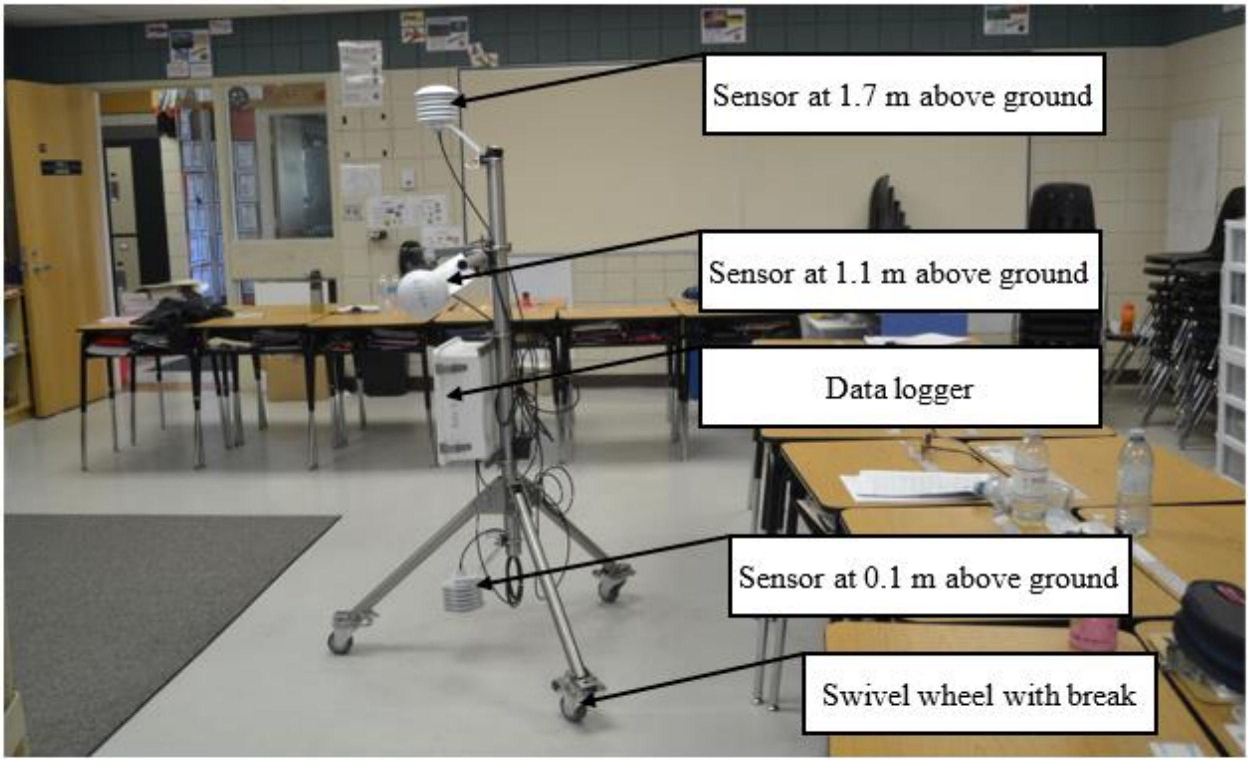

Figure 3.3: Custom built temperature profile apparatus

3.4.1.5.2 Indoor air quality data collection

Table 3.4 shows the indoor air quality parameters measured in this study. The table also shows the equipment and procedures used to measure these parameters. Sampling for indoor air quality parameters was in the same sampling area as thermal comfort parameters and was at least 1 m from wall surfaces, windows, air inlets, extractor fan, and other classroom features that could significantly influence data collection (U.S. EPA, 2003). Indoor air quality measurement equipment were mounted on a single tripod to ease the sampling process and increase accuracy.

Table 3.4: Indoor Air Quality Parameters Field Measurement Protocol

Parameter	Unit	Measurement	Equipment
Carbon dioxide (CO_2)	Parts per million (ppm)	Sample all parameters for 15 minutes at a mounting height of 1.7 m above floor level[4,5]	GrayWolf IQ-610; range of 0 – 10,000 ppm for CO_2; 5 – 20,000 ppb for TVOC; 0 – 500 ppm for CO; ±3% accuracy[6] for three parameters
Total volatile organic compound (TVOC)	Microgram per cubic meter ($\mu g/m^3$)		
Carbon monoxide (CO)	ppm		
Particulate matter	$\mu g/m^3$		GrayWolf PC-3016A; < 0.3 – > 10 µm range; 50% for < 3 µm and 100% for > 4 µm accuracy[7]

[4](ASHRAE, 2010), [5](U.S. EPA, 2003), [6,7](GrayWolf Sensing Solutions, 2014a, 2014b)

3.4.1.5.3 Acoustics data collection

This research included measurement of the acoustics parameters shown in Table 3.5. Background noise and reverberation time were measured in accordance with the Acoustical Performance Criteria, Design Requirements, and Guidelines for Schools, Part 1: Permanent Schools (ASA, 2010). Reverberation time was measured using the interrupted noise method with two signal sources and three receiving positions such that the distance from each source position to each of the three receiving positions was not less than one-third of the longest classroom dimension (ASA, 2010). As shown in Figure 3.4, the signal source was in front of classrooms and the signal receiver at students' seating or listening positions. As described in Table 3.5, noise to signal ratios (SNR) exceeding 35 dB and 45 dB were used to determine RT20 and RT30 (i.e. time taken for sound pressure level to reduce by 20 dB and 30 dB respectively) and extrapolated to determine RT60. Apparent sound transmission class (ASTC) as shown in Table 3.5 was based on the Standard Test Method for Measurement of Airborne Sound Attenuation between Rooms in Buildings (E336-14) (ASTM, 2014). The signal source and receiving room for adjoining classrooms were selected such that the largest was the receiving room. Two signal source positions were selected in the source rooms as shown in Figure 3.5. All doors leading to the source and receiver rooms were closed during the measurement. Reverberation time and ASTC analyses were conducted using the Larson Davis DNA Software version 4.8.1.0.

Table 3.5: Acoustics parameters field measurement protocol

Parameters	Unit	Measurement	Equipment
Background Noise Level	Decibel (dB)	• Sample at noisiest spot at center of classroom at 1.2 m height above floor for both A and C-weighted with a 60 seconds time averaged values for 10 minutes[8] • Set meter to octave and 1/3 octave bands with mid-band frequencies from 63 Hz to 8 KHz[8]	Larson Davis 831 class 1 sound level meter; 0 – 150 dB range; ≤ ±5 dB accuracy[10]
Reverberation Time (RT60)	Seconds (s)	• Pink noise signal played through signal source such that noise to signal ratio (SNR) exceeds 35 dB and 45 dB; signal receiver measured in octave and 1/3 octave for midpoint frequencies from 125 Hz to 4000 Hz[8] • Measure six possible combinations of three receivers and two source positions, recording five decays per receiver position[8]	• Larson Davis 831 class 1 sound level meter; 0 – 150 dB range; ≤ ±5 dB accuracy[10] • Larson Davis BAS001 speaker • Larson Davis BAS002 amplifier
Apparent sound transmission class (ASTC)	N/A	• Turn on signal in source room and move sound level meter slowly in a circular path (not less than 1 m from all surface and source positions) to sample average sound pressure level in both rooms starting with the receiving room[9] • Turn off signal source and measure A-weighted background noise level in one-third octaves with mid-band frequencies from 125 Hz to 4000 Hz in receiving room. • Difference between the sound pressure level and background noise level in the receiving room should be at least 10 dB at each frequency[9]	

[8](Acoustical Society of America, 2010), [9](ASTM, 2014), [10](Larson Davis, 2015)

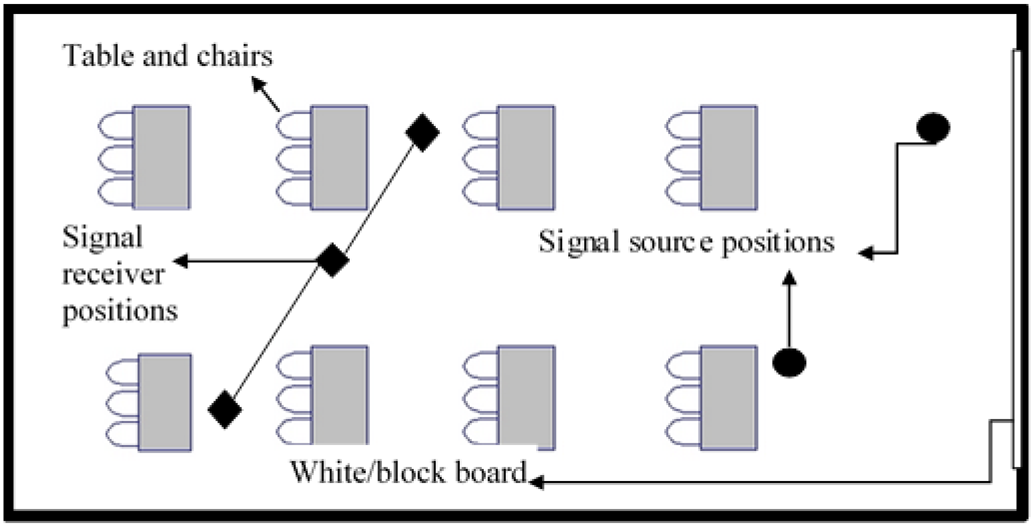

Figure 3.4: Schematic diagram for reverberation time measurement

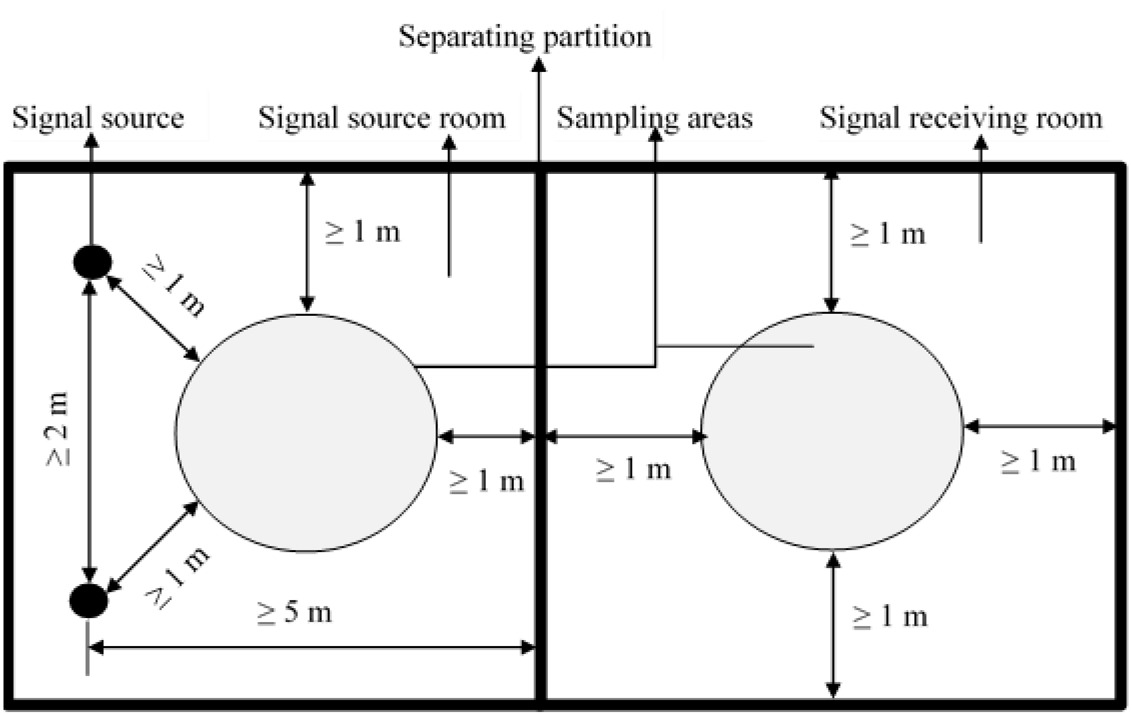

Figure 3.5: Schematic diagram for apparent sound transmission class measurement

3.4.1.5.4 Lighting data collection

Daylight factor (DF) was the only lighting parameter measured in this research due to accessibility restrictions. The initial number of sampling points per sampling space was determined based on a room index (R) given by the expression below (Inan, 2013, p. 127) and as per Table 3.6.

$$R = (L \times W)/[H_M (L + W)]$$

Where L is the length of the space, W is the width of the space, and H_m is the mounting of light fittings above working plane.

Table 3.6: Room Index and Correspondingly Lighting Sampling Points

Room Index	Sampling Points
Below 1	9
1 and below 2	16
2 and below 3	25
3 and above	36

(Inan, 2013, p. 127)

However, nine sampling points were measured for each classroom to minimize variations given that the same light meter was used for both indoor and outdoor daylight measurements respectively. A sampling grid was created in each sampled classroom such that the cells were approximately square, with sampling done at the center of grid cells (Inan, 2013). Table 3.7 describes the DF measurement protocol used in this research.

Table 3.7: Lighting Parameters Field Measurement Protocol

Parameters	Unit	Measurement	Equipment
Daylight factor (DF)	N/A	• Turn off artificial lighting in classroom and measure indoor daylight at sampling points created for average illuminance[11] • Measure outdoor daylight excluding direct sunlight[11] • DF will be determined as the ratio of average indoor daylight to outdoor daylight[11]	Delta Ohm LP PHOT 01; 0.1 – 200000 lux range; ±4% accuracy[12]

[11](Li, Lau, & Lam, 2004), [12](OTM Solutions, 2015)

3.4.2 Stage two

This subsection presents the sampling and data collection strategies employed during the deployment of the SLCA and IEQ field measurements. Additionally, data analyses methods employed for the SLCA and IEQ field measurement data are also presented.

3.4.2.1 Sampling

Participation in the second stage was open to all schools but only the 10 in Table 3.8 were selected from the 15 positive responses due to resource limitation. The SLCA and IEQ field measurements were conducted in 52 classrooms: 16, 15, and 21 in new, renovated, and non-renovated schools respectively. Classrooms in each school were selected based on their locations and sizes. Only classrooms that were occupied at the time of the assessment were selected.

3.4.2.2 Data collection

The SLCA and IEQ field measurements were conducted during the winter of 2016. The SLCA was conducted using a customized Excel spreadsheet on a hand-held micro-computer. The IEQ field measurements were snapshot measurements conducted in each of the 52 classrooms.

Thermal comfort and indoor air quality parameters were measured when classrooms were occupied at the center of the area in front of each classroom where teachers spent most of their time. Daylight and acoustics parameters were measured in the same classrooms when they were unoccupied. Table 3.8 shows the specific dates of the SLCA and IEQ field measurements in each school from March to May of 2016.

Table 3.8: Details of participating schools

Strata	School	Division	Start of operation	Footprint (m^2)	Floors	Grade level	Students	Teachers	Data collection dates[1]
New schools									
	A	1	1991	29,766	1	K-6	230	15	8/3; 10/3
1	B	2	1998	56,900	1	9-12	455	29	11-12/4
	C	1	2012	92,440	2	5-8	660	45	9/3; 29/3
Renovated schools									
	D	2	1959	34,000	1	K-8	185	12	25-26/4
2	E	1	1972	52,562	1	K-4	440	33	15-16/3
	G	1	1986	35,591	1	K-4	363	30	17-18/5
Non-renovated schools									
	H	2	1971	26,000	1	K-4	122	9	22-23/3
3	I	2	1968	37,000	1	K-8	210	14	5-7/4
	J	2	1959	40,000	2	9-12	270	18	14/4; 21/4
	K	1	1961	67,071	2	5-8	500	41	28-29/4

[1]Data collection dates are of the format day/month. The symbol (-) is used for consecutive days while (;) is used to separate non-consecutive data collection days.

3.4.2.3 Data analysis

The normality of the SLCA and IEQ field measurements data for each school stratum was assessed using the Shapiro-Wilk test. The results showed that the SLCA data for all three school strata were not normally distributed while approximately 37% of the strata for the 10 IEQ parameters were not normally distributed. Additionally, 64% of the non-normally distributed strata for the 10 IEQ parameters were for new schools only. Therefore, the non-parametric Kruskal-

Wallis H test was preferred to the parametric analysis of variance to assess differences in SLCA and IEQ field measurements between the three school strata. Subsequently, post hoc pairwise comparison with Bonferroni correction for multiple comparisons was conducted for statistically significant tests to identify pairs of schools that differed. The purpose of this analysis was to determine SLCA's sensitivity to differences in physical condition in relation to IEQ performance. The Spearman's rho test was also used to assess the associations between IEQ-related SLCA scores and IEQ field measurements while the coefficient of determination was calculated to determine the proportions of variance in IEQ field measurements explained by IEQ-related SLCA scores. These analyses were conducted using level 4 SLCA scores.

3.5 Results

This subsection presents the results of the SLCA and IEQ field measurements for the four main factors of IEQ: thermal comfort, indoor air quality, acoustics, and lighting.

3.5.1 Thermal comfort-related SLCA and IEQ field measurements

Figure 3.6 presents the distributions of thermal comfort-related SLCA scores for level components in the three strata of schools. The figure highlights the similarities and differences in thermal comfort-related SLCA scores between the three school strata. Figure 3.6 shows how thermal comfort-related SLCA scores for level 4 components of all schools were in the low region except in one non-renovated school classroom where the main envelope SLCA score was in the medium region. Additionally, SLCA scores for openings, main envelope, and finishes were generally lowest in the new schools relative to the renovated and non-renovated schools; however, the SLCA scores of the renovated schools were not consistently lower relative to the non-renovated schools as evidenced by the openings SLCA scores.

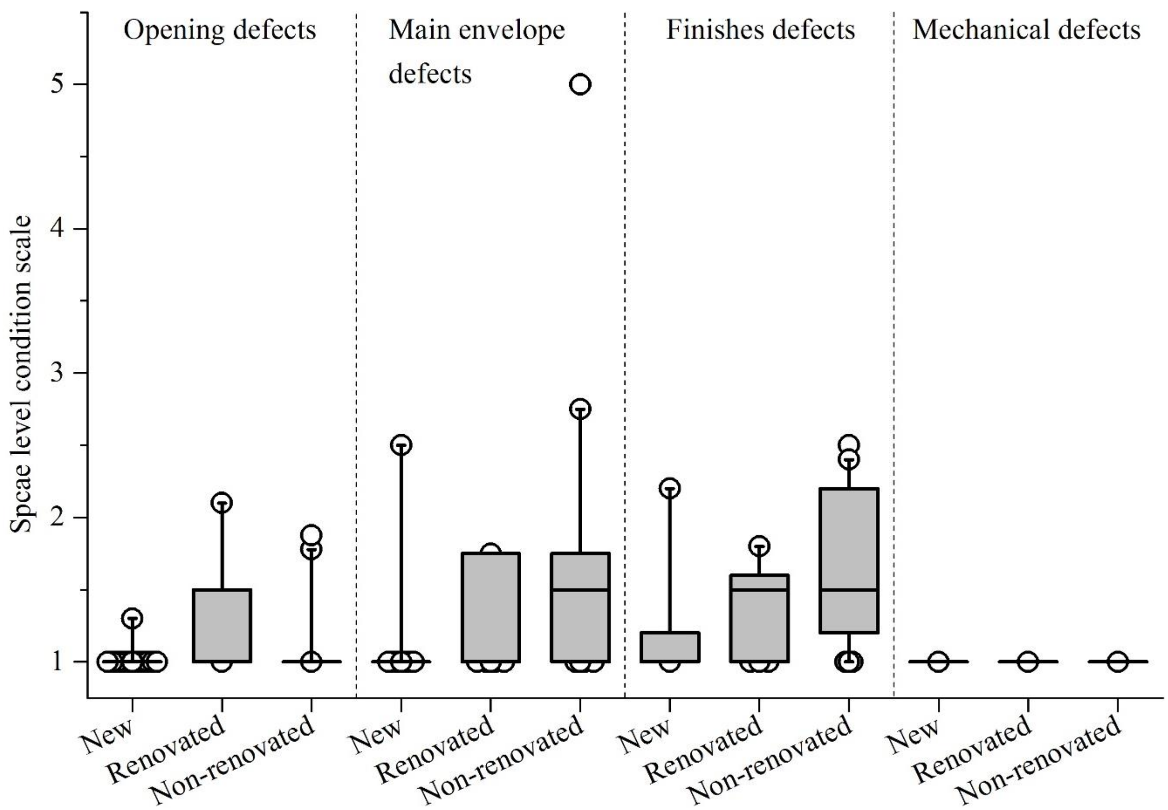

Figure 3.6: Thermal comfort-related SLCA scores for level 4 components

Table 3.9 presents the leading level 2 SLCA scores for thermal comfort-related defects all of which are in the low region, thus, explaining the low levels of SLCA scores for all level 4 components in Figure 3.6. Just like in Figure 3.6, scores of the leading defects were low for new schools relative to both renovated and non-renovated schools. Renovated and non-renovated schools had the same set of leading defects and with similar scores.

The Kruskal-Wallis H test showed statistically significant differences for two thermal comfort-related SLCA components between the three strata of schools. Firstly, the main envelope SLCA scores between the three school strata were statistically significantly different, $H(2) = 6.35$, $p = 0.042$. Lastly, the finishes SLCA scores between the three strata of schools were statistically significantly different, $H(2) = 11.33$, $p = 0.003$. The post hoc analysis revealed that the main envelope SLCA scores for new schools were statistically significantly lower (mean rank = 19.31) than for non-renovated schools (mean rank = 30.25) ($p = 0.041$). For finishes SLCA, the scores for new schools were statistically significantly lower (mean rank = 16.59) than for non-renovated schools (mean rank = 32.93) ($p = 0.003$).

Table 3.9: Leading level 2 SLCA scores for thermal comfort-related defects

School strata	Leve 4 SLCA	Level 2 SLCA	Scores
New	Openings	Broken/damaged window glass	1.19
	Main envelope	Damaged suspended ceiling	1.56
	Finishes	Damaged Ceiling Finish	1.75
Renovated	Openings	Mold damage/damp windows	2.40
	Main envelope	Damaged suspended ceiling	2.40
	Finishes	Damaged Ceiling Finish	2.33
Non-renovated	Openings	Mold damage/damp windows	2.05
	Main envelope	Damaged suspended ceiling	2.76
	Finishes	Damaged Ceiling Finish	2.53

Figure 3.7 depicts the distributions of classrooms' air temperature and relative humidity (RH) for the three strata of schools. The figure depicts similarities and differences in the range of classrooms' air temperature and relative humidity levels in the three school strata. Air temperatures in nearly all classrooms in all schools were within the recommended winter range of 20 – 24 ^{o}C (ASHRAE, 2010). For RH, Figure 3.7 shows that all classrooms in the new schools were below the recommended range of 30 – 70% (ASHRAE, 2010), while approximately 33% and 43% of

renovated and non-renovated schools' classrooms respectively were within the recommended range. Additionally, the widest range of air temperature and RH respectively was in the non-renovated schools, followed by the renovated and new schools respectively in descending order.

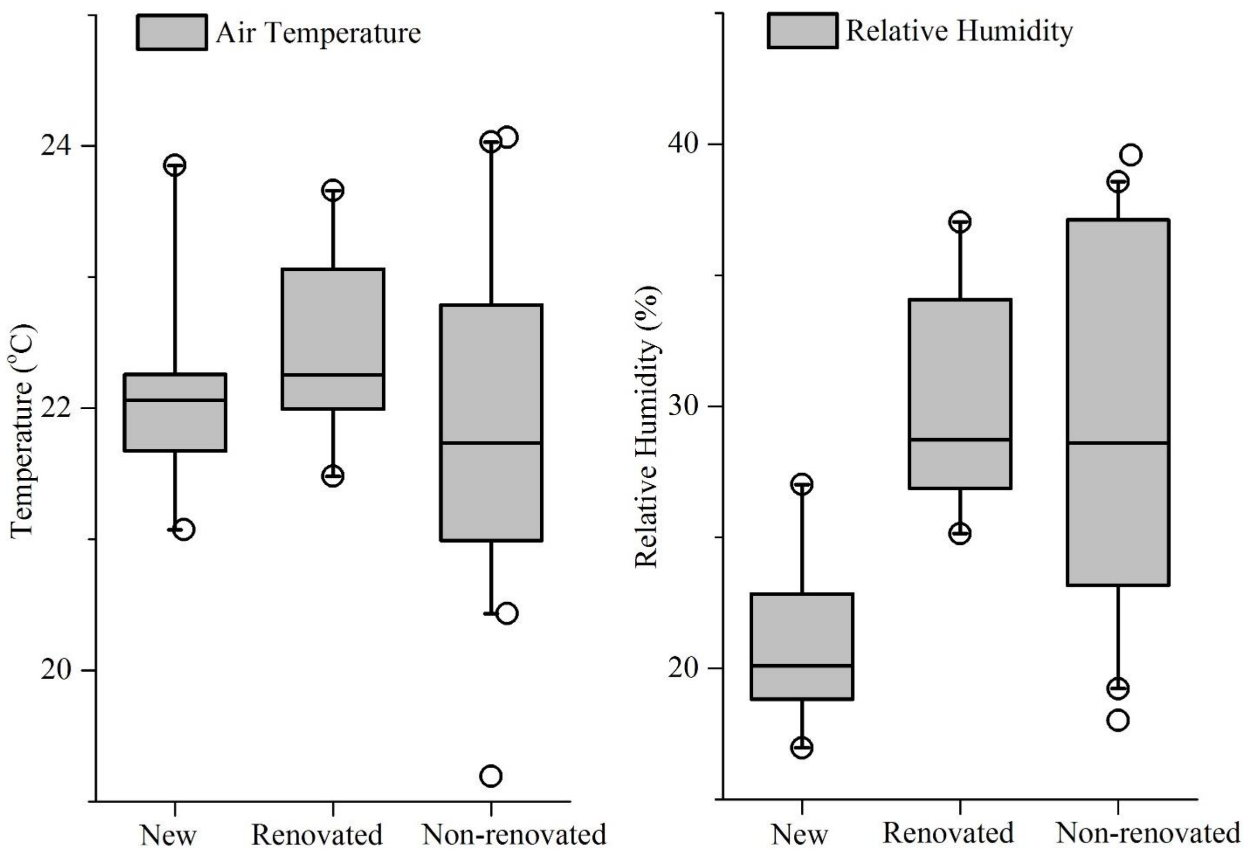

Figure 3.7: Air temperature and relative humidity for new, renovated and non-renovated schools respectively

The Kruskal-Wallis H test showed statistically significant differences in RH only between the three strata of school, H(2) = 21.10, p = 0.0001. The post hoc pairwise comparisons showed that RH values were statistically significantly lower in the new schools (mean rank = 12.25) than for renovated schools (mean rank = 35.27) (p = 0.000) and non-renovated schools (mean rank = 31.10) (p = 0.001). Correlation analyses found a statistically significant association between RH and main envelope SLCA for non-renovated schools only. This strong positive correlation, r = 0.86, p = 0.000, suggests that thermal comfort-related main envelope defects including “damaged external walls” and “damaged suspended ceilings” explained approximately 74% of the variance observed in the RH values for non-renovated schools.

3.5.2 Indoor air quality-related SLCA and IEQ field measurements

Figure 3.8 presents the distributions indoor air quality-related SLCA scores of classrooms in the three strata of schools and highlights the similarities and differences in the range of scores. The figure shows how new schools recorded the lowest scores for all five SLCA components. The distribution of scores for renovated and non-renovated schools was quite similar for most level 4 components except for the electrical and mechanical components where the scores were noticeably distinct. Generally, the SLCA scores for openings, main envelope, and finishes were mostly within the low region for all three strata. However, the majority of electrical and mechanical SLCA scores were in the medium and high regions except for new schools’ electrical SLCA scores where the majority were in the low region.

The leading indoor air quality-related level 2 defects presented in Table 3.10 shows that the highest scores were for the appearance of mechanical and electrical elements for all three school strata. This explains the high scores for the mechanical and electrical SLCA components in Figure 3.8. Additionally, scores for the defect “appearance of screens/blinds” for window openings were in the high region for all schools except new schools which was in the low region.

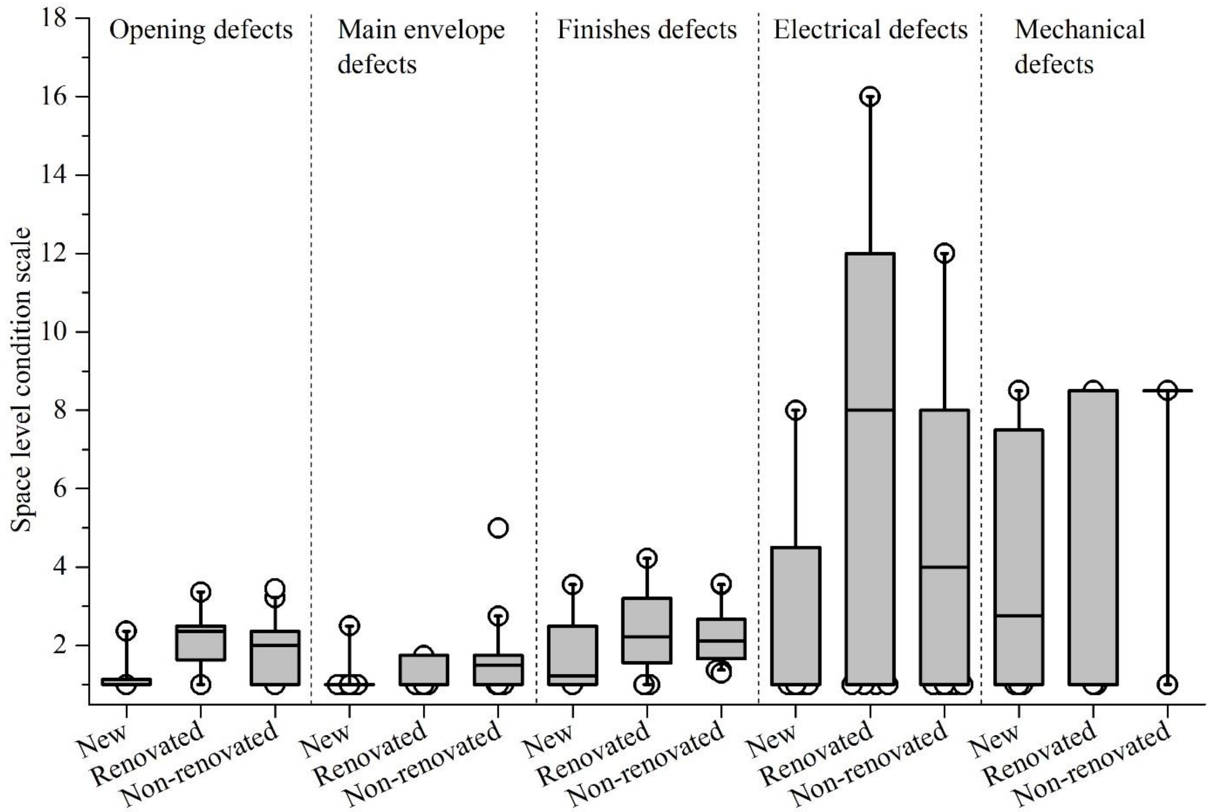

Figure 3.8: Indoor air quality-related SLCA scores for level 4 components

Table 3.10: Leading level 2 SLCA scores for indoor air quality-related defects

School strata	Leve 4 SLCA	Level 2 SLCA	Scores
New	Openings	Appearance of screens/blinds	3.81
	Main envelope	Damaged suspended ceiling	1.56
	Finishes	Painting appearance	4.56
	Electrical	Appearance of luminaires/lamps	2.75
	Mechanical	Appearance of air inlet (diffuser)	6.75
Renovated	Openings	Appearance of screens/blinds	11.07
	Main envelope	Damaged suspended ceiling	2.40
	Finishes	Painting appearance	5.33
	Electrical	Appearance of luminaires/lamps	7.47
	Mechanical	Appearance of air inlet (diffuser)	7.93
Non-renovated	Openings	Appearance of screens/blinds	10.00
	Main envelope	Damaged suspended ceiling	2.76
	Finishes	Ceiling finishes appearance	4.05
	Electrical	Appearance of luminaires/lamps	5.52
	Mechanical	Appearance of air inlet (diffuser)	13.62

The Kruskal-Wallis H test showed statistically significant differences in four indoor air quality-related SLCA components across the three strata of schools. Firstly, the openings SLCA scores between the three schools strata were statistically significantly different $H(2) = 12.14$, $P = 0.002$. Secondly, the main envelope SLCA scores between the three strata of schools were significantly different, $H(2) = 6.35$, $p = 0.042$. Thirdly, the electrical SLCA scores between the three school strata were significantly different, $H(2) = 8.85$, $p = 0.012$. Lastly, the mechanical SLCA scores between the three school strata were significantly different, $H(2) = 11.27$, $p = 0.004$. The post hoc analysis showed firstly statistically significantly lower openings SLCA scores for new schools (mean rank = 16.46) than for non-renovated schools (mean rank = 28.62) ($p = 0.037$) and renovated schools (mean rank = 34.23) ($p = 0.002$). Secondly, main envelope SLCA scores were statistically significantly lower for new schools (mean rank = 19.31) than for non-renovated schools (mean rank = 30.25) ($p = 0.041$) only. Thirdly, the electrical SLCA scores were statistically significantly lower for new schools (mean rank = 18.38) than for renovated schools (mean rank = 33.23) ($p = 0.011$) only. Lastly, the mechanical SLCA scores were found to be statistically significantly lower for new schools (mean rank = 20.25) than for non-renovated schools (mean rank = 34.26) ($p = 0.007$), likewise renovated schools (mean rank = 22.30) and non-renovated schools (mean rank = 34.26) ($p = 0.031$).

Figure 3.9 shows the distributions of CO, CO_2, TVOC, and PM (2.5 and 10) respectively for the new, renovated and non-renovated schools' classrooms and highlights similarities and differences in the range of values. The figure shows how the concentrations of CO, CO_2, and TVOC respectively were within similar ranges across the three strata of schools. CO levels in the three strata of schools were a lot lower than the 90 ppm (15 minutes sampling time) level recommended by the World Health Organization (WHO) (ASHRAE, 2016). The low CO levels were expected given that tobacco smoking was banned in and around the schools. The CO_2 concentration in most of the schools was within the recommended rage of 1000 – 1500 ppm for classrooms (Griffiths & Eftekhari, 2008) and was expected given that all schools were mechanically ventilated and had similar classroom sizes and number of students per class for corresponding grade levels.

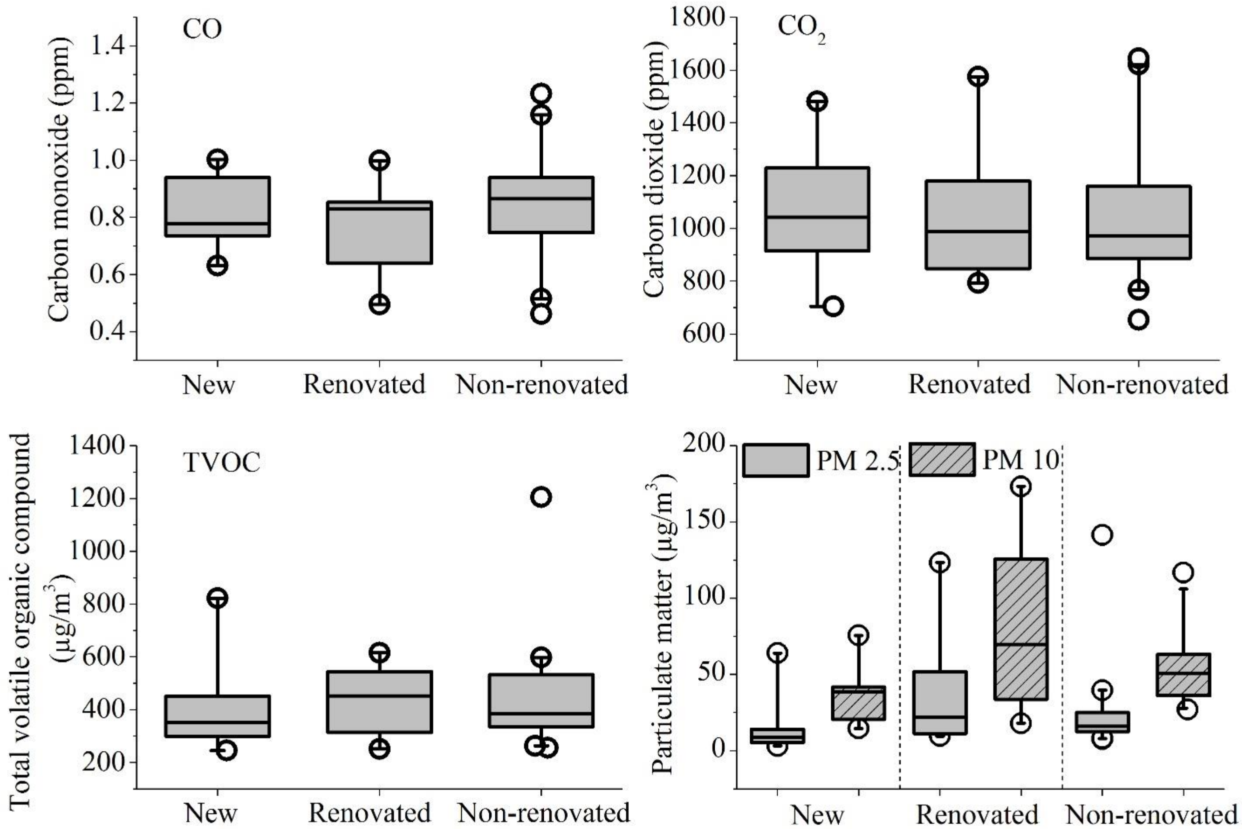

Figure 3.9: Carbon monoxide, carbon dioxide, total volatile organic compound, and particulate matter for new, renovated and non-renovated schools respectively

Although the highest TVOC (i.e. 1205 $\mu g/m^3$) was recorded in non-renovated schools, the concentration of TVOC (Figure 3.9) in most classrooms across the three strata of school were not substantially different. However, TVOC concentrations in most classrooms in all schools were above the range of 200 – 300 μg/m^3 recommended in the literature (Behzadi & Fadeyi, 2012). TVOC concentrations in most of the new schools' classrooms were lower relative to both renovated and non-renovated schools. Figure 3.9 shows PM_{10} and $PM_{2.5}$ concentrations were generally highest in the renovated schools, followed by the non-renovated and new schools respectively in descending order. In the new schools, 94% and 75% of the classrooms were below the WHO recommended concentration limits for $PM_{2.5}$ (i.e. 25 μg/m^3) and PM_{10} (i.e. 50 μg/m^3) (WHO, 2006) respectively. The corresponding percentages for the renovated and non-renovated schools were 60%, 70%, and 71%, 48% respectively for $PM_{2.5}$ and PM_{10}.

The Kruskal-Wallis H test confirmed that $PM_{2.5}$ and PM_{10} were statistically significantly different between the three school strata, $H(2) = 10.95$, $p = 0.004$, and $H(2) = 7.65$, $p = 0.022$ respectively. Post hoc pairwise comparisons showed that $PM_{2.5}$ values were statistically significantly lower for new schools (mean rank = 15.81) than for non-renovated schools (mean rank = 28.50) ($p = 0.028$) and renovated schools (mean rank = 32.29) ($p = 0.006$). For PM_{10}, the values were statistically significantly lower for new schools (mean rank = 17.00) than for renovated schools (mean rank = 30.87) ($p = 0.028$) only.

The association analysis found a weak but statistically significant association between $PM_{2.5}$ and the finishes SLCA scores for non-renovated schools, $r = 0.44$, $p = 0.05$. Finishes defects explained approximately 20% of the observed variance in $PM_{2.5}$ concentrations in non-renovated schools. The concentrations of CO_2 and TVOC were statistically significantly associated with the mechanical SLCA scores in renovated schools. The moderate positive correlations were $r = 0.59$, $p = 0.02$; and $r = 0.55$, $p = 0.04$ for CO_2 and TVOC respectively. These results suggest that mechanical SLCA which included the level 2 item “functioning of air inlets” explained approximately 35% and 30% of the observed variance in CO_2 and TVOC concentrations respectively in renovated schools.

3.5.3 Acoustics-related SLCA and IEQ field measurements

The similarities and differences in the distribution of level 4 SLCA scores related to acoustics in the three strata of schools are presented in Figure 3.10. The figure shows that the scores for the openings and mechanical components are similar across the three strata, while the main envelope and finishes scores varied substantially. The SLCA scores for the mechanical component in each stratum were generally high given that the assessment of the level 1 item “vibration and abnormal heating, ventilation and air-conditioning (HVAC) noise” was either “Yes” (i.e. 16) or “No” (i.e. 1). Figure 3.10 shows that the SLCA scores were relatively lower in most of the new school classrooms for the main envelope and finishes components. Additionally, the main envelope SLCA scores were higher in the renovated schools relative to the non-renovated schools whereas the finishes SLCA scores were higher in the non-renovated than in the renovated schools. Scores of the leading level 2 defects presented in Table 3.11 affirm these observed differences and similarities.

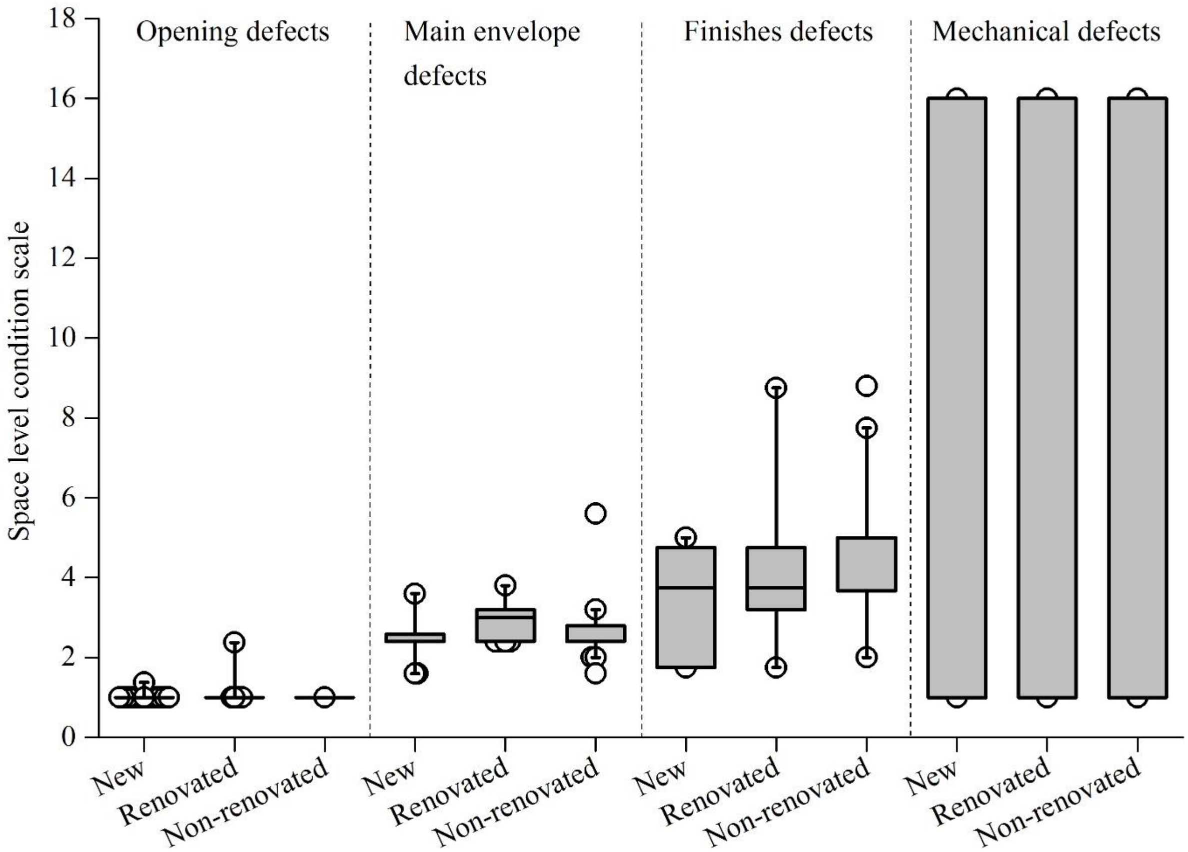

Figure 3.10: Acoustics-related SLCA scores for level 4 components

Table 3.11: Leading level 2 SLCA scores for acoustics-related defects

School strata	SLCA level 4	SLCA level 2	Average scores
New	Openings	Broken/damaged window glass	1.19
	Main envelope	Sound absorbing items – walls (coverage)	7.75
	Finishes	Sound absorbing floor finishes (coverage)	10.00
	Mechanical	Vibration and abnormal HVAC noise	7.56
Renovated	Openings	Mold damage/damp doors	1.73
	Main envelope	Sound absorbing items – walls (coverage)	9.33
	Finishes	Sound absorbing floor finishes (coverage)	11.20
	Mechanical	Vibration and abnormal HVAC noise	5.00
Non-renovated	Main envelope	Sound absorbing items – walls (coverage)	6.67
	Finishes	Sound absorbing floor finishes (coverage)	12.00
	Mechanical	Vibration and abnormal HVAC noise	6.00

The Kruskal-Wallis H test showed that the scores of the main envelope SLCA component between new, renovated, and non-renovated schools were statistically significantly different, $H(2) = 6.94$, $p = 0.031$. Likewise, the differences between the three strata of schools for the scores of the finishes SLCA component were statistically significant, $H(2) = 8.00$, $p = 0.018$. The post hoc pairwise comparisons showed statistically significantly lower main envelope SLCA scores for new schools (mean rank = 21.75) than for renovated schools only (mean rank = 34.07) ($p = 0.048$). Additionally, the post hoc test showed statistically significantly lower finishes SLCA scores for new schools (mean rank = 20.25) than for non-renovated schools only (mean rank = 33.52) ($p = 0.024$). The statistically significant difference in the main envelope SLCA scores between new and renovated schools is attributable to defects including “sound absorbing items - walls” and “damaged internal walls”. Likewise, the statistically significant difference in finishes SLCA scores between new and non-renovated schools is attributable to SLCA defects including “sound absorbing floor finishes” and “sound absorbing ceiling finishes”.

Figure 3.11 depicts the expected similarities in distributions of A and C-weighted background noise across the three strata of schools. Background noise levels were below the recommended maximum thresholds of 35 dB and 55 dB (ASA, 2010) for A and C-weighted respectively across the three strata of schools except for two classrooms in the new schools. Table 3.11 shows that the leading level 2 mechanical SLCA defect, “vibration and abnormal HVAC noise”, was in the medium region across the three strata of schools and was highest in the new schools, thus agreeing with the observed trend of background noise in Figure 3.11.

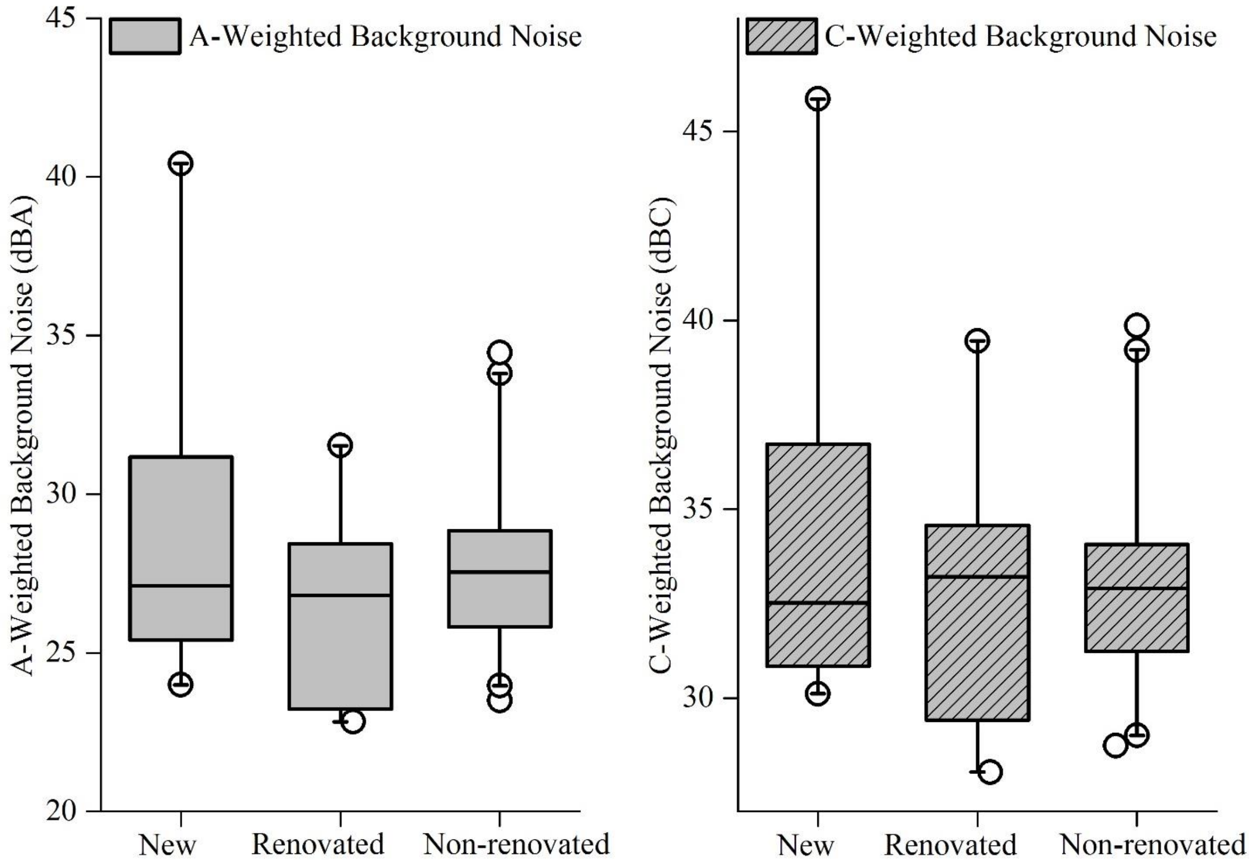

Figure 3.11: A and C-weighted background noise for the three strata of schools

The similarities and differences in distributions of RT60 for three frequencies and ASTC for all three school strata are presented in Figure 3.12. The figure shows higher levels of RT60 at 500 Hz relative to RT60 at 1 KHz and 2 KHz across the three strata of schools. This highlights issues of low frequency noise from indoor sources such as footsteps and HVAC that could lead to occupants' discomfort due to their long decay time. Approximately, 44%, 27% and 37% of new, renovated and non-renovated school classrooms respectively exceeded the maximum threshold of 0.6 seconds for RT60 at 500 Hz for learning spaces with enclosed volume not exceeding 283 m^3 (ASA, 2010). For RT60 at 1 KHz and 2 KHz, the maximum threshold (i.e. 0.6 seconds) was exceeded in 19% and 0% of new; 7% and 7% of renovated; and 37% and 26% of non-renovated school classrooms respectively. Additionally, RT60 at 1 KHz and 2 KHz were generally higher in the non-renovated schools than in the new and renovated schools. For ASTC, Figure 3.12 shows that the ratings were all below the minimum threshold of 50 recommended for walls between adjoining learning spaces (ASA, 2010) except for one classroom in the renovated schools. The ASTC ratings suggest that sound attenuation properties of indoor-to-indoor partition walls in the non-renovated schools did not overly deteriorate relative to the new and renovated schools.

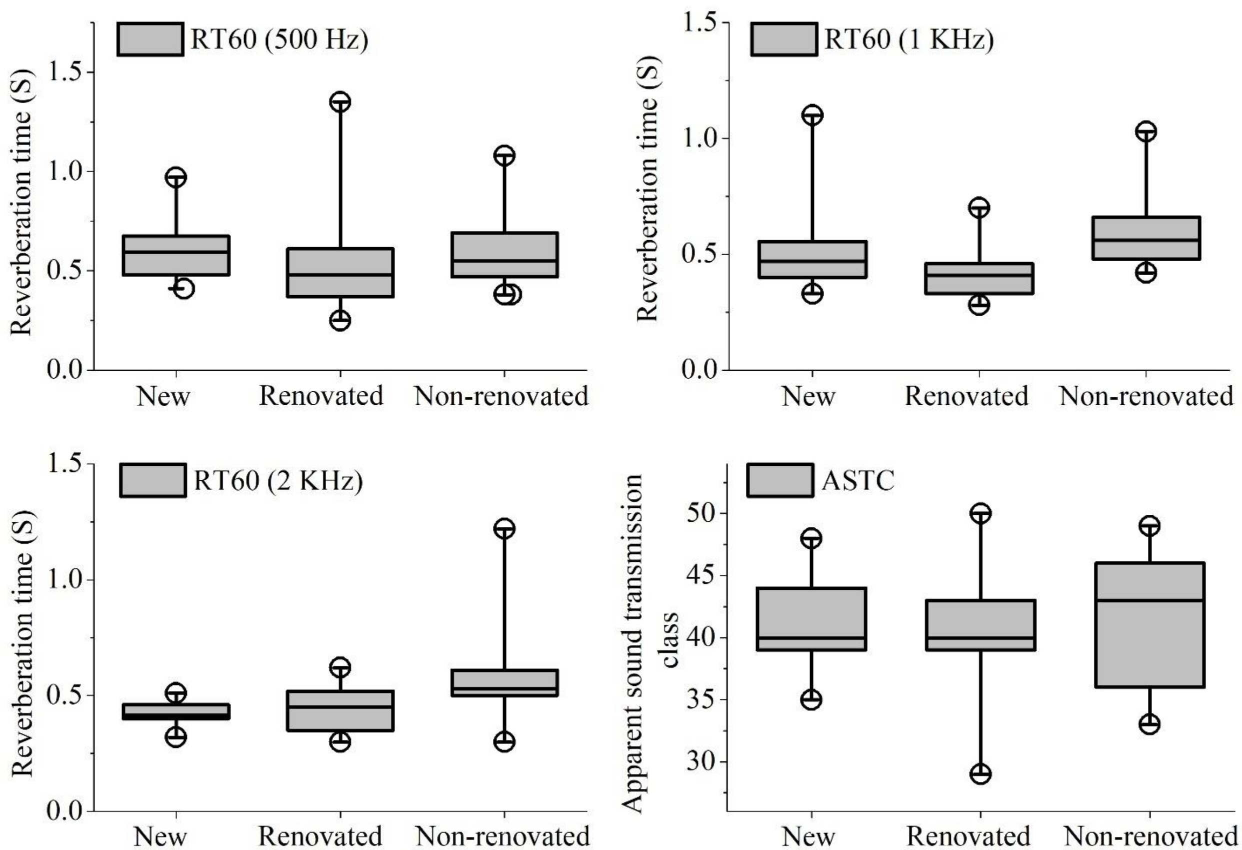

Figure 3.12: Reverberation time and apparent sound transmission class for new, renovated and non-renovated schools

The Kruskal-Wallis H test found statistically significant difference in RT60 at 1 KHz, $H(2) = 15.11$, $p = 0.001$, and in RT60 at 2 KHz, $H(2) = 15.91$, $p = 0.000$ respectively between the three strata of schools. Post hoc pairwise comparisons showed statistically significantly lower RT60 at 1 KHz values for renovated schools (mean rank = 15.33) than for non-renovated schools (mean rank = 34.74) (p = 0.000) only. For RT60 at 2 KHz, the post hoc analysis showed statistically significantly lower values for new schools (mean rank = 16.69) than for non-renovated schools (mean rank = 35.39) (p = 0.000), and for renovated (mean rank = 21.40) than for non-renovated schools (mean rank = 35.39) (p = 0.015). The results suggest that at a high frequency of 2 KHz, the absorption capacity of sound insulation in non-renovated schools were significantly lower than in the new and renovated schools.

The only statistically significant associations between acoustics parameters and related SLCA were between background noise (both A and C-weighted) and the mechanical SLCA scores in all school strata. The significant moderate positive correlations for A-weighted (comparable to C-weighted) were r = 0.661, p = 0.007; r = 0.698, p = 0.004; and r = 0.551, p = 0.010 for new, renovated and non-renovated schools respectively. Hence, the mechanical SLCA component including the level 2 item “vibration and abnormal HVAC noise” explained approximately 44%, 49% and 30% of the observed variance in background noise levels in new, renovated and non-renovated schools respectively.

3.5.4 Lighting-related SLCA and IEQ field measurements

Figure 3.13 highlights the pattern of similarities and differences in lighting-related SLCA scores for level 4 components that are like the others above where the new school stratum was mostly the lowest and the remaining two strata either similar or one exceeding the other. However, the outstanding trend in Figure 3.13 relative to the other SLCA scores is that a substantial proportion of classrooms in both the renovated and non-renovated schools exceeded the low SLCA score region for three out of four components. The leading level 2 SLCA scores shown in Table 3.12 justify the observed pattern of scores for the level 4 components in Figure 3.13.

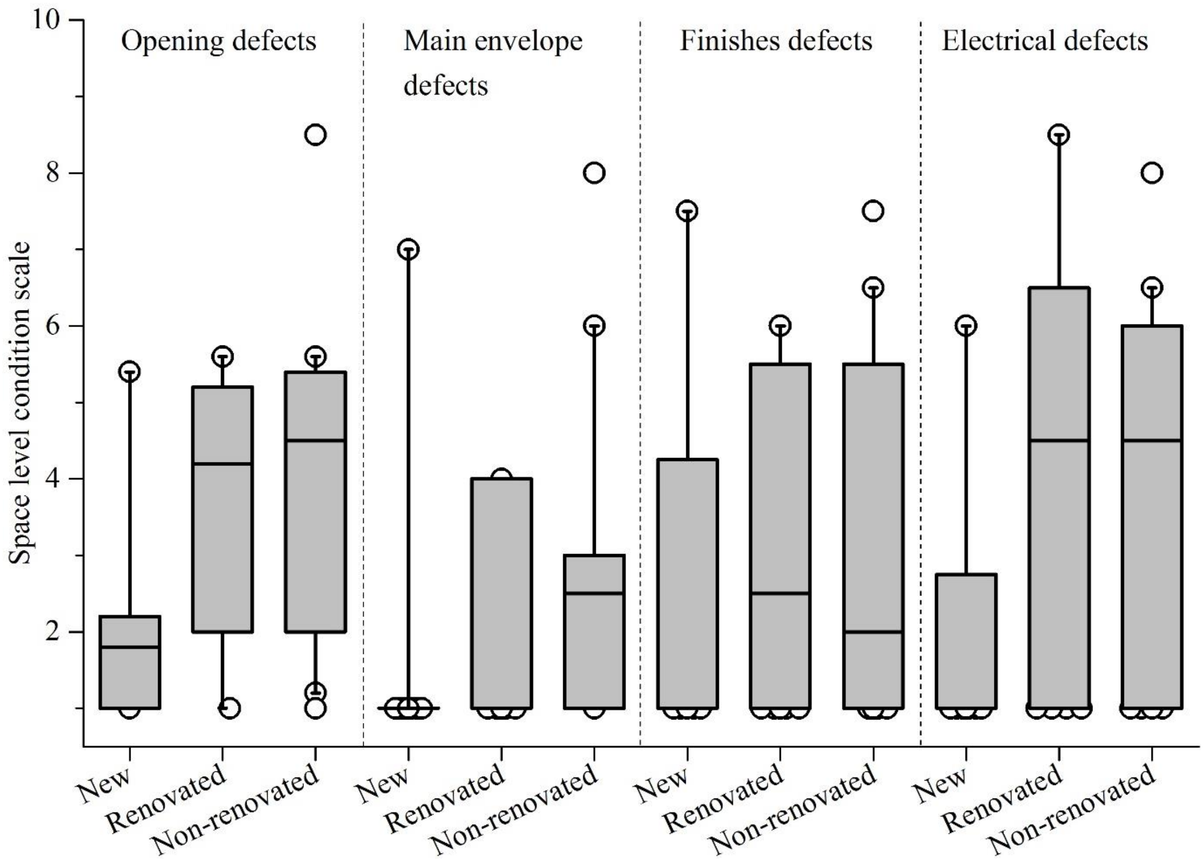

Figure 3.13: Lighting-related SLCA scores for level 4 components

The Kruskal-Wallis H test showed statistically significant differences in two lighting-related SLCA level 4 components. The openings SLCA scores were statistically significantly different between the three schools strata, H(2) = 7.29, p = 0.026. Additionally, the electrical SLCA scores between the three strata of schools were also statistically significantly different, H(2) = 9.53, p = 0.009. Post hoc pairwise comparisons showed statistically significantly lower openings

SLCA scores for new schools (mean rank = 18.06) than for non-renovated schools only (mean rank = 30.67) (p = 0.035). Furthermore, the post hoc test found electrical SLCA scores to be statistically significant lower for new schools (mean rank = 17.53) than for non-renovated schools (mean rank = 29.00) (p = 0.049) and renovated schools (mean rank = 32.57) (p = 0.011). These results affirm the observed substantial difference between new schools on one hand and both renovated and non-renovated on the other for the openings and electrical SLCA scores.

Table 3.12: Leading level 2 SLCA scores for lighting-related defects

School strata	SLCA level 4	SLCA level 2	Average scores
New	Openings	Stained window glazing	4.38
	Main envelope	Damaged suspended ceiling	1.56
	Finishes	Ceiling finishes appearance	2.75
	Electrical	Appearance of luminaires/lamps	2.75
Renovated	Openings	Stained window glazing	5.00
	Main envelope	Damaged suspended ceiling	2.40
	Finishes	Ceiling finishes appearance	3.73
	Electrical	Appearance of luminaires/lamps	7.47
Non-renovated	Openings	Stained window glazing	5.29
	Main envelope	Damaged suspended ceiling	2.76
	Finishes	Ceiling finishes appearance	4.05
	Electrical	Appearance of luminaires/lamps	5.52

Figure 3.14 depicts similarities and differences in the distribution of classrooms' daylight factors values across the three school strata. The figure shows how the daylight factor in most classrooms in all strata was below 2%, the minimum threshold below which artificial lighting would be required indoors (İnan, 2013). Daylight factor was generally higher in new schools relative to both renovated and non-renovated schools, while daylight factor was generally higher in the non-renovated schools relative to the renovated ones. The Kruskal-Wallis H test found no statistically significant differences in daylight factor across the three strata. However, a strong

negative correlation was found between daylight factor and the openings SLCA scores for new schools only, $r = -0.727$, $p = 0.002$. Hence, an increase in openings defects including "stained window glazing" was associated with a decrease in daylight factor and accounted for approximately 52% of the observed variance in new schools' daylight factor scores.

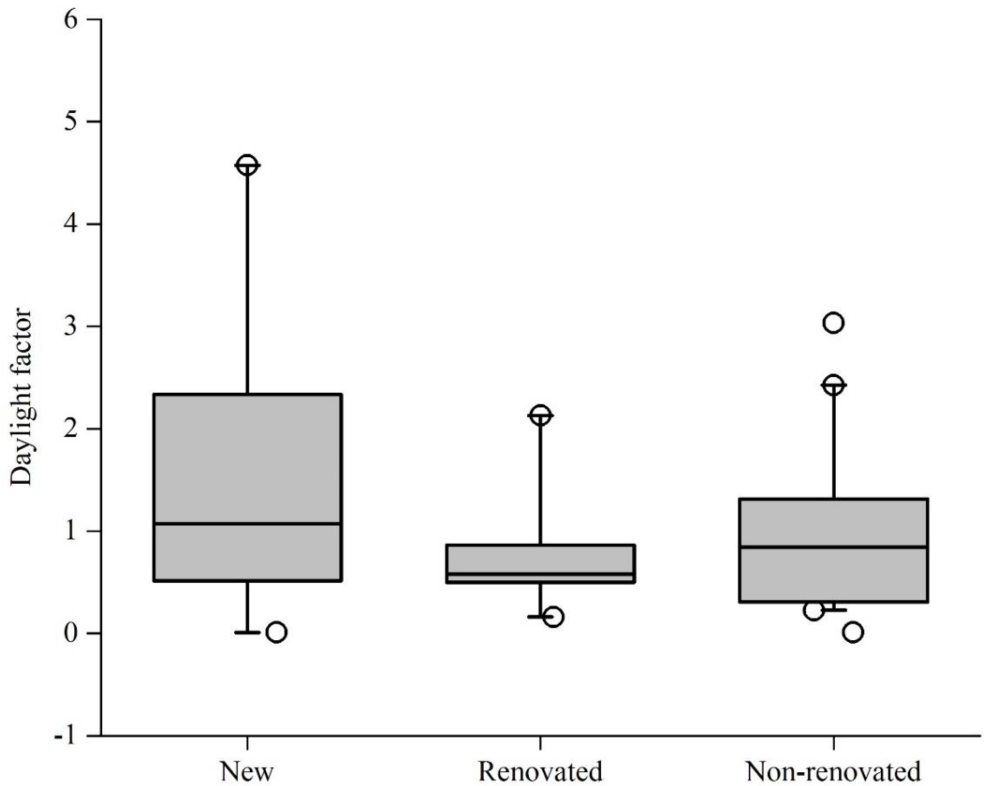

Figure 3.14: Daylight factor for new, renovated and non-renovated schools

3.6 Discussion

The analyses identified several statistically significant differences in SLCA scores across the three strata of schools. Firstly, four statistically significant differences were found between new and renovated schools for level 4 SLCA components related to indoor air quality, acoustics, and lighting. Secondly, eight statistically significant differences were found between new and non-renovated schools for level 4 SLCA components related to thermal comfort, indoor air quality, acoustics, and lighting. Lastly, one statistically significant difference was found between renovated and non-renovated schools for level 4 SLCA components related to indoor air quality. These findings confirmed that the new schools were generally the least defective while the non-renovated schools were the most defective. Additionally, the findings confirmed that the most considerable difference in SLCA scores was between new and non-renovated schools while the least difference was between renovated and non-renovated schools. The findings are logical given that the non-renovated had not experienced substantial upgrades since 2007 to improve their IEQ, thus attesting to the usefulness of the SLCA for IEQ-related BCA.

The renovated and non-renovated schools were each a mix of old and middle age schools constructed to Nation Building Code of Canada versions of 1950 to 1980 (Sadick & Issa, 2017b). The renovated schools, however, had undergone substantial IEQ-related renovations from 2007 to 2014; hence, their SLCA scores were expected to be statistically significantly lower relative to non-renovated schools. However, only one statistically significant difference was found between renovated and non-renovated schools for indoor air quality-related SLCA, where mechanical SLCA scores were statistically significantly higher in the non-renovated schools relative to the renovated schools. The statistically insignificant differences between renovated and non-renovated schools for thermal comfort, acoustics, and lighting-related SLCA scores suggest that those defects were not visibly different. Additionally, the renovated schools were probably the worst prior to their renovations and became like the non-renovated schools after their renovations. The fact that most of the statistically significant differences in SLCA scores were between new and non-renovated schools probably points to the insensitivity of the SLCA to substantial conditional differences that are visibly unapparent.

With respect to the four IEQ factors, the most number (i.e. six) of statistically significant differences for SLCA scores were indoor air quality-related and predominantly related to the mechanical and openings SLCA components. These components respectively include "appearance of air inlet" and "appearance of screens/blinds" as leading defects that are most likely to influence indoor air quality. Furthermore, thermal comfort had one of the least number (i.e. two) of statistically significant differences in related SLCA scores (i.e. main envelope and finishes). The thermal comfort-related SLCA significant differences also include "damaged internal wall" and "damaged ceiling finish" as leading defects which are essential to thermal comfort. These findings also support the SLCA's usefulness for IEQ-related BCA.

Scores for the leading SLCA level 2 defects shows that main envelope scores related to the four IEQ factors across the three school strata were in the low region except for "sound absorbing items – walls" for acoustics-related SLCA. "Sound absorbing items – walls" was included in the main envelope category to accommodate partition walls that doubled as sound absorbers. These low scores suggest that main envelope elements were generally less defective despite the tendency for some main envelope elements like concrete block walls and floors to develop substantial internal cracks that would likely influence dampness, heat transfer, and sound attenuation. The main envelope component of the SLCA does not capture these invisible internal defects; therefore, low main envelope SLCA scores would not necessarily imply low IEQ impact. Additionally, the mechanical component of the SLCA does not capture critical and invisible defects like dampness and mold in ducts that would influence indoor air quality, further highlighting the weakness of the SLCA. This makes the SLCA more suited for visible defects, providing thereby a quick and less costly BCA for strategic school maintenance planning focusing on enhancing IEQ.

IEQ field measurements exhibited a different pattern of statistically significant differences compared to SLCA scores. Unlike the SLCA scores where there was at least one statistically significant difference between pairs of school strata for all four IEQ factors, there was no statistically significant difference between any pair of strata for field measured lighting parameter (i.e. daylight factor). However, like the SLCA results, differences in IEQ field measurements showed that the new schools performed better than the renovated and non-renovated schools, thus agreeing with earlier studies in the literature (Schreuder et al., 2015). Additionally, the IEQ performance of the renovated schools was similar to the non-renovated schools for all four IEQ factors except for acoustics where RT60 at 1 KHz and 2 KHz were statistically significantly higher in the non-renovated schools than in the renovated ones. This finding was less consistent with related studies in literature (e.g. Almeida & de Freitas, 2014) that found statistically significant differences across multiple IEQ factors between renovated and non-renovated schools. However, the finding agrees with differences in SLCA scores between the renovated and non-renovated schools where a statistically significant difference was found for indoor air quality-related SLCA (i.e. mechanical) only. The IEQ of the renovated schools was probably a lot worse than that of the non-renovated ones prior to their renovation. Therefore, the renovations would have thus brought the IEQ of the renovated schools on par with that of the non-renovated schools, thus the lack of a statistically significant difference between the renovated and non-renovated schools.

Tests of associations found theoretically relevant correlations between IEQ-related SLCA scores and IEQ field measurements for all four IEQ factors. The strongest of the statistically significant correlations ($r = 0.86$) was between the main envelope SLCA score and RH for non-renovated schools only. This association is logical given that an increase in SLCA level 1 main envelope defects including "Cracks/Missing units/Holes/Separations though thickness" in walls will likely increase RH, making air temperature feel warmer. Moreover, a substantial increase in RH would lead to dampness indoors, promote mold growth, and influence indoor air quality. The highest statistically significant correlation for indoor air quality ($r = 0.59$) was between CO_2 and the mechanical SLCA score for renovated schools only. The mechanical SLCA component includes the "Functioning of air inlets" through which fresh air is supplied indoors to replace used air and aid ventilation. Hence, the malfunctioning of air inlets would increase CO_2 concentration. For acoustics, background noise statistically significantly correlated with mechanical SLCA in new ($r = 0.66$), renovated ($r = 0.69$), and non-renovated schools ($r = 0.55$) respectively. These correlations suggest that an increase in HVAC noise was associated with a moderate to strong increase in background noise in all schools which is logical given that HVAC noise was the main source of background noise in all schools. A statistically significant strong negative correlation ($r = -0.73$) was found between daylight factor and the openings SLCA category for new schools only given that "stained window glazing" was the leading level 2 SLCA defect in new schools and was in the medium region of the SLCA scale. These statistically significant correlations do not imply causation; however, they offer plausible explanations of how the defective conditions of building elements influence IEQ. Additionally, they justify the need for IEQ-related BCA that goes beyond observing the mere presence or absence of building elements such as operable windows and their usage patterns.

Results of the correlations and variance analyses justify the categorization of SLCA components into thermal comfort, indoor air quality, acoustics, and lighting-related. These IEQ-related categorizations of the SLCA distinguish it from existing BCA instruments including PHAS and BUILDER^{TM}. As a visual inspection instrument, the SLCA should be used in conjunction with other techniques including thermal cameras for detailed building condition assessments. Results of this research, however, support the logic of the SLCA scale whereby higher values will likely translate to adverse IEQ and vice versa.

3.7 Conclusion

This research investigated the usefulness of IEQ-related BCA using the newly developed SLCA in new, renovated and non-renovated schools, attesting to its merits for IEQ-related BCA. The SLCA was developed using a predefined list of defects to minimize ambiguity when interpreting findings and would thus be a useful guide to school divisions when planning and prioritizing IEQ-related maintenance for their schools. Additionally, the SLCA provides building condition information hitherto not obtainable from conventional IEQ field observations and other IEQ data collection methods. The SLCA was developed for schools and particularly classrooms but is easily adaptable for other building and indoor space types. Additionally, the SLCA is not an exhaustive IEQ-related BCA instrument given its focus on visible defects; hence, it is not a substitute for buildings requiring detailed IEQ-related BCA. Routine use of the SLCA preferably along with other IEQ data collection methods would lead to recognizing building condition patterns and to building reliable predictive models with SLCA components as input variables.

The SLCA was used only once in each of the assessed classrooms while IEQ field measurements were snapshot measurements conducted once only; hence, long-term measurements may lead to different conclusions. Consequently, longitudinal studies employing SLCA and IEQ field measurements are needed to validate the findings of this research. The sample of schools and classrooms in this research are relatively small; therefore, studies with larger school samples and classrooms are required to confirm the SLCA's usefulness and produce generalizable findings. Other researchers are invited to use the SLCA to assess its robustness and suggest the required modifications.

3.8 Acknowledgments

The authors are grateful to the Government of Manitoba Public School Finance Board, the two school divisions, and the 32 schools for agreeing to participate in this research and facilitating access to the schools and the data collection. The authors are also grateful to Md Anamul Hasan, Joshua Boateng Akom, and Katia Cavalcanti Parpinelli for their assistance with data collection. This research was funded by a Discovery Grant (RGPIN 418532-2012) from the Natural Sciences and Engineering Research Council of Canada.

3.9 References

Acoustical Society of America. (2010). *Acoustical Performance Criteria, Design Requirements, and Guidelines for Schools, Part 1: Permanent Schools*. (ANSI/ASA S12.60-2010/Part 1). Melville, New York: Acoustical Society of America.

Ahluwalia, S. S. (2008). *A framework for efficient condition assessment of the building infrastructure.* (Ph.D. thesis), University of Waterloo, Waterloo, ON.

Almeida, R. M. S. F., & de Freitas, V. P. (2014). Indoor environmental quality of classrooms in Southern European climate. *Energy and Buildings, 81*, 127-140. doi: 10.1016/j.enbuild.2014.06.020

ASA. (2010). Acoustical performance criteria, design requirements, and guidelines for schools, part 1: permanent schools. Melville, New York: Acoustical Society of America.

ASHRAE. (2004). Thermal Environmental Conditons for Human Occupancy. Atlanta, GA: American Society of Heating, Refrigerating, and Air-Conditioning Engineers.

ASHRAE. (2010). Thermal Environmental Conditons for Human Occupancy. Atlanta: the American Society of Heating, Refrigerating and Air-Conditioning Engineers.

ASHRAE. (2016). Ventilation for acceptable indoor air quality. Atlanta: American Society of Heating, Refrigerating and Air-Conditioning Engineers.

ASTM. (2014). *Standard test method for measurement of airborne sound attenuation between rooms in buildings*. (E336−14). West Conshohocken, PA: American Society for Testing and Materials. Retrieved from http://compass.astm.org.proxy1.lib.umanitoba.ca/download/E336.22070.pdf.

ASTM International. (2008). E2018-08: standard guide for property condition assessments: baseline property condition assessment process. Pennsylvania: ASTM International.

Behzadi, N., & Fadeyi, M. O. (2012). A preliminary study of indoor air quality conditions in Dubai public elementary schools. *Architectural Engineering and Design Management*, *8*(3), 192-213. doi: 10.1080/17452007.2012.683243

Bluyssen, P. M. (2016). Health, comfort and performance of children in classrooms – New directions for research. *Indoor and Built Environment*, 1420326X16661866. doi: 10.1177/1420326X16661866

Brager, G. S., Paliaga, G., & De Dear, R. (2004). *Operable Windows, Personal Control, and Occupant Comfort*. Paper presented at the Ashrae Transactions, Nashville, TN.

Campbell Scientific. (2015). 109-L temperature probe for CR200X-series dataloggers. Retrieved 20 Mrach, 2015, from https://www.campbellsci.ca/109-l-overview

CDC. (2013). Workplace safety and health topics: indoor environmental quality. Retrieved June 4, 2015, from http://www.cdc.gov/niosh/topics/indoorenv/

CERL. (2014). BUILDER® Knowledge-based condition assessment manual for building component-sections (version 3.1.1) (Vol. 2015). Champaign, Illinois: U.S. Army Engineer Research and Development Center.

Creswell, J. W. (2014). *Research design: Qualitative, quantitative, and mixed methods approaches* (4th ed.). Thousand Oaks, California: Sage publications.

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.

Eweda, A., Zayed, T., & Alkass, S. (2013). Space-Based Condition Assessment Model for Buildings: Case Study of Educational Buildings. *Journal of Performance of Constructed Facilities, 29*(1).

Fan, G., Xie, J., Liu, J., & Yoshino, H. (2016). Investigation of indoor environmental quality in urban dwellings with schoolchildren in Beijing, China. *Indoor and Built Environment, 26*(5), 694-716. doi: 10.1177/1420326X16636184

Ghita, S. A., & Catalina, T. (2015). Energy efficiency versus indoor environmental quality in different Romanian countryside schools. *Energy and Buildings, 92*, 140-154.

GrayWolf Sensing Solutions. (2014a). AdvanceSence and DirectSence: indoor air qulaity meters. Retrieved 27 March, 2015, from http://www.wolfsense.com/pdf/GrayWolf-Indoor-Air-Quality-IAQ-Meter-Brochure-lo.pdf

GrayWolf Sensing Solutions. (2014b). PC-3016A: 6 - channel particle counter. Retrieved 29 March, 2015, from http://www.wolfsense.com/pdf/GrayWolf-Particle-Concentration-Counter-Brochure-lo.pdf

Griffiths, M., & Eftekhari, M. (2008). Control of CO2 in a naturally ventilated classroom. *Energy and Buildings, 40*(4), 556-560. doi: http://dx.doi.org/10.1016/j.enbuild.2007.04.013

Hongisto, V., Haapakangas, A., Varjo, J., Helenius, R., & Koskela, H. (2016). Refurbishment of an open-plan office - Environmental and job satisfaction. *Journal of Environmental Psychology, 45*, 176-191. doi: 10.1016/j.jenvp.2015.12.004

HUD. (2012). Public housing assessment system (PHAS): physical condition scoring notice and revised dictionary of deficiency definitions. In Department of Housing and Urban Development (Ed.), (Vol. 2015). Washington: Federal Register.

Huizenga, C., Abbaszadeh, S., Zagreus, L., & Arens, E. (2006). *Air quality and thermal comfort in office buildings: Results of a large indoor environmental quality survey*. Paper presented at the Healthy Buildings: Creating a Healthy Indoor Environment for People, HB 2006, Lisboa.

Inan, T. (2013). An investigation on daylighting performance in educational institutions. *Structural Survey, 31*(2), 121-138.

İnan, T. (2013). An investigation on daylighting performance in educational institutions. *Structural Survey, 31*(2), 121-138. doi: doi:10.1108/02630801311317536

Larson Davis. (2015). Specifications: standards met by model 831. Retrieved 25 March, 2015, from http://www.larsondavis.com/Products/SoundLevelMeters/Model831/Model831Specs.aspx

Li, D., Lau, C., & Lam, J. (2004). Predicting daylight illuminance by computer simulation techniques. *Lighting Research and Technology, 36*(2), 113-128. doi: 10.1191/1365782804li108oa

Newsham, G. R., Birt, B. J., Arsenault, C., Thompson, A. J., Veitch, J. A., Mancini, S., . . . Burns, G. J. (2013). Do 'green'buildings have better indoor environments? New evidence. *Building Research & Information, 41*(4), 415-434.

Noris, F., Adamkiewicz, G., Delp, W. W., Hotchi, T., Russell, M., Singer, B. C., . . . Fisk, W. J. (2013). Indoor environmental quality benefits of apartment energy retrofits. *Building and Environment, 68*, 170-178. doi: 10.1016/j.buildenv.2013.07.003

OTM Solutions. (2015). LP PHOT 01, LP RAD 10, LP PAR 01, LP UVA 01, LP UVB 01, LP UVC 01 photometric/radiametric probes with mV signal output. LP PHOT 01 with RS485 MODBUS-RTU output. Retrieved 31 March, 2015, from http://www.otm.sg/files/LP%20PHOT%2001S.pdf

Sadick, A.-M., & Issa, M. H. (2017b). Differences in teachers' satisfaction with indoor environmental quality and their well-being in new, renovated and non-renovated schools. *Indoor and Built Environment, 0*(0). doi: 10.1177/1420326X17717074

Schreuder, E., van Heel, L., Goedhart, R., Dusseldorp, E., Schraagen, J. M., & Burdorf, A. (2015). Effects of newly designed hospital buildings on staff perceptions: A pre-post study to validate design decisions. *Health Environments Research and Design Journal, 8*(4), 77-97. doi: 10.1177/1937586715573736

Thomsen, K. E., Rose, J., Mørck, O., Jensen, S. Ø., Østergaard, I., Knudsen, H. N., & Bergsøe, N. C. (2016). Energy consumption and indoor climate in a residential building before and after comprehensive energy retrofitting. *Energy and Buildings, 123*, 8-16. doi: http://dx.doi.org/10.1016/j.enbuild.2016.04.049

U.S. EPA. (2003). A standardized EPA protocol for characterizing indoor environmental quality Retrived from http://www.epa.gov/iaq/base/pdfs/2003_base_protocol.pdf

Wells, E. M., Berges, M., Metcalf, M., Kinsella, A., Foreman, K., Dearborn, D. G., & Greenberg, S. (2015). Indoor air quality and occupant comfort in homes with deep versus conventional energy efficiency renovations. *Building and Environment, 93, Part 2*, 331-338. doi: http://dx.doi.org/10.1016/j.buildenv.2015.06.021

WHO. (2006). *WHO Air quality guidelines for particulate matter, ozone, nitrogen dioxide and sulfur dioxide: Global update 2005 summary of risk assessment*. Geneva: World Health Organization

Zinzi, M., Agnoli, S., Battistini, G., & Bernabini, G. (2016). Deep energy retrofit of the TM Plauto School in Italy—A five years experience. *Energy and Buildings*, *126*, 239-251.

Connecting Section

The previous chapter, chapter 3, focused on the potential impact of the physical conditions of space enclosing elements like walls and windows on IEQ of classrooms. Based on the analyses of data from new, renovated, and non-renovated schools, the chapter concluded that the SLCA developed in this research was useful for IEQ-related BCA in schools. Additionally, the results supported the thesis that physical conditions of space enclosing elements are likely to substantially influence IEQ, thus justifying the need for IEQ-related BCA. Chapter 3, therefore, addressed objective one of this thesis.

The impact of the physical conditions of space enclosing elements on IEQ parameters like air temperature and particulate matter would likely translate to either a positive or negative impact on occupants' IEQ satisfaction and well-being. Chapter 2 suggested that occupants' IEQ satisfaction and well-being were not the same concepts. The next chapter, chapter 4, therefore focused on determining the extent to which IEQ satisfaction factors (i.e. ventilation and thermal comfort, lighting, and acoustics and privacy) are direct measures of occupants' well-being (i.e. psychological, social, and physical). This assessment was based on an adapted IEQ satisfaction survey and newly developed well-being surveys for teachers in school context. Chapter 4, therefore, addresses objective 2 of this thesis and contributed to determining the impact of the physical conditions of school building elements on IEQ parameters and subsequently on teachers' IEQ satisfaction and well-being in chapter 6.

CHAPTER 4: Occupants' Indoor Environmental Quality Satisfaction Factors as Measures of School Teachers' Well-Being

A version of this chapter was published in the "Building and Environment" Journal.

Sadick, A.-M., & Issa, M. H. (2017). Occupants' indoor environmental quality satisfaction factors as measures of school teachers' well-being. Building and Environment, 119, 99-109. doi: https://doi.org/10.1016/j.buildenv.2017.03.045

The first author was responsible for the conception and design of the work, the data collection, data analysis and the drafting of the journal paper. The second author supervised the work and critically revised the paper.

4.1 Abstract

Most studies that investigated the impact of buildings' indoor environmental quality focused on office buildings, with those studying schools focusing on the impact on students' well-being rather than teachers'. Additionally, most of these studies limited their assessment of well-being to occupants' satisfaction with indoor environmental quality factors (e.g. thermal comfort and lighting), overlooking essential aspects related to psychological, social, and physical well-being. This paper presents results of a study conducted in 32 schools in Manitoba, Canada, to investigate the extent to which occupants' indoor environmental quality satisfaction factors can be used as measures of teachers' psychological, social, and physical well-being. The study involved adapting, deploying, and refining an existing indoor environmental quality satisfaction survey; and developing, deploying, refining, and validating three new surveys to evaluate teachers' psychological, social, and physical well-being in schools. Three existing validated well-being surveys in the literature for assessing generic psychological, social, and physical well-being were also deployed with the other surveys to teachers in the 32 schools. The association analyses between these different surveys found ventilation and thermal comfort to be the most significant measure of teachers' physical well-being with moderately positive correlations, while lighting and acoustics and privacy were insignificant measures of well-being, thus reinforcing the need to distinguish between occupants' indoor environmental quality satisfaction and their well-being in future research. The newly developed well-being surveys include some factors not found in the existing generic well-being surveys and are therefore likely to produce the most representative assessment of teachers' well-being for detailed indoor environmental quality impact investigation.

Keywords: indoor environmental quality, occupant satisfaction, occupant well-being, school buildings, teachers' well-being

4.2 Introduction

There is compelling evidence in the literature supporting the premise that improving buildings' IEQ is likely to have a positive impact on occupants' well-being (Agha-Hossein et al., 2013; Kim & De Dear, 2012; Sisask et al., 2013). Despite this evidence, most studies (e.g. de Korte et al., 2015; Maula et al., 2016; Newsham et al., 2013) that investigated the impact of IEQ on occupants focused on office buildings. Relatively, fewer studies focused on schools, with most of them (e.g. De Giuli, Pontarollo, De Carli, & Di Bella, 2014; Issa et al., 2011; Noullett et al., 2010) investigating the impact of schools' IEQ on students' performance and well-being rather than teachers' (Kielb et al., 2015). The few that explored the impact on teachers' well-being (e.g. Buckley et al., 2005; Kielb et al., 2015; Sisask et al., 2013) linked improved IEQ to improved teachers' well-being. Another limitation of most existing IEQ studies (e.g. Bluyssen et al., 2011a; Turunen et al., 2014; Vieira et al., 2016) is their restriction of the definition of well-being to occupants' IEQ satisfaction, ignoring other essential subdivisions of personal well-being such as psychological, social, and physical (Dodge et al., 2012). There is also little empirical evidence on the extent to which IEQ satisfaction factors such as thermal comfort and lighting measure occupants' psychological, social, and physical well-being, particularly teachers'. Most of the predominant well-being measures found in the social science literature are not for specific life domains (Dagenais-Desmarais & Savoie, 2012). They are context-free and thus likely to exclude well-being manifestations that are unique to teachers in school environments.

This study is part of a broader one conducted in collaboration with the Government of Manitoba Public School Finance Board and two Manitoba school divisions with the overall goal of assessing the impact of schools' physical and IEQ conditions on teachers' well-being. The main goal of this specific study, however, was to assess the extent to which existing occupants' IEQ satisfaction measures can be used to assess teachers' psychological, social, and physical well-being in school environments. Specific objectives included adapting, deploying, and refining an existing IEQ survey to evaluate teachers' IEQ satisfaction in schools; developing, deploying, refining, and validating three new surveys to assess teachers' psychological, social, and physical well-being in school respectively; and determining the extent to which the refined IEQ survey assessed teachers' well-being. Refining the IEQ and well-being surveys entailed determining the most significant items required to assess teachers' IEQ satisfaction and well-being respectively in school environments. Validating the new well-being surveys involved deploying three existing validated context-free well-being surveys for psychological, social, and physical well-being and investigating the associations between the new and existing surveys. The newly developed and validated teachers' well-being surveys addressed the weakness of the existing context-free well-being surveys given that they include several manifestations of well-being that are unique to teachers in school environments. Determining the extent to which IEQ factors assessed teachers' well-being involved investigating the associations of the refined IEQ satisfaction factors with the newly developed and validated teachers' well-being surveys and the existing validated well-being surveys respectively. This chapter addresses objective two of this research presented in chapter 1.

4.3 Background information

This section summarizes the literature review conducted for this study and starts with a definition of IEQ followed by a review of the impact of IEQ on building occupants. Furthermore, the concept of well-being as it pertains to the IEQ and social science literature is discussed in addition to the instruments used to measure well-being.

4.3.1 Indoor environmental quality and its impact on building occupants

The Center for Disease Control and Prevention (CDC) (2013a) defined IEQ as "the quality of a building's environment in relation to the health and well-being of those who occupy space within it". Most studies that investigated the impact of IEQ on occupants focused on office buildings and in line with the CDC definition, some of them (e.g. Fang, Wyon, Clausen, & Fanger, 2004; Witterseh et al., 2004) investigated the impact on occupants' health. For example, Witterseh et al. (2004) found that several sick building syndrome symptoms including headache, throat and eye irritation worsened with increasing indoor air temperature. Several studies (e.g. Djukanovic, Wargocki, & Fanger, 2002b; Kamaruzzaman, Egbu, Zawawi, Ali, & Che-Ani, 2011; Nicol et al., 2006) also investigated the impact of office buildings' IEQ on employee's performance. A desktop study (Djukanovic et al., 2002b) simulated office tasks such as reading, typing, and addition to assess performance. It predicted that if indoor air quality was improved such that only 10% of office workers were dissatisfied, the annual increase in productivity would be 10 times that of the required increase in energy and maintenance costs. de Korte et al. (2015) studied the impact of pre-set radiant heat on office tasks using the dual visual memory task consisting of a reading task followed by a computer task and found no significant impact on the performance of those tasks. In a more recent study, Maula et al. (2016) investigated the impact of slightly warmer temperature (i.e. 29^{o}C) on work performance in a mock open-plan office and found a negative effect on working memory. These studies relied on measures of cognitive performance as a proxy to assess the performance of office workers due to the difficulty of measuring that performance in real time. Others (e.g. Feige, Wallbaum, Janser, & Windlinger, 2013; Singh, Syal, Grady, & Korkmaz, 2010) investigated the impact of IEQ on self-assessed productivity of office workers, raising concerns about the objectivity of that assessment as self-assessed productivity is likely to be exaggerated.

Most of the IEQ studies in schools (e.g. Bakó-Biró et al., 2012; Issa et al., 2011; Kielb et al., 2015) focused on students rather than teachers (Kielb et al., 2015). Issa et al. (2011) noticed decreased absenteeism and increased student performance in green schools compared to conventional and energy-retrofitted schools. Both Sörqvist (2010) and Boman (2004) found a negative effect on student learning resulting from intelligible speech. Tanner (2008) showed a positive relationship between daylighting and students' academic achievement. For teachers, Madureira et al. (2009) found a significant association between the concentration of indoor air pollutants (e.g. CO_2 and TVOC) and the prevalence of fatigue, headaches, and thinking difficulties. More recently, Kielb et al. (2015) found a significant association between the prevalence of asthma among teachers and indoor air quality problems such as mold and dust.

4.3.2 Well-being in the IEQ literature

In the IEQ literature, the concept of occupant well-being is not explicitly defined. Occupant well-being, often termed occupant comfort or satisfaction usually refers to satisfaction with the four main IEQ factors namely indoor air quality, thermal comfort, acoustics, and lighting (Bluyssen et al., 2011a; Bluyssen et al., 2011b; Turunen et al., 2014; Vieira et al., 2016) and is generally assessed using questionnaire surveys. Several IEQ satisfaction surveys have been developed including the Center for the Built Environment (CBE) IEQ survey (Zagreus, Huizenga, Arens, & Lehrer, 2004), the Health Optimization Protocol for Energy-efficient Buildings (HOPE) survey (Building Research Establishment, 2002), the Building Use Studies (BUS) survey (Brown, 2009), the Building In Use (BIU) survey (Preiser & Vischer, 2006), Building Occupants Survey System Australia (BOSSA) (Kim et al., 2016), and the National Research Council Canada (NRC) environmental feature ratings (Veitch, Charles, Farley, & Newsham, 2007). The wording of questions for specific IEQ factors in the different surveys varies, however, they are not conceptually divergent. For example, the CBE survey include the thermal comfort question "How satisfied are you with temperature in your workspace?" (Huizenga et al., 2006, p. 393), while the HOPE and BOSSA surveys respectively include "How would you describe typical working conditions in the office …Temperature in winter" (Building Research Establishment, 2002, p. 4), and "Please rate your satisfaction with the temperature conditions of your normal work area…?" (Kim et al., 2016, p. 205).

Bluyssen et al. (2011a) studied IEQ satisfaction using 5,732 office building respondents from the HOPE survey database and concluded that occupants' well-being cannot be limited to their satisfaction with IEQ factors. Additionally, the environmental comfort model proposed by Vischer (2007a) reached a similar conclusion, with the model defining occupants' comfort as a function of physical, functional, and psychological comfort and not just occupants' satisfaction with IEQ factors. Some of the IEQ surveys include items that assess occupants' personal well-being beyond IEQ satisfaction. The BOSSA survey has an item for assessing the impact of work environment on occupants general health (Kim et al., 2016). The BUS survey also includes three items respectively for assessing general health, overall well-being, and stress levels with respect to indoor work environments (Brown, 2009). However, these well-being assessments are less detailed and will provide a limited assessment of occupants' well-being. The HOPE survey includes a whole section on personal well-being; however, the items are focused mainly on sick building syndromes and their frequencies (Building Research Establishment, 2002). Only a few IEQ studies (e.g. Aries et al., 2010; Newsham et al., 2013; Schreuder et al., 2015) explored occupants' well-being using surveys from the social sciences; however, these studies focused on offices. Newsham et al. (2013) found that respondents of green office buildings experienced more positive feelings relative to those of conventional office buildings. Additionally, Schreuder et al. (2015) found a significant positive change in the well-being of respondents who moved from old office buildings to new ones with superior IEQ. Only Aries et al. (2010) investigated the relationship between occupants' IEQ satisfaction and their well-being using surveys from the social sciences and found a significant association between view quality and physical and psychological comfort. These results reinforce the need for research focused on how IEQ satisfaction relates to or assesses occupants' psychological, social, and physical well-being to address the limited empirical evidence on this topic, particularly for school teachers.

4.3.3 Well-being in the social science literature

The World Health Organization (WHO) defines health as "a state of complete physical, mental and social well-being and not merely the absence of disease or infirmity" (Capio et al., 2014). Dodge et al. (2012, p. 230) saw individual well-being as "the balance point between an individual's resource pool (i.e. psychological, social, and physical) and the challenges faced (i.e. psychological, social, and physical)". For building occupants, the balance can be disturbed by adverse indoor environmental conditions (Aries et al., 2010; La Placa et al., 2013). Review of the predominant well-being measures in the social sciences confirms Bluyssen et al. (2011a) assertion that occupants' well-being cannot be limited to IEQ satisfaction. For example, Ryff's Scale of Psychological Well-Being includes the factors "positive relations with others" and "environmental mastery" (Ryff, 1989, p. 1072). Additionally, Keyes' Five Factors Social Well-being Model includes the factors "social integration" and "social contribution" (Keyes, 1998, pp. 138,139). Furthermore, the RAND-36 survey's physical well-being segment includes the factors "physical functioning" and "energy/fatigue" (Hays & Morales, 2001, P. 357). These factors of personal well-being are essential to the well-being of all building occupants, including school teachers, thus calling into question the extent to which IEQ satisfaction factors assess occupants' well-being. Most of the well-being measures found in the social sciences are composed of generic assessment items (i.e. context-free), thus, making them applicable to different life domains such as home, school, and offices. However, the complex social web in school where teachers are engaged in nurturing the academic and social development of students in collaboration with their colleagues and superiors is distinct from the context of homes and offices. Hence, the context-free well-being measures in the literature may include items relevant to teachers in school but will also exclude items unique to school environments and as such may not adequately capture teachers' well-being.

4.4 Methods

This research was conducted in two school divisions in the province of Manitoba (Canada) with a total of 32 schools and 852 teachers. The schools were composed of new, renovated, and non-renovated schools with start dates of operation ranging from 1950 to 2012. Most of the schools were constructed with concrete block walls while others were a mix of concrete block walls and drywall partitions. The schools were all mechanically ventilated; however, some of the old schools had no operable windows. Table 4.1 presents average values of IEQ physical measurement data from 52 classrooms in a sample of 10 schools. The table presents a general view of the IEQ conditions of classrooms in most of the 32 schools.

Table 4.1: Average values of selected IEQ parameters for a sample of 10 schools

IEQ parameters	Mean	Standard deviation
Carbon dioxide	1089.19	251.65
Relative humidity	26.35	6.62
Air temperature	22.08	0.99
Background noise dB (A)	28.22	3.85
Reverberation time (RT60 at 1KHz)	0.53	0.18
Daylight factor	1.16	1.01

This research adopted an exploratory sequential mixed-method design that started with qualitative data collection and analysis (i.e. stage one) followed by quantitative data collection and analysis (stage two) (Creswell, 2014). Figure 4.1 shows the two-stage process related to the development of the teachers' IEQ satisfaction and well-being surveys only.

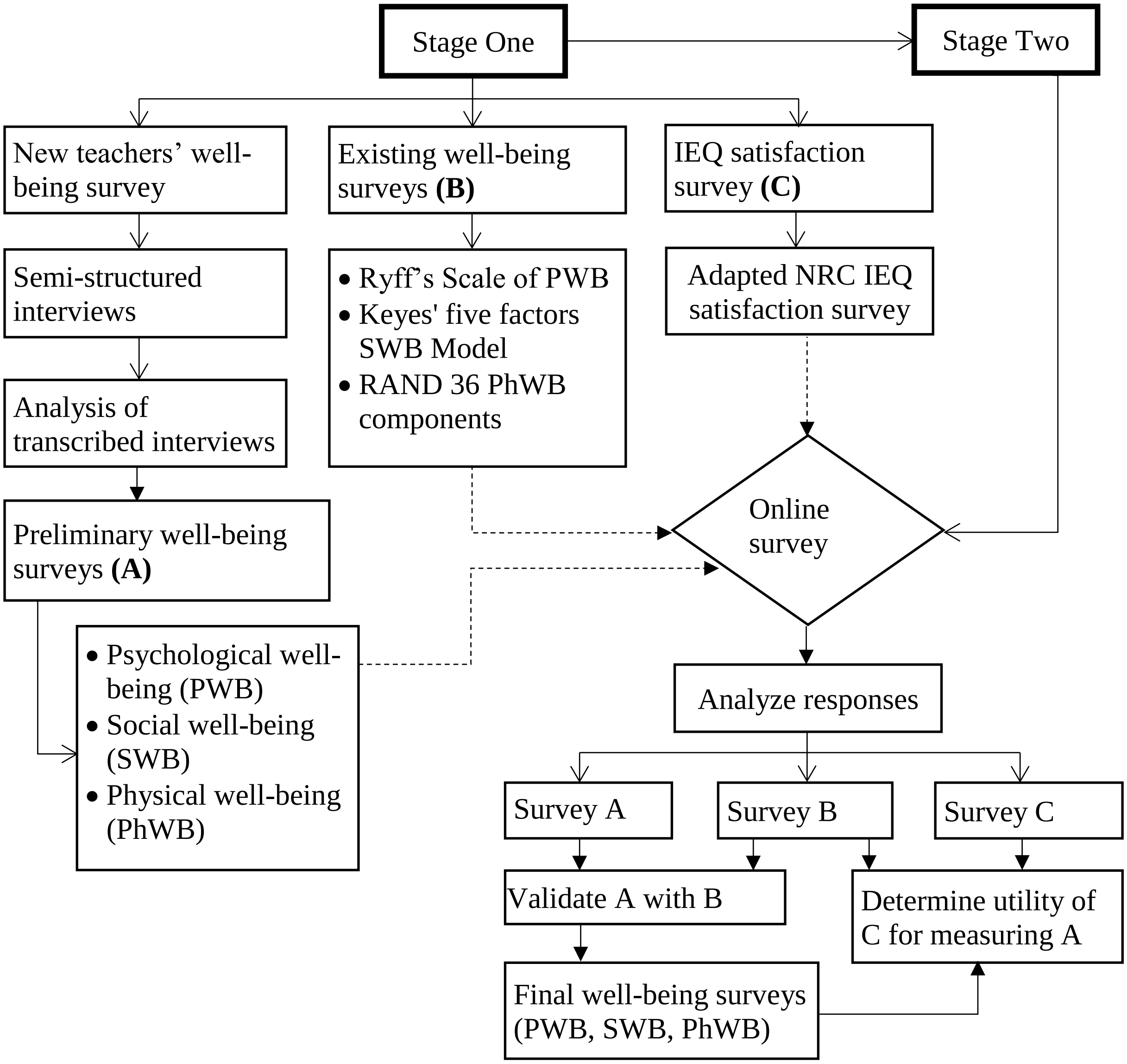

Figure 4.1: Outline of two stage research methodology

4.4.1 Stage one

This subsection presents the sampling, data collection, and data analyses method employed for adapting the exiting IEQ satisfaction survey and developing the preliminary well-being surveys. This stage was approved by the University of Manitoba Research Ethics Board as evidenced by the certificate in appendix B.

4.4.1.1 Sampling

Purposeful sampling was employed in selecting teachers for the semi-structured interviewed conducted that resulted in the preliminary well-being surveys. Unlike theoretical sampling that is driven by emerging theoretical concepts, purposeful sampling is more pragmatic (Emmel, 2013). Purposeful sampling involves the use of multiple sampling strategies together to identify information-rich cases that will contribute to the understanding of a social concept (Emmel, 2013). Two purposeful sampling strategies were used in this research. Quota sampling (Emmel, 2013) was used to ensure that the number of teachers selected for the semi-structured interviews was reflective of the number of teachers in the respective divisions. Furthermore, the concept of maximum variation (Emmel, 2013) was employed to ensure a varied interview sample in terms of gender, years of teaching experience, and school grade levels.

Qualitative studies generally have smaller sample sizes than quantitative studies. Contrary to quantitative sampling that has strict requirements for determining sample size, qualitative sampling seeks to identify participants whose account will enhance the richness of the data; hence, less could be more (Emmel, 2013). There are no explicit procedures for deciding sample sizes for qualitative studies; these are usually recommended for the different types of studies. These recommendations are not strict and can, therefore, vary from one study to the other. Theoretical saturation is probably the best criterion for deciding when to stop data collection in a qualitative study. Theoretical saturation occurs when additional data does not provide new perspectives on the concept in question. Guest, Bunce, and Johnson (2006) used semi-structured interviews with 60 participants and noted that they made most code changes after analyzing 12 of these interviews only, suggesting that a sample size of 12 may be appropriate for qualitative research using semi-structured interviews. However, the study sample was quite homogeneous; hence, contextual issues may increase the size beyond 12. Dagenais-Desmarais and Savoie (2012) used a sample of 20 participants to explore the well-being of office workers. Emmel (2013) argued that qualitative researchers must decide on their sample size before, during, and after data collection based on practicality and resource availability. Therefore, a sample of 20 teachers was used for the qualitative stage in this research. Invitation emails shown in Appendix C were sent to all the teachers in the 32 schools to voluntarily participate in these interviews. Of the 25 positive responses, 20 were selected based on school grade levels, years of teaching experience, gender, and age to attain sample variation. The 20 interview participants were from 10 of the 32 schools.

4.4.1.2 Data collection

For teachers' IEQ satisfaction, the NRC's environmental features rating survey (Newsham et al., 2013) developed for office building occupants was adapted for teachers' in schools. The NRC survey was adapted for this study due to its Canadian context.

Semi-structured interviews were conducted to identify the manifestations of teachers' psychological, social, and physical well-being in school environments and subsequently used to develop the new preliminary well-being surveys (Dagenais-Desmarais & Savoie, 2012). This interview type is a middle ground between unstructured and structured interviews (Galletta, 2012). Researchers develop a number of open-ended questions to guide the interview and add to them by asking follow-up questions to gain a deeper understanding of the concepts being studied (Galletta, 2012). This is similar to the study by Dagenais-Desmarais and Savoie (2012) who used semi-structured interviews to develop the model of PWB at work. The open-ended questions presented in Appendix D were divided into three sections as follows: psychological well-being, social well-being, and physical well-being. For each section, predefined open-ended questions based on literature (Massé et al., 1998) were used to identify the relevant manifestations of personal well-being, while follow-up questions explored the manifestations most likely to influence the work of teachers in their classrooms. As seen in Appendix D, questions in sections 1 and 2 explored respondents' understanding of PWB and SWB respectively, as well as recent incidents over the last four weeks where respondents experienced PWB and SWB. Section 3 explored respondents' PhWB, referencing their physical activities in school. The predefined questions were approved by the University of Manitoba Research Ethics Board. The interviews were conducted one-on-one privately in the respondents' schools. Each interview was audio recorded and ranged from 30 minutes to one hour. Respondents were required to read and sign the informed consent form shown in appendix E before the start of their interview. In addition, respondents completed the demographic information questionnaire in appendix F. Three existing validated well-being surveys namely the Ryff 's scale of psychological well-being (Ryff, 1989), the Keyes' five-factor social well-being model (Keyes, 1998), and RAND 36 physical well-being components (Hays & Morales, 2001) were identified for validating the new teachers' well-being surveys. Each validation survey represents the predominant instrument used for the respective subdivision of well-being. Details of the validation surveys are given in chapter 2.

4.4.1.3 Analysis

The wording of the 18 items in the NRC survey was modified to suit the context of school teachers. The item "Amount of lighting on the desktop" (Newsham et al., 2012a, p. 20, p. 20) was replaced with two items: "Amount of daylight in your classroom" and "Amount of electric light in your classroom"' thus increasing the number of items by one. The 19 items adapted IEQ satisfaction survey is presented in Appendix G.

Following examples (Dagenais-Desmarais & Savoie, 2012; Massé et al., 1998) in the literature, the well-being interview data were analyzed using a mix of content analysis and grounded theory analytical strategies as shown in Figure 4.2. Data fragments (base codes) representing manifestations of well-being were extracted and assigned descriptive labels related to the well-being subdivision of interest. About 75% of the base codes emerged from the first 10 interviews. The base codes for psychological, social, and physical well-being were respectively integrated to form categories. Constant comparative analysis was conducted within and between categories to identify similarities and differences for the creation of subcategories. The subcategories represented the different dimensions of well-being manifestations for the three subdivisions of personal well-being. The number of well-being manifestations included in the preliminary well-being surveys was based on a number of recommendations (Massé et al., 1998) including the number of respondents who reported a specific manifestation and the ability of a manifestation to capture the meaning of other manifestations. All non-school related well-being manifestations were omitted. The preliminary teachers' psychological (TPWB), social (TSWB), and physical well-being (TPhWB) surveys included 34, 32, and 24 assessment items respectively as shown in Appendix H. The interview transcripts were analyzed using the QSR Nvivo version 10 software. The factors that influence human concepts like well-being vary and are not universally uniform. For example, factors that affect teachers' well-being in schools would most likely be different from those that affect office workers. Therefore, by basing the items making up the preliminary well-being measures on the experiences of teachers in schools, the chances of producing content valid final well-being measures increased.

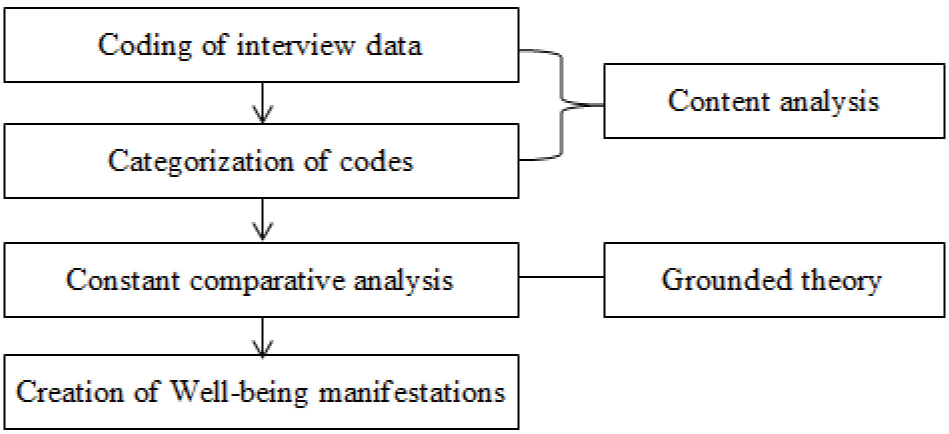

Figure 4.2: Development of Preliminary Well-Being Surveys

4.4.2 Stage two

This subsection presents the sampling and data collection methods employed during the deployment of the adapted IEQ satisfaction survey and the well-being surveys developed in stage one. It also describes the data analyses methods in refining and validating the surveys developed in stage one. This second stage was approved by the University of Manitoba Research Ethics Board as evidenced by the certificate in appendix I.

4.4.2.1 Sampling

Given that the total number of teachers in the two school divisions that participated in this study was 852, a sample of 260 respondents was required for a 95% confidence level and 5% margin of error(Dessel, 2013). Hence, a sample of 300 was targeted for this study. Considering that the average response rate for online surveys is about 25% (Shih & Fan, 2008), the survey was administered to all teachers in the 32 schools in the two divisions. Appendix J shows the invitation email sent to the schools.

4.4.2.2 Data collection

Stage two involved administering an online survey composed of the adapted IEQ satisfaction survey (survey C), the three preliminary well-being surveys (survey A), and the three existing well-being surveys (survey B) presented in chapter 2. All three surveys were administered together and only once to all teachers in the two participating school divisions and were divided into four modules as shown in Table 4.2. The preamble to the 19 items adapted IEQ satisfaction survey was “For each of the following, please select the appropriate checkbox that best expresses your level of satisfaction with the…”. The assessment was based on a seven-point scale from “Very Unsatisfactory” (- 3) to “Very Satisfactory” (+ 3) adopted from the NRC survey. The adapted IEQ satisfaction survey is presented in Appendix G.

Table 4.2: Online survey components

Modules	Name	Content
Module 1	Environmental Feature Rating	• NRC’s environmental features rating (adapted) (Veitch et al., 2007) • Demographic information
Module 2	Psychological Well-being	• Preliminary TPWB survey • Ryff ‘s scale of psychological well-being (Ryff, 1989)
Module 3	Social Well-being	• Preliminary TSWB survey • Keyes’ five-factor social well-being model (Keyes, 1998)
Module 4	Physical Well-being	• Preliminary TPhWB survey • RAND 36 physical well-being components (Hays & Morales, 2001)

Each of the three preliminary well-being surveys assessed one subdivision of teachers' well-being as shown in Table 4.2. The preceding preamble to the assessment items was: "For each statement below, indicate which answer best describes your present agreement or disagreement with each statement" (Clarke, Marshall, Ryff, & Wheaton, 2001, p. 90). In line with the predominant well-being measures in the literature, these items were assessed on a six-point scale from "Strongly Disagree" (1) to "Strongly Agree" (6). The three preliminary well-being surveys are presented in appendix H. Three existing validated well-being surveys in the literature were used to validate the newly developed TPWB, TSWB, and TPhWB surveys. These included Ryff's scale of psychological well-being (Clarke et al., 2001), Keyes' five factors social well-being model (Keyes, 1998), and RAND 36 physical well-being components (Hays et al., 1994; Hays & Morales, 2001).

The survey was administered using the Qualtrics online platform. An invitation email with a link to the survey was sent out to all teachers inviting them to participate in the study. Respondents were required to read and agree to an informed consent before accessing the survey. Appendix K shows a copy of the invitation email whereas appendix L includes a copy of the informed consent form. To minimize the survey completion time, each respondent was assigned module 1 and an additional module randomly assigned using the Qualtrics module randomizer set to even distribution. The randomization strategy employed in this research is consistent with other studies (e.g. Newsham et al., 2013) that administered lengthy online surveys. A total of 234 responses were received, representing a response rate of 27.46%, and each subject was surveyed only once. All 234 respondents were assigned module 1, while 80, 78, and 76 were assigned modules two, three, and four respectively. The survey was administered during the winter of 2016. The surveys were approved by the University of Manitoba Research Ethics Board.

4.4.2.3 Data analysis

The objectives of the analyses were the following: 1) to refine the adapted IEQ satisfaction and the three preliminary well-being surveys for assessing teachers' IEQ satisfaction and well-being respectively, 2) to assess the validity and reliability of the three final well-being surveys, and 3) to assess the extent to which the refined IEQ satisfaction factors assess teachers' well-being in school environments.

Litte's MCAR test was used to assess the distribution of missing data for each component of the online survey. The threshold for excluding cases with missing data was five percent and above, after which the expectation maximization (EM) algorithm was used to impute missing data (Tabachnick & Fidell, 2001). The EM algorithm was preferred given that its estimation is based on the variability inherent in the existing data (Tabachnick & Fidell, 2001). Univariate outliers were identified using standardized values with an absolute of 3.29 as cut-off (Tabachnick & Fidell, 2001). The Mahalanobis distance statistics at $p < 0.001$ was used to identify multivariate outliers and excluded from the analysis (Tabachnick & Fidell, 2001). Absolute values above 3 and 8 for skewness and Kurtosis respectively were the thresholds for univariate normality. Multivariate normality was examined using a scatter plot of chi-square versus Mahalanobis distance (Wan Nor, 2015).

As part of refining the adapted IEQ survey, a confirmatory factor analysis (CFA) was conducted to assess the model fit between the NRC survey's three-factor structure of IEQ satisfaction (Veitch et al., 2007) and the teachers' IEQ satisfaction data in this study. The objective of the CFA was to determine the suitability of the NRC's three-factor structure of IEQ satisfaction (developed for office occupants) for assessing teachers' IEQ satisfaction in schools. Following the established CFA convention (Veitch et al., 2007), multiple indices were used to determine the model goodness of fit. The results showed a lack of model fit; hence, an exploratory factor analysis (EFA) was conducted to determine a suitable factor structure for teachers' IEQ satisfaction. The EFA conducted for the IEQ data followed the same procedures described below for the well-being surveys.

The inductive process employed in developing the preliminary well-being surveys was to ensure that the final surveys will be grounded in teachers' conception of well-being in schools. As part of refining the preliminary surveys, EFAs were conducted to identify the significant items and factor structures of the final TSWB, TSWB, and TPhWB respectively, using the 34, 30, and 24 items of their respective preliminary well-being survey. Hence, the objective of the EFAs was to make the final well-being surveys parsimonious by excluding items of the preliminary surveys that were conceptually insignificant in measuring teachers' well-being in school. Preliminary data screening for each EFA was conducted using a correlation matrix and the Kaiser-Meyer-Olkin's (KMO) measure of sampling adequacy for individual items. The inclusion criteria for variables were a correlation coefficient greater than 0.3 with multiple items and a KMO threshold of 0.5. The number of factors to extract was determined using multiple methods including eigenvalue greater than one criterion, scree plot, and parallel analysis. Based on the range of the suggested number of factors, multiple EFAs were conducted to determine the preferred solution. Considering the relatively small sample size in this research, principal axis factoring was the preferred extraction method given that it is less sensitive to minimal violations of multivariate normality (Costello & Osborne, 2005). Additionally, the oblique rotation promax was preferred given that well-being factors were expected to correlate. The preferred solutions were factor structures with the least cross loadings, a minimum of three items per factor, and a minimum item loading of 0.4 (Costello & Osborne, 2005). Items were also excluded for parsimony considerations and conceptual conflict with assigned factor labels (Dagenais-Desmarais & Savoie, 2012).

A two-tailed correlation test was used to assess the convergent validity of the final TPWB, TSWB, and TPhWB survey respectively with its corresponding existing survey. This was to determine the suitability of the newly developed surveys as measures of teachers' well-being. A two-tailed test was preferred to concurrently determine the likelihood of either a convergent (significant positive) or divergent (significant negative) validity between corresponding well-being surveys. The internal consistency and reliability of the final well-being surveys were determined using Cronbach's alpha (α). The α values were calculated to determine the likelihood of attaining consistent results when the final well-being surveys are deployed in future. Finally, the associations of the refined IEQ satisfaction factors with the existing well-being surveys and the final teachers' well-being surveys were assessed using two-tailed correlation test. The objective of these correlation tests was to assess the extent to which the refined IEQ satisfaction factors assess teachers' well-being.

Individual IEQ factor satisfaction and well-being scores were calculated as an average of the retained items for each of the final factor solutions after reverse coding of negatively keyed items (i.e. items with a negative sign in parenthesis). The statistical analyses were conducted using IBM SPSS version 23; however, the parallel analysis was conducted using O'Connor's (2000) SPSS program.

4.5 Results

This section presents results of the analysis conducted to refine the adapted IEQ survey and the preliminary teachers' well-being surveys, as well as the convergent validity of the final well-being surveys and the suitability of the IEQ factors as measures of occupants' well-being.

4.5.1 Factor structure of teachers' IEQ satisfaction survey

This subsection presents results of both the CFA and EFA conducted for the adapted IEQ satisfaction survey data. A total of 189 cases were considered for the analysis after excluding cases with more than five percent missing values, univariate outliers, and multivariate outliers.

4.5.1.1 Exploratory factor analysis

Confirmatory factor analysis (CFA) showed a lack of model fit between the NRC's three-factor solution of IEQ satisfaction (Veitch et al., 2007) and the teachers' IEQ satisfaction data. The chi-square value of 533.753 was statistically significant, thus showing a significant divergence between the three-factor solution and the current data. Moreover, the normed fit index, the comparative fit index, and the root mean square error of approximation were 0.72 (less than 0.9), 0.77 (less than 0.95), and 0.12 (greater than 0.06) respectively (Tabachnick & Fidell, 2001). The

CFA was not modified to avoid the risk of forcing the model to fit the teachers' IEQ satisfaction data in this research considering the contextual difference between schools and offices (i.e. the original context of the adapted survey). Hence, an EFA was conducted for the current data to identify the most significant IEQ factors and items that are relevant to school teachers. Examination of the correlation matrix showed the absence of singularity and multicollinearity, while the KMO measure of sampling adequacy for individual items were all above the 0.5 benchmark. The omnibus KMO measure of sampling adequacy of 0.883 exceeded the 0.6 cut-off value. The preliminary EFA for the 19 items with principal axis factoring suggested extracting five factors based on the eigenvalue greater one rule. Similarly, the scree plot suggested extraction of five factors. However, parallel analysis for 1000 permutations of the raw teachers' IEQ data suggested extraction of two factors. Hence, multiple EFAs were conducted in turn using principal axis factoring for extraction and altering the number of factors to extract from two to five. The preferred factor structure was a three-factor solution with 12 items accounting for 65.63% of the total variance as shown in Table 4.3.

The inter-factor correlation coefficients exceeded the threshold of 0.32 (Tabachnick & Fidell, 2001), thus supporting the use of the promax oblique rotation. All item loadings (see Table 4.3) were greater than or equal to 0.4, except the item "Amount of background noise (i.e. not speech) you hear in your classroom" which had a loading of 0.35 under factor three: "Acoustics and Privacy". This item was exceptionally included, considering that it is one of the fundamental variables of building acoustics assessment. Each of the factors in Table 4.3 accounts for a significant proportion of total variance and have significant α values that attest to their satisfactory internal consistency and reliability. The labels for the three factors: "Lighting" (L_{sat}), "Ventilation and Thermal Comfort” (VTC_{sat}), and “Acoustics and Privacy” (AP_{sat}) were adopted from NRC’s (Veitch et al., 2007) three-factor solution given that the items loading to the respective factors in this study suggested no conceptual change.

Table 4.3: 12 items three-factor solution for teachers' IEQ satisfaction survey

Item	Factor			Item
	F1	F2	F3	variance
F1 – Lighting				
1-Amount of daylight in your classroom	0.93			0.74
15-Your access to a view of outside from your classroom	0.77			0.59
17-Quality of lighting (both electric and daylight) in your classroom	0.72			0.61
2-Amount of electric light in your classroom	0.40			0.31
F2 – Ventilation and Thermal Comfort				
4-Temperature in the classroom where you teach regularly		0.80		0.55
13-Air movement in your classroom		0.73		0.66
14-Your ability to alter or control physical conditions (such as temperature, light etc.) in your classroom		0.72		0.47
3-Overall indoor air quality in your classroom (i.e. smells bad, stuffy, stale air etc.)		0.67		0.54
F3 – Acoustics and Privacy				
7-Level of visual privacy within your classroom			0.99	0.74
6-Level of privacy for both teaching and non-teaching related conversations in your classroom			0.89	0.71
19-Degree of enclosure of your work area by walls, screens or furniture			0.55	0.50
10-Amount of background noise (i.e. not speech) you hear in your classroom			0.35	0.28
Percentage of variance explained (%)	40.30	14.77	10.56	
Cronbach’s alpha (α)	0.81	0.82	0.79	
Inter-factor correlations				
F1	1			
F2	0.50	1		
F3	0.35	0.56	1	

4.5.2 Factor structures of teachers' well-being surveys

This subsection presents results of the EFAs conducted to refine the preliminary teachers' well-being surveys. The number of cases considered for the analysis after excluding cases with more than five percent missing values, univariate outliers, and multivariate outliers was 61, 63, and 54 for TPWB, TSWB, and TPhWB respectively. Additionally, two variables were excluded from the analysis of TSWB due to the lack of univariate normality.

4.5.2.1 Exploratory factor analysis

Review of the correlation matrices and the KMO measure of sampling adequacy for individual items reduced the number of variables from 34 to 26, 30 to 27, and 24 to 20 for TPWB, TSWB, and TPhWB respectively. The omnibus KMO measure of sampling adequacy for the remaining variables were 0.74, 0.80, and 0.70 respectively for TPWB, TSWB, and TPhWB, thus, exceeding the threshold value of 0.6 (Tabachnick & Fidell, 2001). Results of the EFAs that followed are reported below.

4.5.2.2 Teachers' psychological well-being

The Initial EFA of the 26 variables of TPWB suggested extraction of eight factors based on the eigenvalue greater than one rule. Additionally, the scree plot suggested extraction of four factors whereas parallel analysis suggested extraction of two factors. Consequently, multiple EFAs were conducted by varying the number of factors to extract from two to eight. The preferred solution for TPWB was a two-factor solution with 12 items, accounting for 50.25% of the total variance observed as shown in Table 4.4. The inter-factor correlation of 0.51 exceeded the recommended threshold of 0.32 for correlated factors, thus supporting the choice of the promax rotation method. All item loadings (Table 4.4) exceeded the threshold of 0.4, thus contributing significantly to the conceptual meaning of their respective latent factors. Additionally, the α values affirm the internal consistency of both factors, and each of them accounted for a significant proportion of the total variance. These two factors were labeled as F1 – "Job satisfaction and professionalism" and F2 – "Felling of accomplishment and recognition".

Table 4.4: 12 Items two-factor solution for the new final TPWB survey

Item	Factor		Item variance
	F1	F2	
F1 – Job satisfaction and professionalism			
25-My classroom is not fit for teaching and learning (-)	0.75		0.43
3-I am able to cope with everyday student interactions in class	0.67		0.37
19-I know my responsibilities as a teacher in school	0.67		0.54
14-I get all the support I need to do my work in school	0.67		0.65
12-I feel secured to perform my duties as a teacher	0.59		0.48
30-My workload in school is too much (-)	0.51		0.31
F2 – Feeling of accomplishment and recognition			
18-I help my students to get the support they need		0.67	0.44
11-I feel eager to make a difference in my school		0.67	0.43
12-I like the occasional compliments and feedback from my colleagues		0.61	0.33
28-My students appreciate my support		0.57	0.31
33-The achievements of my students are gratifying		0.55	0.30
29-My students' personal problems are mine too		0.54	0.30
Percentage of variance explained (%)	35.07	15.18	
Cronbach's alpha (α)	0.81	0.75	
Inter-factor correlations			
F1	1		
F2	0.51	1	

4.5.2.3 Teachers' social well-being

The eigenvalue greater than one rule and the scree plot suggested extraction of seven and eight factors respectively from the initial 27 variables of TSWB, while parallel analysis suggested three factors. Following multiple EFAs, the final solution consisted of three factors with 12 items and accounting for 74.10% of total variance as shown in Table 4.5. The three factors are F1 – "Social Functioning in School", F2 – "Social Connectedness in School", and F3 – "Classroom Socialization". Additionally, each factor accounted for a significant proportion of total variance and had satisfactory internal consistency as evidenced by the α values, while factor loadings were all above 0.4. Although the inter-factor correlation of 0.23 between F1 and F3 was marginally below the 0.32 threshold, F3 significantly correlated with F2, validating thereby the choice of the promax rotation.

Table 4.5: 12 items three-factor solution for the new final TSWB survey

Item	Factors			Item variance
	F1	F2	F3	
F1 – Social Functioning in School				
30-We figure out a way to work through our differences	0.91			0.71
29-There is mutual respect amongst people in my school	0.83			0.74
19-In my school, learning is a collective responsibility	0.79			0.60
22-In my school, you see people caring about other people	0.72			0.61
31-We get to interact and laugh together as colleagues	0.64			0.56
F2 – Social Connectedness in School				
8-I feel connected to my colleagues in school		0.96		0.87
14-I have positive interactions with people in my school		0.92		0.81
7-I feel comfortable expressing my feelings to some people in school		0.69		0.73
5-I enjoy the company of people in my school		0.68		0.66
F3 – Classroom Socialization				
9-I get close and have conversation with students			0.83	0.65
4-I contribute to the social development of my students			0.79	0.62
17-I purposely plan for classroom social interactions			0.46	0.39
Percentage of variance explained (%)	47.23	18.15	8.56	
Cronbach's alpha (α)	0.89	0.90	0.72	
Inter-factor correlations				
F1	1			
F2	0.56	1		
F3	0.23	0.55	1	

4.5.2.4 Teachers' physical well-being

For TPhWB, the initial number of factors to extract based on eigenvalue greater than one, scree plot, and parallel analysis was six, nine, and two respectively. The preferred result after multiple EFAs consisted of two factors with 11 items and accounting for 56.23% of total variance as shown in Table 4.6. These two factors are F1 – "Role and Work Environment Outcomes" and F2 – "Physical Functioning in Class". The inter-factor correlation of 0.50 confirms the choice of the promax rotation. The two factors have satisfactory item loadings, significant internal consistency values, and each account for a significant proportion of total variance.

Table 4.6: 11 items two-factor solution for the new final TPhWB survey

Item	Factor		Item variance
	F1	F2	
F1 – Role and Work Environment Outcomes			
11-I get allergic reactions in school due to conditions of my work environment (-)	0.98		0.76
9-I frequently get running nose, dry throat and lips, or watery eyes in school (-)	0.81		0.68
14-I have bodily pains that affect my work in school (-)	0.60		0.32
1-I always feel tired in class (-)	0.58		0.48
12-I get bodily pains from standing and movements in class (-)	0.57		0.56
8-I feel uncomfortable due to the level of air temperatures in my classroom (-)	0.54		0.30
10-I frequently raise my voice in class due to high background noise (-)	0.46		0.30
F2 – Physical Functioning in Class			
4-I engage in fun activities with my students in school		0.70	0.38
20-I wish I could do less walking in the classroom (-)		0.70	0.51
5-I feel alert and energetic in my classroom		0.58	0.54
6-I feel comfortable standing, bending, kneeling or sitting on the floor to help my students		0.53	0.35
Percentage of variance explained (%)	41.48	14.75	
Cronbach's alpha (α)	0.85	0.73	
Inter-factor correlations			
F1	1		
F2	0.50	1	

4.5.3 Validity and reliability of the final teachers' well-being surveys

Table 4.7 presents the two-tailed Pearson correlation coefficients between the final TPWB, TSWB, TPhWB surveys and their corresponding existing well-being surveys. The coefficients of correlation were all moderately positive and statistically significant. The levels of association with existing well-being measures found in this study are within the range of values (i.e. r = 0.19 to 0.53) reported in the literature for similar convergent validity studies (Dagenais-Desmarais & Savoie, 2012). Hence, each of the three measures of teachers' well-being had satisfactory convergent validity with its corresponding existing measure. The α values for the final well-being surveys were 0.87, 0.90, and 0.80 for TPWB, TSWB, and TPhWB respectively, thus, exceeding the threshold of 0.70 for an acceptable level of internal consistency and reliability (Tabachnick & Fidell, 2001).

Table 4.7: Validity of teachers' final well-being surveys

Validation Measures	Correlation coefficients and significance level		
	TPWB	TSWB	TPhWB
Ryff's scale of psychological well-being	0.40** (0.001)		
Keyes' social well-being model		0.30* (0.018)	
RAND 36 physical well-being components			0.47** (0.000)

Note: ** denotes significant correlation at level 0.01; * denotes significant correlation at level 0.05; Values in parenthesis denotes the level of significance for correlation coefficients

4.5.4 Refined IEQ satisfaction factors as measures of teachers' well-being

Table 4.8 presents the results of the tests of associations of the refined IEQ satisfaction factors with the existing well-being surveys and the final teachers' well-being surveys. Apart from VTC_{sat} which significantly correlated with the existing physical well-being measure (i.e. RAND

36), L_{sat} and AP_{sat} did not significantly correlate with any of the existing well-being measures. Additionally, VTC_{sat} correlated significantly with the three final teachers' well-being measures, while L_{sat} and AP_{sat} significantly correlated with TPhWB only.

Table 4.8: Associations of refined IEQ satisfaction factors with the existing well-being surveys and the final teachers' well-being surveys

Well-being measures	IEQ satisfaction factors		
	L_{sat}	VTC_{sat}	AP_{sat}
Existing			
Ryff's scale of psychological well-being	0.004	0.081	0.027
	(0.977)	(0.836)	(0.836)
Keyes' social well-being model	0.000	-0.177	-0.228
	(0.360)	(0.360)	(0.073)
RAND 36 physical well-being components	0.147	0.341*	0.090
	(0.288)	(0.012)	(0.519)
New			
Final TPWB	0.213	0.280*	0.200
	(0.099)	(0.029)	(0.121)
Final TSWB	0.124	0.347**	0.231
	(0.333)	(0.005)	(0.069)
Final TPhWB	0.359**	0.612**	0.376**
	(0.008)	(0.000)	(0.005)

Note: ** denotes significant correlation at level 0.01; * denotes significant correlation at level 0.05; Values in parenthesis denotes the level of significance for correlation coefficients above

4.6 Discussion

The refined IEQ satisfaction survey developed in this study was compared to the original NRC IEQ survey developed by Veitch et al. (2007). Although the difference in sample size makes direct comparison insignificant, the CFA and EFA results in this study seem to project the uniqueness of teachers' perception of IEQ satisfaction. The factor labels in this study were adopted from Veitch et al. (2007); however, the item compositions and factor loadings varied significantly. The L_{sat} factor in this study includes the item "Amount of daylight in your classroom" that had the highest factor loading, thus making it the most significant lighting item ahead of both access to a view of outside and quality of lighting. This outcome agrees with earlier IEQ studies in schools (e.g. Tanner, 2008) that found a significant association between students' performance and daylit classrooms, thus highlighting the significance of the amount of daylight to teachers' satisfaction with the quality of lighting. In contrast, Veitch et al. (2007) had no separate item for daylight, while the quality of lighting and access to a view of outside were the most and least significant items respectively.

Although the refined teachers' IEQ satisfaction survey developed in this study contextualizes teachers' IEQ satisfaction to school environments, the survey is conceptually in line with the IEQ literature. The four items of the VTC_{sat} factor in this study includes all three items of Veitch et al's (2007) VTC_{sat} factors in addition to the item "Your ability to alter or control physical conditions (such as temperature, light etc...) in your classroom". This item had a significant factor loading of 0.72 under the VTC_{sat} factor. Although the item included the control of other indoor space parameters such as the amount of light, the highly significant loading under the VTC_{sat} factor suggests that the teachers were probably more concerned with controlling indoor air temperature. This result is not surprising considering that most classrooms in this study had no thermostat for decentralized control of temperature, while a significant number had non-operable windows, and is in line with the findings of others (e.g. Toftum, 2010; Zhang & Barrett, 2012) in the IEQ literature. Visual privacy and speech privacy were the most significant items of the AP_{sat} factor with factor loadings of 0.99 and 0.89 respectively, demonstrating their relative importance to teachers who seem to prefer an indoor environment that minimizes distractions from outside, and from nearby classrooms. The significance of speech privacy in this study resonates with the results of both Sörqvist (2010) and Boman (2004) who found a negative association between speech intelligibility and student performance.

The results also confirmed that the final TPWB, TSWB, and TPhWB surveys developed as part of this research assess the subdivision of teachers' well-being for which they were intended. The surveys demonstrated convergent validity with their corresponding established well-being surveys in the literature. The α values of the three new final well-being surveys attest to their satisfactory internal consistency and reliability. The moderately positive correlations between the newly developed teachers' well-being surveys and their corresponding existing surveys affirm the uniqueness of the new teachers' well-being surveys. Very strong positive correlations would have implied that the new well-being surveys are not significantly different from the existing context-free well-being surveys. For example, the TSWB survey includes the factor "Social Connectedness in School" which is directly comparable to the "Social Integration" factor in Keyes' social well-being model. However, the TSWB also includes the factor "Classroom Socialization" which is conceptually related to the Keyes' social well-being model in general but is unique to teachers' social well-being in school. Hence, the moderately positive correlations confirm the difference between final teachers' well-being surveys and their corresponding existing surveys.

The preliminary well-being surveys used for developing the final well-being surveys were established from interviews with 20 out of the 852 teachers. Hence, the preliminary well-being surveys were probably not adequately representative of teachers' well-being manifestations in the population. However, given that the first 10 interviews produced about 75% of the preliminary well-being surveys' base codes, it seems fair to assume that the sample of 20 was reasonably saturated. Hence, additional interviews could have led to new base codes and probably different composition of items in the final well-being surveys, but plausibly including most of the current items. The preliminary well-being surveys were administered to the 32 schools including the 10 schools that participated in the interviews, thus questioning the validity and generality of the final well-being surveys beyond the sample of schools in this study. Due to restrictions by the University of Manitoba Ethics Review Board, it was not possible to identify and exclude the 20 teachers who participated in the interview from completing the online survey or to exclude their responses if they completed the survey. However, approximately 71% of the responses included in the analysis were from the 23 schools that did not participate in the interviews and would likely minimize the concerns of validity and generality of the final well-being surveys. Additional validity studies with different samples of schools will be required to confirm the validity and generality of the teachers' well-being surveys.

The preliminary teachers' well-being surveys included IEQ-related items that were identified as potential manifestations of teachers' well-being in stage one of this study. For instance, the preliminary TPWB survey included the items "I am happy because I control air temperature in my classroom" and "The amount of daylight in my class affects my mood (-)". Additionally, the preliminary TSWB survey included the items "High background noise in class affects my interaction with students (-)". Results of the EFA showed that none of these IEQ-related items loaded significantly to either TPWB or TSWB, except for the more generic TPWB item "My classroom is not fit for teaching and learning" which doubled as the most significant item of the "Job satisfaction and professionalism" factor. Hence, the EFA results suggest that those IEQ-related items were insignificant manifestations of TPWB and TSWB. Nevertheless, some IEQ-related items were significant manifestations of TPhWB. These included the items “I feel uncomfortable due to the level of air temperatures in my classroom (-)” and “I frequently raise my voice in class due to high background noise (-)” under the factor “Role and Work Environment Outcomes”.

The two-tailed correlation tests between the refined IEQ satisfaction factors and the existing well-being surveys suggested that the former are probably insignificant measures of well-being except for VTC_{sat} which significantly correlated with RAND 36. Given that the preamble to the IEQ survey items adapted for this study was satisfaction-based just like other surveys in the IEQ literature, most of the IEQ factors were expected to correlate significantly with Ryff’s scale of psychological well-being. However, the seemingly hedonic underpinning of IEQ satisfaction may explain why its factors did not significantly correlate with the eudaimonically inclined Ryff’s scale. This is because psychological well-being measures are either hedonic or eudaimonic; with the former focusing on human happiness and satisfaction and the latter on “optimal functioning”, and “self-actualization” (Dagenais-Desmarais & Savoie, 2012, p. 661, p. 661). This reinforces the need for IEQ satisfaction questions that are eudaimonically inclined given that building indoor environments are expected to enhance human functioning in all domains of life. The correlation tests showed that VTC_{sat} was significantly associated with the three final teachers’ well-being measures while L_{sat} and AP_{sat} significantly correlated with the TPhWB measure only. These significant associations between the IEQ satisfaction factors and the final teachers’ well-being measures can be attributed to the contextualization of these new teachers’ well-being measures. Only VTC_{sat} correlated significantly with the both RAND 36 and the final TPhWB, thus suggesting that VTC_{sat} is a significant measure of TPhWB. In contrast, the lack of concurrent significant associations of L_{sat} and AP_{sat} with the final teachers' well-being surveys and their corresponding existing well-being surveys, suggest that both L_{sat} and AP_{sat} were less significant measures of well-being. This finding is in contrast with Aries et al. (2010) who found a significant relationship between view quality and physical and psychological comfort. These insignificant correlations of L_{sat} and AP_{sat} with the well-being measures in this study are probably because most of the teachers were very satisfied with both IEQ factors and not because those factors are not measures of teachers' well-being. Additionally, IEQ satisfaction surveys, in general, appear to be deductive and significantly influenced by the need to correlate objective and subjective assessments. Probably, an inductively conceived questionnaire with assessment items grounded in the qualitative IEQ perceptions of teachers would have led to significant associations with the three contextualized final teachers' well-being measures developed in this study.

The tests of associations between the three final teachers' well-being measures and the refined IEQ satisfaction factors in this study suggested that adverse IEQ is likely to have a direct physical impact first, that would in turn indirectly impact psychological and social well-being, as depicted in Figure 4.3. Solid lines (Figure 4.3) indicate a direct impact, long dashes indicate a likely indirect second stage impact, while long dash dots indicate another potential direct impact of IEQ on well-being. Although L_{sat} and AP_{sat} did not significantly correlate with RAND 36, the direct impact on physical well-being is suggested because of their significant correlation with the final TPhWB measure. This is also the case for the suggested direct impact of VTC_{sat} on psychological and social well-being due to its significant correlation with the final TPWB and TSWB measures. The design of this study did not allow for correlation tests between the three measures of teachers' well-being. However, an earlier study (Hays et al., 1994) concluded that physical well-being has a positive impact on psychological well-being. Additionally, it seems logical to expect physical well-being to have an impact on social well-being, hence the predicted indirect impact of IEQ satisfaction factors on psychological and social well-being through physical well-being. These suggested impact relationships will require further research (i.e. path analysis or structural equation modeling) for verification and validation, ideally using inductively conceived measures of IEQ satisfaction and well-being.

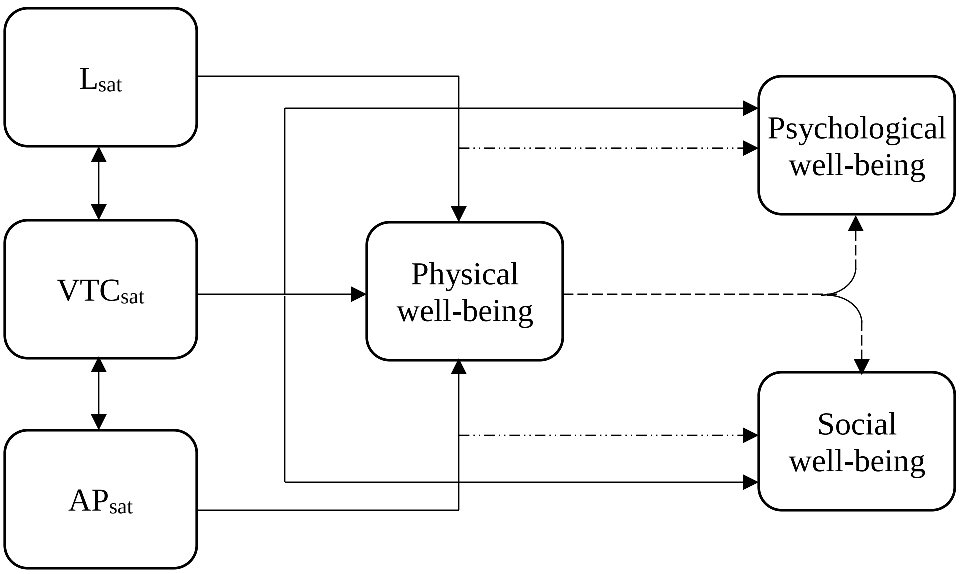

Figure 4.3: Hypothetical two stage impact of IEQ satisfaction factors on occupants' well-being

4.7 Conclusion

This research investigated the use of occupants' IEQ satisfaction factors as measures of school teachers' well-being. The results showed that the newly developed TPWB, TSWB, and TPhWB surveys are valid measures of the corresponding subdivision of teachers' personal well-being. These developed and validated well-being surveys are conceptually related to their corresponding context-free well-being surveys; however, they are unique given that they also include factors that are unique to teachers in schools compared to other life domains. Hence, the new well-being surveys are likely to produce a more representative assessment of those subdivisions of teachers' well-being in schools compared to their corresponding existing surveys. The VTC_{sat} factor of IEQ satisfaction was the most significant measure of TPhWB; however, the moderately positive correlations suggest that TPhWB cannot be limited to VTC_{sat}. Additionally, the lack of concurrent associations of L_{sat} and AP_{sat} with the corresponding measures of the two sets of well-being surveys only implies that both IEQ factors were insignificant measures of well-being in this study and not that they are not measures of occupants' well-being.

Results of this study provide evidence which suggests that occupants' IEQ satisfaction should not generally be misconstrued to be equivalent to occupants' well-being. However, a normed practice of measuring both IEQ satisfaction factors and other subdivisions of occupants' well-being (teacher and building occupants in general) should probably be the preferred strategy moving forward. Considering the deductive nature of most existing IEQ satisfaction surveys, inductively conceived surveys may yield different results where most IEQ satisfaction factors will align with occupants' well-being and lead to identifying significant perception patterns over time. These patterns will likely feed into IEQ enhancement strategies to maximize teachers' well-being in schools, ultimately benefiting the teaching and learning process. Additionally, the hypothetical model shown in Figure 4.3 could serve as the starting point for exploring the impact mechanism of IEQ satisfaction vis-à-vis teachers' well-being and other building occupants'.

The sample size in this study was found to be satisfactory for the EFAs that were conducted; however, the sample size is relatively small and thus minimizes the generality of the results. Further studies in different schools with larger samples of teachers will be required to validate the findings of this study. The VTC_{sat} factor of IEQ satisfaction included the item "Your ability to … control physical conditions (such as temperature, light etc…) in your classroom". The reference to the control of lighting and other IEQ parameters can potentially lead to conflicting conclusions; hence, future studies should consider including different control items to relevant factors of IEQ satisfaction. Furthermore, future studies should consider conducting controlled experiments or employ other strategies of inquiry where participants will be exposed to varying levels of indoor lighting and acoustics parameters to assess the associations of L_{sat} and AP_{sat} with the subdivisions of occupants' well-being. IEQ researchers and practitioners are encouraged to use these measures to determine their confirmatory validity and required improvements.

4.8 Acknowledgment

This research would not have been possible without the support of the Government of Manitoba Public School Finance Board, the two School Division, and the 32 schools in terms of agreeing to participate in this research and facilitating access to the schools and the data collection. The authors are particularly grateful to the teachers who participated in the interviews and the online survey. The authors are also grateful to Dr. Baafour Nyantekyi-Kwakye for his assistance with the data collection and Mr. Joshua Boateng Akom for proof-reading the final manuscript. This research was funded by a Discovery Grant (RGPIN 418532-2012) from the Natural Sciences and Engineering Research Council of Canada.

4.9 References

Agha-Hossein, M. M., El-Jouzi, S., Elmualim, A. A., Ellis, J., & Williams, M. (2013). Post-occupancy studies of an office environment: Energy performance and occupants' satisfaction. *Building and Environment*, *69*(0), 121-130. doi: http://dx.doi.org/10.1016/j.buildenv.2013.08.003

Aries, M. B., Veitch, J. A., & Newsham, G. R. (2010). Windows, view, and office characteristics predict physical and psychological discomfort. *Journal of Environmental Psychology*, *30*(4), 533-541.

Bakó-Biró, Z., Clements-Croome, D., Kochhar, N., Awbi, H., & Williams, M. (2012). Ventilation rates in schools and pupils' performance. *Building and Environment*, *48*, 215-223.

Bluyssen, P. M., Aries, M., & van Dommelen, P. (2011a). Comfort of workers in office buildings: The European HOPE project. *Building and Environment, 46*(1), 280-288.

Bluyssen, P. M., Janssen, S., van den Brink, L. H., & de Kluizenaar, Y. (2011b). Assessment of wellbeing in an indoor office environment. *Building and Environment, 46*(12), 2632-2640.

Boman, E. V. A. (2004). The effects of noise and gender on children's episodic and semantic memory. *Scandinavian Journal of Psychology, 45*(5), 407-416.

Brown, Z. B. (2009). *Occupant comfort and engagement in green buildings: examining the effects of knowledge, feedback and workplace culture*. (PhD thesis), University of British Columbia.

Buckley, J., Schneider, M., & Shang, Y. (2005). Fix it and they might stay: School facility quality and teacher retention in Washington, DC. *The Teachers College Record, 107*(5), 1107-1123.

Building Research Establishment. (2002) HOPE office environment survey.

Capio, C., Sit, C. P., & Abernethy, B. (2014). Physical Well-Being. In A. Michalos (Ed.), *Encyclopedia of Quality of Life and Well-Being Research* (pp. 4805-4807): Springer Netherlands.

Center for Disease Control and Prevention. (2013a). Workplace safety and health topics: indoor environmental quality. Retrieved 4 June, 2015, from http://www.cdc.gov/niosh/topics/indoorenv/

Clarke, P. J., Marshall, V. W., Ryff, C. D., & Wheaton, B. (2001). Measuring psychological well-being in the Canadian study of health and aging. *International Psychogeriatrics, 13*(S1), 79-90.

Costello, A. B., & Osborne, J. W. (2005). Best Practices in Exploratory Factor Analysis: Four Recommendations for Getting the Most From Your Analysis. *Practical Assessment Research & Evaluation, 10*(7), 1-9.

Creswell, J. W. (2014). *Research design: Qualitative, quantitative, and mixed methods approaches* (4th ed.). Thousand Oaks, California: Sage publications.

Dagenais-Desmarais, V., & Savoie, A. (2012). What is psychological well-being, really? A grassroots approach from the organizational sciences. *Journal of Happiness Studies, 13*(4), 659-684.

De Giuli, V., Pontarollo, C. M., De Carli, M., & Di Bella, A. (2014). Overall assessment of indoor conditions in a school building: An Italian case study. *International Journal of Environmental Research, 8*(1), 27-38.

de Korte, E. M., Spiekman, M., Hoes-van Oeffelen, L., van der Zande, B., Vissenberg, G., Huiskes, G., & Kuijt-Evers, L. F. (2015). Personal environmental control: Effects of pre-set conditions for heating and lighting on personal settings, task performance and comfort experience. *Building and Environment, 86*, 166-176.

Dessel, G. V. (2013). How to determine population and survey sample size? Retrieved 10 July, 2018, from https://www.checkmarket.com/blog/how-to-estimate-your-population-and-survey-sample-size/

Djukanovic, R., Wargocki, P., & Fanger, P. O. (2002b). *Cost-benefit analysis of improved air quality in an office building*. Paper presented at the Indoor Air 2002, Monterey, California.

Dodge, R., Daly, A. P., Huyton, J., & Sanders, L. D. (2012). The challenge of defining wellbeing. *International Journal of Wellbeing, 2*(3).

Emmel, N. (2013). *Sampling and Choosing Cases in Qualitative Research: A Realist Approach* (pp. 1-169). Retrieved from SAGE Research Methods database Retrieved from http://dx.doi.org/10.4135/9781473913882

Fang, L., Wyon, D., Clausen, G., & Fanger, P. O. (2004). Impact of indoor air temperature and humidity in an office on perceived air quality, SBS symptoms and performance. *Indoor air, 14*(s7), 74-81.

Feige, A., Wallbaum, H., Janser, M., & Windlinger, L. (2013). Impact of sustainable office buildings on occupant's comfort and productivity. *Journal of Corporate Real Estate, 15*(1), 7-34.

Galletta, A. (2012). *Mastering the Semi-structured Interview and Beyond : From Research Design to Analysis and Publication*. New York: New York University Press.

Guest, G., Bunce, A., & Johnson, L. (2006). How Many Interviews Are Enough?: An Experiment with Data Saturation and Variability. *Field Methods, 18*(1), 59-82. doi: 10.1177/1525822x05279903

Hays, R. D., Marshall, G. N., Wang, E. Y. I., & Sherbourne, C. D. (1994). Four-year cross-lagged associations between physical and mental health in the Medical Outcomes Study. *Journal of consulting and clinical psychology, 62*(3), 441.

Hays, R. D., & Morales, L. S. (2001). The RAND-36 measure of health-related quality of life. *Annals of medicine, 33*(5), 350-357.

Huizenga, C., Abbaszadeh, S., Zagreus, L., & Arens, E. (2006). *Air quality and thermal comfort in office buildings: Results of a large indoor environmental quality survey*. Paper presented at the Healthy Buildings: Creating a Healthy Indoor Environment for People, HB 2006, Lisboa.

Issa, M., Rankin, J., Attalla, M., & Christian, A. (2011). Absenteeism, performance and occupant satisfaction with the indoor environment of green Toronto schools. *Indoor and Built Environment, 20*(5), 511-523.

Kamaruzzaman, S. N., Egbu, C., Zawawi, E. M. A., Ali, A. S., & Che-Ani, A. I. (2011). The effect of indoor environmental quality on occupants' perception of performance: A case study of refurbished historic buildings in Malaysia. *Energy and Buildings, 43*(2), 407-413.

Keyes, C. L. M. (1998). Social well-being. *Social psychology quarterly*, 121-140.

Kielb, C., Lin, S., Muscatiello, N., Hord, W., Rogers-Harrington, J., & Healy, J. (2015). Building-related health symptoms and classroom indoor air quality: a survey of school teachers in New York State. *Indoor air, 25*(4), 371-380.

Kim, J., Candido, C., Thomas, L., & de Dear, R. (2016). Desk ownership in the workplace: The effect of non-territorial working on employee workplace satisfaction, perceived productivity and health. *Building and Environment, 103*, 203-214. doi: http://dx.doi.org/10.1016/j.buildenv.2016.04.015

Kim, J., & De Dear, R. (2012). Nonlinear relationships between individual IEQ factors and overall workspace satisfaction. *Building and Environment, 49*, 33-40.

La Placa, V., McNaught, A., & Knight, A. (2013). Discourse on wellbeing in research and practice. *International Journal of Wellbeing, 3*(1).

Madureira, J., Alvim-Ferraz, M. C. M., Rodrigues, S., Gonçalves, C., Azevedo, M. C., Pinto, E., & Mayan, O. (2009). Indoor Air Quality in Schools and Health Symptoms among Portuguese Teachers. *Human and Ecological Risk Assessment: An International Journal, 15*(1), 159-169.

Massé, R., Poulin, C., Dassa, C., Lambert, J., Bélair, S., & Battaglini, A. (1998). The structure of mental health: Higher-order confirmatory factor analyses of psychological distress and well-being measures. *Social Indicators Research, 45*(1-3), 475-504.

Maula, H., Hongisto, V., Östman, L., Haapakangas, A., Koskela, H., & Hyönä, J. (2016). The effect of slightly warm temperature on work performance and comfort in open-plan offices-a laboratory study. *Indoor air, 26*(2), 286-297.

Newsham, G., Birt, B., Arsenault, C., Thompson, L., Veitch, J., Mancini, S., . . . Burns, G. (2012a). *Do green buildings outperform conventional buildings? Indoor environment and energy performance in North American offices*. (RR-329). Retrieved from http://nparc.cisti-icist.nrc-cnrc.gc.ca/npsi/ctrl?action=shwart&index=an&req=20857897&lang=en.

Newsham, G. R., Birt, B. J., Arsenault, C., Thompson, A. J., Veitch, J. A., Mancini, S., . . . Burns, G. J. (2013). Do 'green'buildings have better indoor environments? New evidence. *Building Research & Information, 41*(4), 415-434.

Nicol, F., Wilson, M., & Chiancarella, C. (2006). Using field measurements of desktop illuminance in European offices to investigate its dependence on outdoor conditions and its effect on occupant satisfaction, and the use of lights and blinds. *Energy and Buildings, 38*(7), 802-813.

Noullett, M., Jackson, P. L., & Brauer, M. (2010). Estimation and characterization of children's ambient generated exposure to PM2.5 using sulphate and elemental carbon as tracers. *Atmospheric Environment, 44*(36), 4629-4637. doi: http://dx.doi.org/10.1016/j.atmosenv.2010.08.004

O'connor, B. P. (2000). SPSS and SAS programs for determining the number of components using parallel analysis and Velicer's MAP test. *Behavior Research Methods, Instruments, & Computers, 32*(3), 396-402.

Preiser, W., & Vischer, J. (2006). *Assessing building performance*. Oxford: Routledge.

Ryff, C. D. (1989). Happiness is everything, or is it? Explorations on the meaning of psychological well-being. *Journal of personality and social psychology, 57*(6), 1069.

Schreuder, E., van Heel, L., Goedhart, R., Dusseldorp, E., Schraagen, J. M., & Burdorf, A. (2015). Effects of newly designed hospital buildings on staff perceptions: A pre-post study to validate design decisions. *Health Environments Research and Design Journal, 8*(4), 77-97. doi: 10.1177/1937586715573736

Shih, T.-H., & Fan, X. (2008). Comparing response rates from web and mail surveys: A meta-analysis. *Field Methods, 20*(3), 249-271.

Singh, A., Syal, M., Grady, S. C., & Korkmaz, S. (2010). Effects of green buildings on employee health and productivity. *American Journal of Public Health, 100*(9), 1665-1668.

Sisask, M., Värnik, P., Värnik, A., Apter, A., Balazs, J., Balint, M., . . . Cosman, D. (2013). Teacher satisfaction with school and psychological well-being affects their readiness to help children with mental health problems. *Health Education Journal*, 0017896913485742.

Sörqvist, P. (2010). Effects of aircraft noise and speech on prose memory: What role for working memory capacity? *Journal of Environmental Psychology*, *30*(1), 112-118.

Tabachnick, B. G., & Fidell, L. S. (2001). *Using multivariate statistics* (4 ed.). Needham Height, MA: Allyn & Bacon.

Tanner, C. K. (2008). Explaining relationships among student outcomes and the school's physical environment. *Journal of Advanced Academics, 19*(3), 444-471.

Toftum, J. (2010). Central automatic control or distributed occupant control for better indoor environment quality in the future. *Building and Environment, 45*(1), 23-28. doi: http://dx.doi.org/10.1016/j.buildenv.2009.03.011

Turunen, M., Toyinbo, O., Putus, T., Nevalainen, A., Shaughnessy, R., & Haverinen-Shaughnessy, U. (2014). Indoor environmental quality in school buildings, and the health and wellbeing of students. *International Journal of Hygiene and Environmental Health, 217*(7), 733-739.

Veitch, J. A., Charles, K. E., Farley, K. M. J., & Newsham, G. R. (2007). A model of satisfaction with open-plan office conditions: COPE field findings. *Journal of Environmental Psychology*, *27*(3), 177-189. doi: 10.1016/j.jenvp.2007.04.002

Vieira, E. M. d. A., Silva, L. B. d., & Souza, E. L. d. (2016). The influence of the workplace indoor environmental quality on the incidence of psychological and physical symptoms in intensive care units. *Building and Environment, 109,* 12-24.

Vischer, J. C. (2007a). The concept of workplace performance and its value to managers. *California management review, 49*(2), 62-79.

Wan Nor, A. (2015). The graphical assessment of multivariate normality using SPSS. *Education in Medicine Journal, 7*(2).

Witterseh, T., Wyon, D. P., & Clausen, G. (2004). The effects of moderate heat stress and open-plan office noise distraction on SBS symptoms and on the performance of office work. *Indoor air, 14*(s8), 30-40.

Zagreus, L., Huizenga, C., Arens, E., & Lehrer, D. (2004). Listening to the occupants: a Web-based indoor environmental quality survey. *Indoor air, 14*(s8), 65-74.

Zhang, Y., & Barrett, P. (2012). Factors influencing the occupants' window opening behaviour in a naturally ventilated office building. *Building and Environment, 50,* 125-134. doi: http://dx.doi.org/10.1016/j.buildenv.2011.10.018

Connecting Section

The previous chapter, chapter 4, focused on assessing the extent to which IEQ satisfaction factors are direct measures of occupants' well-being. The chapter presented details of how an existing IEQ satisfaction survey was adapted and refined for teachers. Additionally, the chapter presented the development, refinement, and validation of surveys for assessing teachers' psychological, social, and physical well-being. Results of statistical analyses showed that although occupants' IEQ satisfaction factors, especially ventilation and thermal comfort, measures aspects of occupants' well-being, they are most likely not direct measures of occupants' well-being. Therefore, concurrent assessment of occupants' IEQ satisfaction and well-being would be essential in determining the likely impact of physical conditions of space enclosing elements on IEQ and subsequently on occupants' satisfaction and well-being. The results of this chapter also suggested that the impact of IEQ on occupants' well-being is plausibly indirect through their IEQ satisfaction. Chapter 4 addressed objective two of this thesis.

The next chapter, chapter 5, is a logical extension of chapter 4. Chapter 5 focused on assessing school teachers' IEQ satisfaction and their well-being in different school types (i.e. new, renovated, and non-renovated) using scores of the refined IEQ satisfaction survey and the refined and validated well-being surveys. Detailed descriptions of the three strata of schools and the IEQ-related renovations executed in the renovated schools were presented in chapter 3. The aim of chapter 5 was to determine whether IEQ-related renovations of the renovated schools resulted in significant differences in teachers IEQ satisfaction and well-being between the renovated and non-renovated school, and the opposite between the renovated and new schools. The chapter focused on the statuses of the schools as new, renovated, and non-renovated only and does not account for specific physical conditions. Chapter 5 addresses objective three of this thesis.

CHAPTER 5: Differences in Teachers' Satisfaction with Indoor Environmental Quality and their Well-Being in New, Renovated, and Non-Renovated Schools

A version of this chapter was published in the "Indoor and Built Environment" Journal.

Sadick, A.-M., & Issa, M. H. (2017). Differences in teachers' satisfaction with indoor environmental quality and their well-being in new, renovated, and non-renovated schools. Indoor and Built Environment, 0(0). doi: 10.1177/1420326X17717074

The first author was responsible for the conception and design of the work, the data collection, data analysis and the drafting of the journal paper. The second author supervised the work and critically revised the paper.

5.1 Abstract

Most studies on buildings' renovations in relation to indoor environmental quality and occupants' well-being have focused on offices, while those investigating schools focused on students rather than teachers. Most of these studies limited their assessment of well-being to occupants' satisfaction with indoor environmental quality factors, overlooking essential aspects related to psychological, social, and physical well-being. This paper presents the results of a research conducted in 32 schools in Manitoba, Canada, to assess teachers' indoor environmental quality satisfaction and well-being in new, renovated, and non-renovated schools. The research involved adapting and refining an indoor environmental quality satisfaction survey and developing and refining three new surveys to assess teachers' psychological, social, and physical well-being. The results of the refined surveys showed statistically significant differences in teachers' satisfaction with indoor environmental quality factors between the new and renovated schools on one hand and the non-renovated ones on the other. However, no statistically significant differences were found in teachers' psychological, social, and physical well-being perceptions between all pairs of the three school categories analyzed. Association analyses suggested a potential indirect impact of schools' renovations on teachers' well-being via their satisfaction with indoor environmental quality. The results of this study should aid school managers in making strategic decisions about the maintenance of their existing schools.

Keywords: Indoor environmental quality, Maintenance, Renovations, Schools, Teachers, Well-being

5.2 Introduction

The working condition of building elements such as walls, windows, and floors decline during buildings' operation phase due to known and unknown factors including visible defects and exposure to adverse environmental conditions (Langevine, Allouche, & AbouRizk, 2006a). This will affect buildings' performance with respect to energy consumption and primarily, the provision of safe and comfortable indoor environments for occupants. Hence, the maintenance (i.e. renovation, repair, refurbishment, and retrofit) of buildings during their service life is fundamental to accomplishing their functional requirements (Mendell & Heath, 2005). Educational buildings constitute a significant proportion of public infrastructure. In Canada, they represented half of the public infrastructure as of 2008 (Gaudreault, Overton, & Trstenjak, 2009). From 2012 to 2014, Canada spent an average of CAD$ 1.69 billion (Statistics Canada, 2016) on the repair of educational infrastructure.

Several studies (Angela, Abbas, & David, 2011; Exner, D'Alonzo, Paoletti, Pascual, & Pernetti, 2017; Ott & Bolliger, 2015) assessed the relationship between buildings' maintenance and their energy performance considering the potential economic benefits of reduced energy consumption. Others (Liu, Rohdin, & Moshfegh, 2015; Noris et al., 2013; Wells et al., 2015) investigated occupants' satisfaction with IEQ in relation to buildings' maintenance. While some studies (Földváry, Bukovianska, & Petráš, 2015; Ghita & Catalina, 2015; Thomsen et al., 2016) focused on investigating the impact of energy retrofitting on IEQ, others (Hongisto et al., 2016; Noris et al., 2013; Singh, Attia, Mahapatra, & Teller, 2016) focused on IEQ-related maintenance in general. Although results generally suggested that improving IEQ improved occupants' satisfaction, these studies usually focused on office buildings, with limited empirical evidence on how the maintenance of school buildings influenced occupants' IEQ satisfaction and well-being.

The substantial expenditure on school buildings' maintenance calls for empirical research focused on end-user benefits to justify the outlay and improve strategic maintenance decision-making. IEQ research in schools has historically focused on students (Allen & Marples, 1998; Bradley & Sato, 2008; Toyinbo et al., 2016) despite a study (Buckley et al., 2005) in the United States showing that improvements in school facilities could lead to teacher retention more than salary increases. Another study (Harris & Sass, 2014b) reported a positive association between teacher effectiveness and student test scores, thus, reinforcing the need to improve the working condition of school buildings to enhance teachers' performance.

This research focused on investigating the impact of IEQ-related renovations on teachers' IEQ satisfaction and well-being, by assessing the differences in teachers' IEQ satisfaction and well-being in new, renovated and non-renovated schools in Manitoba, Canada. IEQ-related renovations in this research refer to renovations implemented with the aim of enhancing buildings' IEQ performance and ultimately their occupants' IEQ satisfaction. Examples include improving the thermal properties of building envelopes with insulation to minimize indoor temperature fluctuations and thus improve occupants' thermal comfort. They also include using mechanical ventilation to decrease the concentration of indoor air pollutants, increase indoor ventilation rates and thus improve indoor air quality satisfaction.

This research is part of a large study aiming to analyze the physical and IEQ conditions of schools in relation to teachers' IEQ satisfaction and well-being. As part of the large study, an existing IEQ satisfaction survey was adapted and refined to assess school teachers' IEQ satisfaction. Additionally, three new well-being surveys were developed and validated to assess teachers' psychological, social and physical well-being. This research was based on responses from these surveys. Hence, this research should be of interest to school divisions as well as design and operation and maintenance professionals looking to renovate existing schools, or design and build new ones. It should also be of interest to IEQ researchers looking to study the link between the physical condition of existing buildings and their occupants' IEQ satisfaction and well-being. This chapter addresses objective three of this research stated in chapter 1.

5.3 Background information

Buildings are renovated for several reasons such as to enhance their aesthetic appearance, to extend their service life, and to increase their rental value (Eweda, Zayed, & Alkass, 2015). Another driving force of building renovation is the potential cost savings associated with reducing buildings' energy consumption (Thomsen et al., 2016; Wells et al., 2015). Zinzi et al. (2016) noted 80% energy savings in a three-story school building after deep energy retrofits. Energy retrofits generally involve enhancing the thermal performance of building envelopes, installing energy efficient heating, ventilation, air-conditioning (HVAC) systems, and lighting upgrades (Ghita & Catalina, 2015; Liu et al., 2015). Evidence in the literature (Almeida & de Freitas, 2014; Ghita & Catalina, 2015; Hongisto et al., 2016) points to growing research interest in building renovations aimed at improving IEQ.

The studies reviewed in this section were sourced from electronic databases including Engineering Village, Science Direct and Scopus using the "AND" Boolean logic and a combination of keywords including "air quality", "energy retrofit", "indoor environment quality", "indoor air quality", "occupants' satisfaction", "renovation", "refurbishment", "retrofit", "schools", "school building" and "thermal comfort". Studies that did not include an assessment of occupants' IEQ satisfaction in relation to IEQ renovations were excluded. This resulted in a total of 10 peer-reviewed journal papers or studies, three of which focused on school buildings. These 10 studies were categorized into one of three types: 1) renovated versus non-renovated, 2) pre-renovation versus post-renovation, and 3) post-renovation. Renovation was used in this context to represent building maintenance interventions including retrofits, refurbishments, and repairs.

5.3.1 Renovated versus non-renovated

Studies under this category investigated occupants' IEQ satisfaction in renovated versus non-renovated buildings of the same occupancy type, in the same geographic area, and with the same climate. Table 5.1 summarizes the studies under this category. These studies support the thesis that IEQ-related renovations could improve occupants' IEQ satisfaction though none of them reported the statistical significance of their observed differences. Moreover, these studies involved surveying occupants in the renovated buildings post-renovation only. Pre-renovation differences were not accounted for.

Table 5.1. summary of renovated versus non-renovated buildings research studies

Study	Building/renovation details	Results
Liu et al. (2015)	*Buildings:* multi-family buildings; one energy retrofitted and five non-energy retrofitted. *Retrofit details:* improved thermal properties of building envelope and installed energy efficient HVAC.	Occupants of energy retrofitted buildings were the most satisfied with thermal comfort, indoor air quality, and acoustics; thermal comfort satisfaction difference was markedly high.
Földváry et al. (2015)	*Buildings:* naturally ventilated homes*;* six energy retrofitted and six non-energy retrofitted. *Retrofit details:* thermally insulated facades, energy efficient windows, and localized radiator control.	Occupants of energy retrofitted homes were the most satisfied with thermal comfort, however; they were the most dissatisfied with indoor air quality due to improved airtightness of envelopes and low ventilation rate.
Ghita and Catalina (2015)[a]	*Buildings:* naturally ventilated schools; one new, one renovated, and one old school. *Renovation details:* improved thermal properties of building envelope.	Students in new and renovated schools were the most satisfied with thermal comfort.

[a]This study was included in this category as new buildings represent a special case of non-renovated buildings.

5.3.2 Pre-renovation versus post-renovation

Pre-renovation versus post-renovation refers to studies that surveyed the IEQ satisfaction of the same group of occupants before and after a renovation intervention. The advantage of these studies is their ability to determine the specific effect of IEQ-related renovations due to their use of the same group of respondents in their pre-post research design. Their findings, summarized in

Table 5.2, confirmed findings of the renovated versus non-renovated studies and the thesis that IEQ-related renovations could improve occupants' IEQ satisfaction.

Table 5.2. Summary of pre-renovation versus post-renovation research studies

Study	Building/renovation details	Results
Hongisto et al. (2016)	*Buildings:* open-plan office; one refurbished office building. *Refurbishment details:* improved indoor air quality, thermal comfort, acoustics, and occupant density.	Statistically significant improvement in occupants' IEQ satisfaction and job satisfaction.
Noris et al. (2013)	*Buildings:* apartments; 16 energy retrofitted apartments. *Retrofit details:* retrofitted to improve energy performance and indoor air quality.	Majority of respondents reported improved indoor air quality.
Schreuder et al. (2015)	*Buildings:* office buildings; moved from 11 old to three new office buildings. *New building details:* environmentally friendly with superior IEQ.	Statistically significant improvement in IEQ satisfaction and well-being.
Zinzi et al. (2016)	*Buildings:* school building; three-story high renovated. *Renovation details:* insulated building envelope, installed mechanical ventilation, energy efficient windows, and new sun shades.	Proportion of students satisfied with thermal comfort, indoor air quality, daylighting, and acoustics before the renovations increased substantially after the renovations.

5.3.3 Post-renovation

Post-renovation studies summarized in Table 5.3 investigated occupants' IEQ satisfaction in renovated buildings only without comparing them to any other group of occupants or to the same group prior to the renovation, thereby limiting the implication of their results. Their results did not consistently confirm the thesis that IEQ-related renovations could improve occupants' IEQ satisfaction.

Table 5.3: Summary of post-renovation research studies

Study	Building/renovation details	Results
Singh, Mahapatra, and Teller (2014)	*Buildings:* homes; 80 renovated homes. *Refurbishment details:* double glazed windows and insulated roofing.	Majority of occupants were dissatisfied with thermal comfort.
Salleh, Kamaruzzaman, Riley, Ahmad Zawawi, and Sulaiman (2015)	*Buildings:* school buildings*;* 240 renovated buildings. *Retrofit details:* single unit homes, single and double-story terrace homes, and office buildings converted to kindergarten.	Teachers and other staff were most satisfied with daylight but were dissatisfied with indoor air quality and acoustics due to proximity of schools to busy road and violations of minimum classroom space requirements for children in Malaysia.
Wells et al. (2015)	*Buildings:* homes*;* 12 low-income new homes. *New building details:* six deep energy (DER) retrofitted and six energy star (ES) retrofitted.	Occupants of ES retrofitted homes were most satisfied with thermal comfort relative to those of DER due to latter's unfamiliarity with the newly installed heating system.

5.4 Methods

This two-stage, mixed-method research was conducted in collaboration with the Government of Manitoba Public School Finance Board and two Manitoba school divisions. Stage one involved adapting NRC's IEQ satisfaction survey developed for office workers (Veitch et al., 2007)) to assess teachers' IEQ satisfaction in schools. Additionally, preliminary surveys were developed to assess TPWB, TSWB, and TPhWB in schools using an inductive approach. These well-being surveys excluded questions on teachers' personal characteristics such as current health status due to restrictions by the University of Manitoba Research Ethics Board on collecting such data. The second stage involved administering an online survey composed of the adapted IEQ satisfaction survey and the new preliminary teacher well-being surveys developed in stage one.

Additionally, the administered surveys were refined through factor analysis shown in chapter 4. This chapter presents results from the refined adapted IEQ satisfaction and well-being surveys.

5.4.1 Study location and buildings

The two school divisions that participated in this research had a total of 32 schools. The schools were stratified into three based on their start date of operation and renovation records. The strata were named as new, renovated, and non-renovated schools. Detailed descriptions of the stratification strategy were presented in chapter 3 that explored the physical conditions of space enclosing elements in relation IEQ of classrooms in the new, renovated, and non-renovated schools. Schools in stratum 1 (i.e. new) were constructed in accordance with the NBC versions 1985 to 2010. Three of the oldest new schools were substantially upgraded within the last 10 years to enhance their IEQ while the rest only experienced routine maintenance such as replacing broken items (e.g. damaged window glazing). Schools in stratum 2 (i.e. renovated) were a mix of old and middle age schools constructed to NBC versions 1950 to 1980. All the schools in this stratum experienced substantial renovations from the year 2007 to 2014 to improve the quality of their indoor environments. Details of those renovations were presented in chapter 3. Stratum 3 schools (i.e. non-renovated) were also a mix of old and middle age schools constructed to NBC versions 1950 to 1980. However, they did not undergo the substantial IEQ-related renovations experienced by stratum 2 schools. Therefore, new schools were expected to have the most comfortable indoor environment followed by renovated and non-renovated schools respectively in descending order. Consequently, this research aimed to test the hypothesis that teachers' IEQ satisfaction and their well-being were statistically significantly higher in the new and renovated schools than in the non-renovated ones. It also aimed to test the hypothesis that teachers' IEQ satisfaction and well-being in the new and renovated schools were not statistically significantly different.

5.4.2 Study sample and online survey

The 852 teachers in all the 32 schools were invited to participate in this study. Table 5.4 presents the number of schools and teachers in each of the three strata of schools. The online survey was divided into four modules. Module 1 included the adapted IEQ satisfaction survey and demographic information. The core module of the original NRC survey (Veitch et al., 2007) included 18 items for assessing ventilation and thermal comfort, lighting, and acoustics and privacy. In adapting this survey, the wording of the items was slightly modified to suit school teachers and school environments, with an additional item included for daylight thus increasing the number of items from 18 to 19. Each of the 19 items was assessed using a seven-point scale from "Very Unsatisfactory" (-3) to "Very Satisfactory" (+3), like the NRC survey.

Table 5.4: Details of the study sample

Name of stratum	Abbreviated stratum name	Start date of operation	Number of schools	Number of teachers
New schools	New	1992 – 2012	7	172
Old/middle age recently renovated	Renovated	1971 – 1950	17	557
Old/middle age not recently renovated	Non-renovated	1971 – 1950	8	123

Modules 2, 3 and 4 consisted of the newly developed TPWB, TSWB, and TPhWB surveys respectively for assessing those three subdivisions of teachers' personal well-being principally in school environments. Items of the well-being surveys were assessed using a six-point scale from "Strongly Disagree" (1) to "Strongly Agree" (6). Most of the respondents completed the survey within 15 to 30 minutes. A total of 234 responses was recorded, resulting in a response rate of 27.5%. The survey was administered online using Qualtrics during the winter of 2016. Each respondent was assigned two modules: module 1 and an additional module assigned randomly. The total number of responses considered for analysis in chapter after excluding outliers were 177 for IEQ satisfaction, 61 for TPWB, 62 for TSWB, and 54 for TPhWB.

5.4.3 Refining of occupants' satisfaction and well-being surveys

The adapted IEQ satisfaction survey and the three newly developed well-being surveys were refined through factor analysis to extract the significant factors that defined their structure. Additionally, the three well-being surveys were validated by correlating them to their corresponding existing context-free validated well-being surveys. Details of factors, final surveys and their validation were presented in chapter 4. The final IEQ satisfaction survey consisted of 12 items and three factors namely "Lighting" (L_{sat}), "Ventilation and thermal comfort" (VTC_{sat}), and "Acoustics and privacy" (AP_{sat}). The TPWB survey consisted of 12 items and two factors namely "Job satisfaction and professionalism" and "Feeling of accomplishment and recognition". The TSWB survey consisted of 12 items and three factors namely "Social Functioning in School", "Social Connectedness in School" and "Classroom Socialization". The TPhWB survey also included 11 items and two factors namely "Role and Work Environment Outcomes" and "Physical Functioning in Class".

5.4.4 Data analysis

The scores for each of the three factors of IEQ were calculated by averaging the ratings of the items making up each factor. The factor scores were subsequently averaged to reach the overall IEQ satisfaction scores. The scores for TPWB, TSWB, and TPhWB were each calculated by averaging the ratings of the multiple items making up each survey. The IEQ satisfaction ratings were re-coded from their original scale of "Very Unsatisfactory" (-3) to "Very Satisfactory" (+3) to "Very Unsatisfactory" (1) to "Very Satisfactory" (7) for consistency and ease of comparison with the well-being ratings. Furthermore, the IEQ satisfaction ratings were categorized into three zones: the "dissatisfaction zone" (1.00 – 3.49), the "neutral zone" (3.50 – 4.49) and the "satisfaction zone" (4.50 – 7.00). Similarly, the well-being perception ratings were categorized into three perception levels: a "low level" (1.00 – 2.49), a "medium level" (2.50 – 4.49) and a "high level" (4.50 – 6.00). These categorizations did not involve re-coding the IEQ satisfaction and well-being ratings. Outliers were determined using standardized ratings with an absolute value of 3.29 as cut-off (Tabachnick & Fidell, 2001).

The differences in the mean ranks of teachers' IEQ satisfaction and well-being levels between the three strata of schools were assessed using the Kruskal-Wallis H test because the ratings were not normally distributed based on the Shapiro-Wilk test. Statistically significant differences were further investigated using pairwise comparisons with Bonferroni correction for multiple comparisons to determine the pairs of school strata that were statistically significantly different. The tests for the well-being levels were all statistically insignificant; hence, further analyses of differences were conducted based on the gender and age of respondents using either the Kruskal-Wallis H test or the Mann-Whitney U test. The five age groups shown in Table 5.5

were divided in two (i.e. 18-39 and 40-60+) for this analysis. Effect sizes were calculated to determine the magnitude of the differences in IEQ satisfaction and well-being for all statistically significant pairwise comparisons (Field, 2005). The Spearman rho correlation coefficients (ρ) were calculated to determine the levels of association between the three IEQ satisfaction factors and the three subdivisions of well-being.

5.5 Results

The section starts with the demographic information related to the survey, then proceeds to describe the results on the differences in IEQ satisfaction and well-being between the three strata of schools.

5.5.1 Demographic information

Table 5.5 presents the demographic information of the respondents included in the analysis. Table 5.5 shows that the number of responses from the renovated schools exceeded those in the new and non-renovated schools. This was expected given that 17 of the 32 schools were renovated schools. The age of respondents was fairly distributed from 18 to 59 years old, with most of them haven worked in their current school for three or more years and spent on average more than 30 hours per week in class. The number of female respondents was more than twice the number of males but fits the general observations made during site visits to 15 of the 32 schools.

Table 5.5. Demographic information

	School strata		
	New	Renovated	Non-renovated
School division			
Division 1	24	59	14
Division 2	28	15	37
Gender			
Female	38	57	41
Male	14	17	10
Age			
18 - 29	6	10	8
30 - 39	16	31	23
40 - 49	12	20	9
50 - 59	16	13	10
60 or over	2	0	0
Number of years in current school			
Less than a year	5	12	7
1 - 2 years	5	9	3
3 - 5 years	23	15	17
More than 5 years	19	38	24
Class time per week			
Less than 10 hours	7	9	1
10 – 20 hours	3	6	4
11 - 30 hours	7	7	7
More than 30 hours	33	51	39

5.5.2 Stratum level satisfaction with overall IEQ and its factors

Figure 5.1 depicts differences and similarities in the distribution of overall IEQ satisfaction ratings for teachers in the three strata of schools. Teachers in the new and renovated schools were the most satisfied with overall IEQ, with about 78.85% and 71.62% of respondents respectively in the satisfaction zone. For the non-renovated schools, only 47.06% of the respondents were satisfied. The most notable observation in Figure 5.1 is the relatively low median and mean level of overall IEQ satisfaction for teachers in the non-renovated schools.

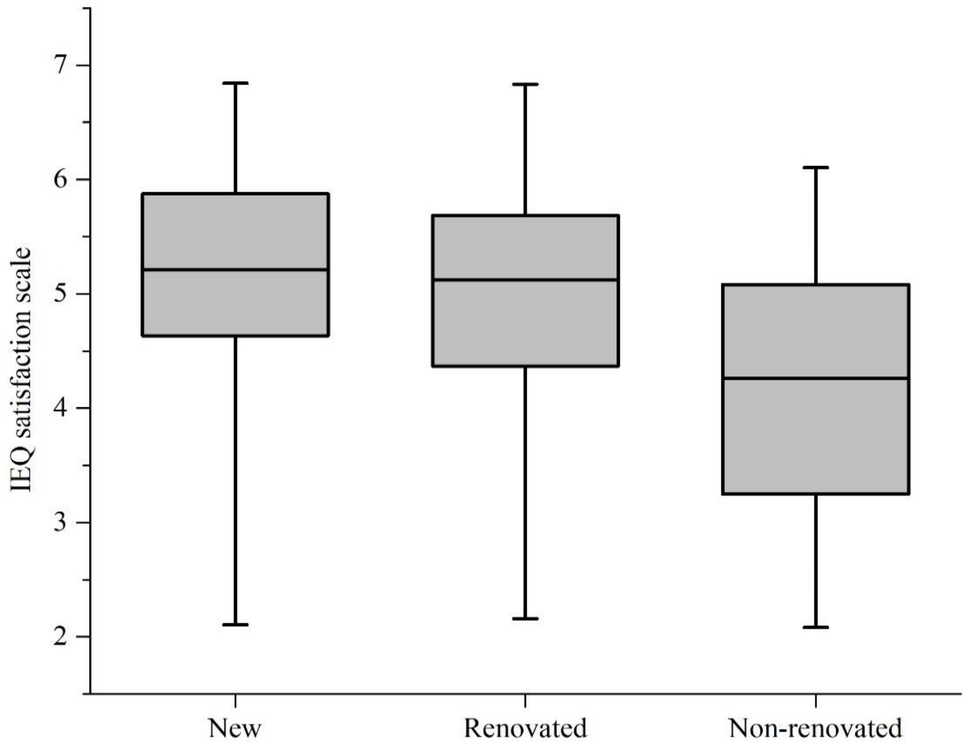

Figure 5.1. Stratum level distribution of overall IEQ satisfaction ratings

The histogram in Figure 5.2 depicts differences in respondents' satisfaction with the three factors of IEQ. The figure shows that the satisfaction levels with the three IEQ factors of teachers in the new and renovated schools were all above 60%, while those of teachers in the non-renovated schools were all below 60%. The proportion of teachers satisfied with the L_{sat} factor was substantially higher in both the new and renovated schools than in the non-renovated schools. The items assessed as part of the L_{sat} factor included the amount of daylight and access to a view of outside. The respective mean ratings of these two items were 5.34, 5.19 for new schools; 4.78, 5.05 for renovated schools; and 3.90, 3.76 for non-renovated schools. These mean ratings show that most teachers in the non-renovated schools were dissatisfied with these two items. This is not surprising given that most of these schools did not undergo major renovations within the last 10 years and thus probably have glazed windows with low light transmittance.

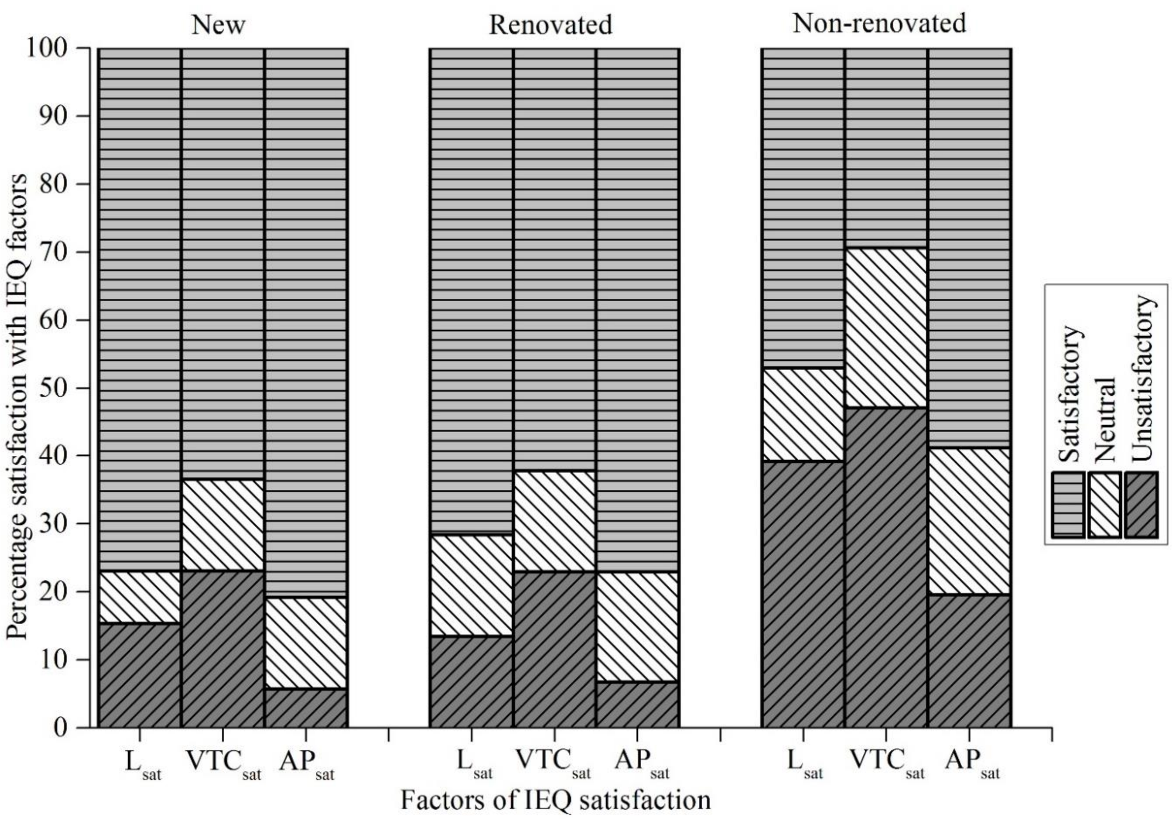

Figure 5.2. Stratum level teachers' satisfaction with IEQ factors.

As shown in Figure 5.2, teachers in the non-renovated schools were the least satisfied with AP_{sat}; however, the proportion of teachers dissatisfied with AP_{sat} (i.e. 19.61%) was lower than those dissatisfied with L_{sat} (i.e. 39.22%). The main source of dissatisfaction with AP_{sat} in the non-renovated schools was background noise with a mean rating of 4.19 and was probably caused by the noise emanating from the aging HVAC systems in these schools. Figure 5.2 also shows that VTC_{sat} was the factor with the lowest ratings in all three strata of schools, and with the most telling difference in satisfaction levels. Although teachers in the new and renovated schools were exceedingly more satisfied with VTC_{sat} than those in the non-renovated, none of the strata achieved the American Society of Heating, Refrigeration, and Air-conditioning recommendation of 80% satisfaction level (ASHRAE, 2010). As shown in Figure 5.2, the percentage of teachers dissatisfied with VTC_{sat} was the highest of the three IEQ satisfaction factors in each school strata, with the non-renovated schools recording the highest dissatisfaction level. Figure 5.3 depicts the mean ratings for the four items making up the VTC_{sat} factor and highlights its root source of differences.

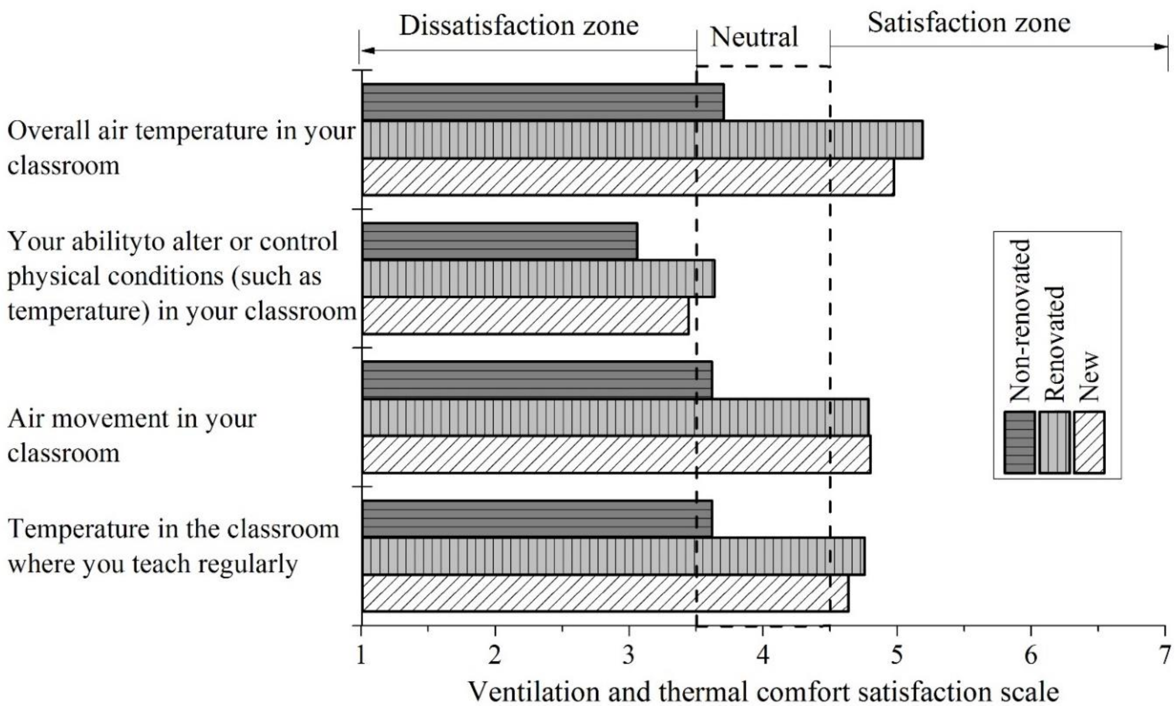

Figure 5.3. Stratum level mean teacher ratings of VTC_{sat} items

Teachers' ratings of the four items of VTC_{sat} in the non-renovated schools as shown in Figure 5.3 were generally low, with the mean ratings of three out of the four items falling in the lower region of neutral. In contrast, the mean ratings of three out of the four items for teachers in the new and renovated schools fell in the lower region of the satisfaction zone, thus explaining the generally low levels of satisfaction with VTC_{sat} in comparison to the other IEQ satisfaction factors. In general, the results suggest that respondents' limited ability to control VTC_{sat} parameters was the root cause of their dissatisfaction. The low ratings for occupants' control of their thermal environment across the three strata of schools were not surprising given that air temperature in almost all the schools was controlled remotely or onsite by the school divisions rather than by teachers themselves.

5.5.3 Stratum level differences between IEQ satisfaction factors

The Kruskal-Wallis H test showed statistically significant differences in the mean ranks of IEQ satisfaction factors across the three strata of schools. Firstly, the mean ranks for L_{sat} were 102.45 (n = 52), 95.01 (n = 74), and 66.53 (n = 51) for the new, renovated, and non-renovated schools respectively, and were statistically significantly different, $H(2) = 14.43$, $p = 0.001$. Secondly, the mean ranks for VTC_{sat} were 97.85 (n = 52), 100.33 (n = 74), and 63.54 (n = 51) for the new, renovated, and non-renovated schools respectively, and were statistically significantly different, $H(2) = 17.82$, $p = 0.0005$. Lastly, the mean ranks for AP_{sat} were 97.88 (n = 52), 94.73 (n = 74), and 71.63 (n = 51) for the new, renovated, and non-renovated schools respectively, and were statistically significantly different, $H(2) = 8.40$, $p = 0.015$.

The post hoc pairwise comparisons with Bonferroni correction for multiple comparisons are presented in Table 5.6, along with their effect sizes. The table shows statistically significant differences between the new and non-renovated schools and between the renovated and non-renovated schools for the three factors of IEQ satisfaction. None of the differences between the new and renovated schools were statistically significant. The effect sizes for all pairwise comparisons showed that the largest differences in teachers' IEQ satisfaction were in VTC_{sat}, followed by L_{sat} and finally AP_{sat}. The effect sizes of VTC_{sat} between both the new and non-renovated schools and the renovated and non-renovated schools suggest medium to high differences in satisfaction levels. Furthermore, the effect size of L_{sat} suggests a medium to high difference between the new and non-renovated schools and a low to medium difference between the renovated and non-renovated schools. Lastly, the effect sizes of the two statistically significant differences in AP_{sat} between the new and non-renovated schools and between the renovated and non-renovated schools suggest medium differences in satisfaction levels.

Table 5.6. Post hoc pairwise comparison of IEQ satisfaction variables

Pairwise comparisons	Test statistics	Adjusted significance	Effect size
L_{sat}			
New-non-renovated	35.893	0.001*	0.344
Renovated-non-renovated	28.455	0.007*	0.277
New-renovated	7.438	1.000	0.076
VTC_{sat}			
New-non-renovated	34.307	0.002*	0.327
Renovated-non-renovated	36.792	0.0005*	0.359
New-renovated	-2.485	1.000	0.019
AP_{sat}			
New-non-renovated	26.257	0.027*	0.255
Renovated-non-renovated	23.102	0.039*	0.223
New-renovated	3.155	1.000	0.031

5.5.4 Stratum level perception of the subdivisions of personal well-being

Figure 5.4 presents the similarities and differences in teachers' perception levels for the three subdivisions of well-being in the three strata of schools. Except for TPhWB in the new schools, teachers in all three strata of schools rated their well-being as high or medium.

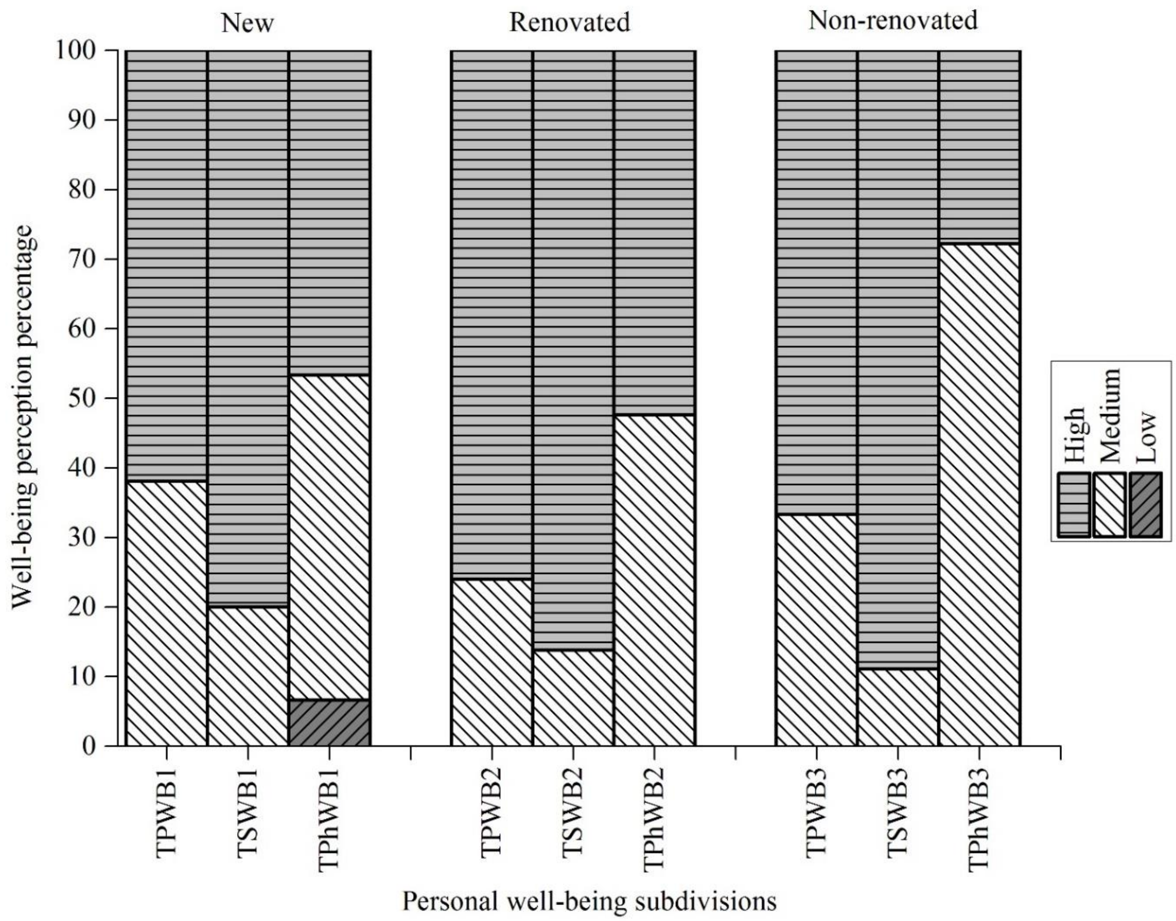

Figure 5.4. Stratum level teachers' perception of the three subdivisions of personal well-being

Figure 5.4 shows that the highest ratings in each school stratum were for TSWB with mean ratings of 5.22, 5.09, and 4.96 in the renovated, non-renovated, and new schools respectively. This contradicted the consistently high IEQ ratings in the new and renovated schools relative to the non-renovated. The TPWB was the second highest rated subdivision of well-being in each stratum with mean ratings of 4.79, 4.74, and 4.67 in the renovated, new, and non-renovated schools respectively. TPhWB was the lowest rated subdivision in each stratum with mean ratings of 4.53, 4.07, and 4.00 in the renovated, new, and non-renovated schools respectively.

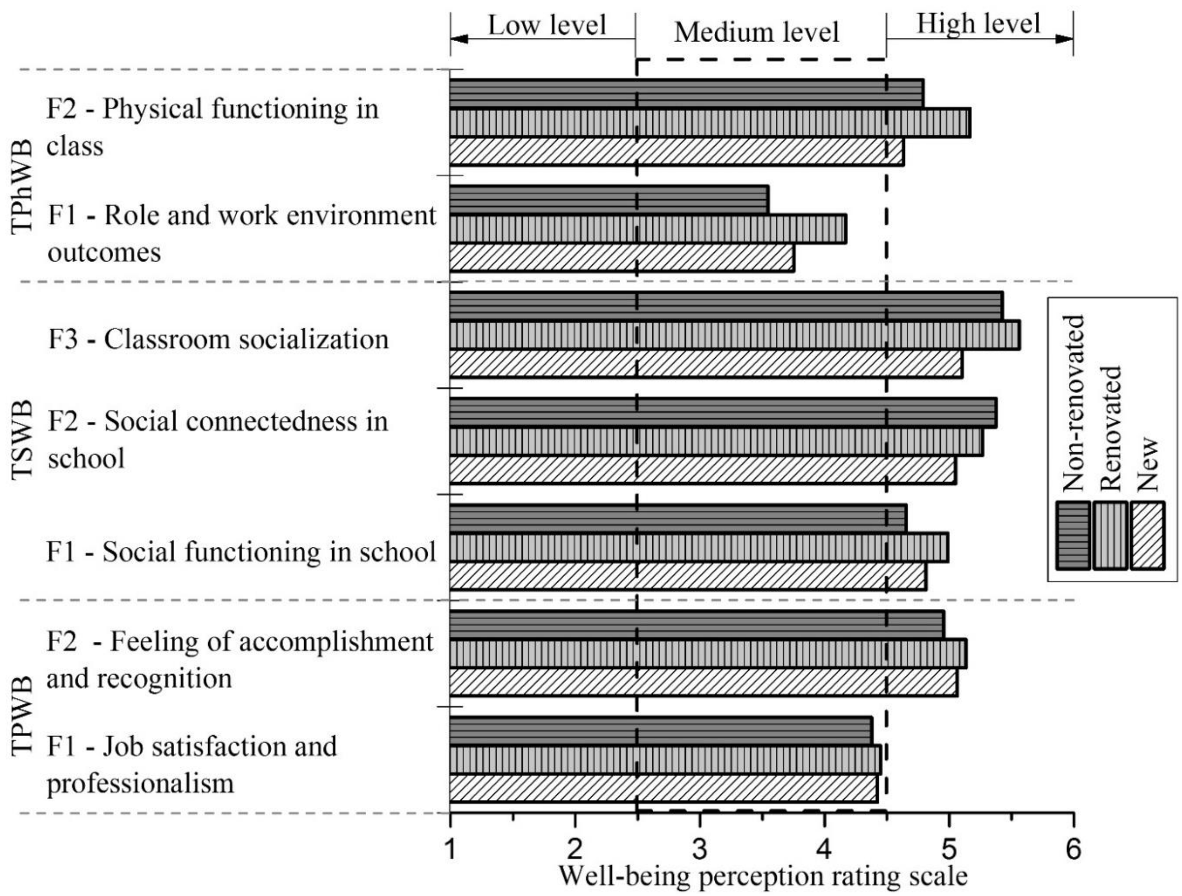

Figure 5.5. Stratum level mean ratings of the factors of personal well-being subdivisions

Figure 5.5 shows the similarities and differences in the mean ratings of TPWB, TSWB, and TPhWB factors for the three school strata. As shown, the mean ratings of the three factors of TSWB for each school stratum were in the high-level zone, thus explaining the general high mean ratings for TSWB. The "Role and work environment outcomes" factor of the TPhWB was the least rated of all the well-being factors and explains why TPhWB was the lowest rated subdivision of well-being. The items of the factor "Role and work environment outcomes" described mainly the negative consequences on teachers working in a school's indoor environment including "I frequently get running nose, dry throat and lips, or watery eyes in school". The low ratings for this TPhWB factor across all school strata corresponded with the low ratings of the VTC_{sat} factor in this study: a result that is in line with those of previous IEQ studies (Madureira et al., 2009; Witterseh et al., 2004). Examination of both Figure 5.4 and Figure 5.5 shows marginal differences in well-being perception levels between the three strata of schools.

5.5.5 Stratum level differences between subdivisions of individual well-being

The Kruskal-Wallis H test showed no statistically significant differences between TPWB, TSWB, and TPhWB across the three school strata. Therefore, between strata and within strata analyses were conducted to determine if the two individual characteristics of teachers' gender and age influenced their well-being ratings. The Kruskal-Wallis H test between the three strata for TPWB and TSWB showed no statistically significant difference between gender and the two age groups. For TPhWB, the test showed a statistically significant difference between females and the 40-60+ age groups. Firstly, the mean ranks for females were 18.55 (n = 8), 28.62 (n = 17), and 18.72 (n = 16) for the new, renovated and non-renovated schools respectively. Lastly, the mean ranks for the 40-60+ age groups were 10.42 (n = 6), 17.71 (n = 12), and 9.50 (n = 8) respectively for the new, renovated and non-renovated schools respectively. Pairwise comparison with Bonferroni correction for multiple comparisons showed that none of the pairs of strata were statistically significantly different for both females and the two age groups. The Mann-Whitney U test within each stratum for TSWB and TPhWB showed no statistically significant difference for gender and the two age groups. Additionally, the test showed no statistically significant difference in TPWB within each stratum for gender and the two age groups except in the non-renovated schools, where TPWB mean ranks were significantly different between females (mean = 4.86) and males (mean = 4.13), U = 6.00, z = -2.10, p = 0.04.

5.5.6 Associations between well-being and IEQ satisfaction factors

Table 5.7 shows that VTC_{sat} was not statistically significantly associated with TPWB; however, it had the highest statistically significant moderate positive associations with TSWB and TPhWB. AP_{sat} had the second highest statistically significant moderate associations with both TSWB and TPhWB, whereas L_{sat} was moderately associated with TPhWB only.

Table 5.7. Correlations between IEQ variables and well-being measures

New teachers' well-being measures	Correlation coefficient and significance level (*p*)		
	L_{sat}	VTC_{sat}	AP_{sat}
Teachers' psychological well-being (TPWB)	0.199 (0.125)	0.230 (0.075)	0.239 (0.064)
Teachers' social well-being (TSWB)	0.207 (0.106)	0.485**(0.000)	0.351**(0.005)
Teachers' physical well-being (TPhWB)	0.348**(0.010)	0.582**(0.000)	0.383**(0.004)

Note: ** denotes significant correlation at level 0.01; * denotes significant correlation at level 0.05; values in parenthesis denotes the level of significance for correlation coefficients

5.6 Discussion

The results of this research supported the hypothesis that teachers' satisfaction with IEQ was statistically significantly higher in the new and renovated schools than in the non-renovated schools. It also supported the hypothesis that the difference in teachers' satisfaction with IEQ in the new versus the renovated schools was statistically insignificant. As building codes improve over the years, newer versions are generally expected to improve the overall performance of buildings which should translate to more comfortable, safer and healthier indoor environments for occupants. Hence, the new schools were expected to have the best indoor environmental conditions and thus the most satisfied teachers given that they followed recent versions of the NBC relative to the renovated and non-renovated schools. However, the insignificant difference between teachers' IEQ satisfaction in the new and renovated schools suggests that the IEQ-related renovations of the latter probably improved their IEQ performance to the level of the IEQ performance of the new schools. This was evident in the pattern of IEQ satisfaction in both strata of schools, where for example both groups of teachers were concurrently satisfied and dissatisfied with items of VTC_{sat}.

Given that the renovated and non-renovated schools were similar (i.e. a mix of old and middle age schools), the statistically significant difference between their teachers' IEQ satisfaction can be attributed to the IEQ-related renovations of the renovated schools. These renovations involved tightening building envelopes with insulation to minimize thermal loses and enhance thermal comfort. While this strategy would have reduced both the exfiltration of indoor air contaminants and infiltration of outdoor air, the refurbishing or replacing of existing HVAC systems in the renovated schools would have increased the supply of outdoor air for ventilation, reducing the concentration of indoor air contaminants. Hence, the synergy between both strategies probably led to significantly higher VTC_{sat} for teachers in the renovated schools than the non-renovated schools. Similar propositions can also be used to explain the differences in both L_{sat} and AP_{sat} between teachers in renovated and non-renovated schools. These findings are consistent with the ones in the literature (Ghita & Catalina, 2015; Schreuder et al., 2015; Thomsen et al., 2016) regarding the likely impact of IEQ-related renovations on occupants IEQ satisfaction.

The research also supported the hypothesis that the difference in teachers' well-being in the new versus the renovated school was statistically insignificant but did not support the hypothesis that teachers' well-being was statistically significantly higher in the renovated schools than in the non-renovated. This suggested that IEQ-related renovations did not lead to noteworthy improvements in the well-being perception of teachers in the renovated schools like they did for their IEQ satisfaction. It may also be that the renovated schools experienced substantial improvement in well-being without that improvement leading to statistically significant differences with the non-renovated schools. This could be because the physical and IEQ conditions of the renovated schools, and their teachers' well-being were worse prior to the renovations than the conditions of the non-renovated ones.

Further analyses suggested that the gender and age of teachers influenced their well-being perception. TPhWB scores for both females and teachers within the 40-60+ age bracket was statistically significantly different across the three strata of schools. Although the post hoc analysis showed no significant differences between pairs of school strata, this suggests that the impact of IEQ-related renovations on teachers' well-being is probably highly dependent on personal characteristics such as gender, age and other characteristics not included in this study. The results also showed that female teachers' perception of TPWB was statistically significantly higher than male teachers in the non-renovated schools, but not in the new and renovated schools.

The study results also showed statistically significant weak to medium associations of TSWB and TPhWB with the three IEQ variables. Although the significant correlations do not imply causation, one potential explanation is that the IEQ-related renovations may have enhanced IEQ satisfaction and subsequently enhanced teachers' TPhWB and TSWB perceptions. The insignificant associations between TPWB and IEQ variables do not imply a lack of relationship as these may become statistically significant with a larger sample size. They may also be due to TPWB being the least physically observable of the three well-being subdivisions.

With respect to IEQ satisfaction, the effect sizes in this study showed that the magnitude of the observed difference in VTC_{sat} satisfaction in renovated versus non-renovated schools was the largest, followed by L_{sat} and AP_{sat}. Hence, based on the results of this research, IEQ-related renovations are likely to have the most positive impact on VTC_{sat} followed by L_{sat} and AP_{sat}. Although AP_{sat} significantly correlated with TSWB and TPhWB while L_{sat} significantly correlated with TPhWB only, L_{sat} was ranked second to VTC_{sat} not based on its effect size but because of the reported biological benefits of light generally, and particularly its impact on learning in schools. Bright light, both natural and artificial, synchronizes the internal body clock with the daily day and night routine so that people are awake during the day and sleep at night (van Bommel, 2006b). Hence, bright light, especially daylight exposure during the day contributes to alertness during daytime and quality of sleep at night (van Bommel, 2006b). For schools, in particular, Tanner (2008) found a significant positive relationship between daylighting and students' academic achievement.

The results of this study can be used by school divisions as part of their maintenance decision-making process. Nielsen, Jensen, Larsen, and Nissen (2016) proposed goal setting as the first stage of developing a sustainable renovation decision-making tool. This involved defining clients' sustainability objectives, criteria, and appropriate weightings. School divisions looking to renovate their schools can define the objectives of their renovation interventions in terms of the specific improvements they would like to see in teachers' IEQ satisfaction and well-being. They can use the study's IEQ and well-being surveys to establish suitable benchmarks for IEQ satisfaction and well-being. They can also use the effect sizes for the differences in each IEQ factor between the renovated and non-renovated schools as the respective weightings for prioritization. These effect sizes may be reassessed for prioritization purposes as indoor conditions improve. Nielsen et al. (2016) also proposed the registration and ranking of buildings as part of the sustainable renovation decision-making tool. Registration involves collecting information on the renovation needs of buildings. With this information, school divisions can categorize each defect in each school building into three based on the IEQ factor that is expected to improve when a defect is repaired. This should allow them to prioritize the maintenance needs of each school, and rank each school based on those needs as part of their maintenance decision-making process.

5.7 Conclusion

This research investigated teachers' IEQ satisfaction and well-being in new, renovated, and non-renovated schools. The results suggested that IEQ-related renovations in existing schools can be an effective strategy for improving teachers' IEQ satisfaction and probably their well-being. Considering that the renovated and non-renovated school strata were each composed of both old and middle age schools, the statistically significant differences in teachers' IEQ satisfaction between the two strata of schools can be attributed to the IEQ-related renovations in the renovated schools. This assertion is further supported by the statistically insignificant difference in teachers' IEQ satisfaction between the renovated and new schools probably due to the improved indoor conditions in the former because of the IEQ-related renovations they underwent. However, this study suggested that IEQ-related renovations would require planned integration of different strategies to yield the desired IEQ satisfaction outcome. For example, the likely synergy between reinsulating building envelopes and refurbishing or replacing existing HVAC systems in the renovated schools seem to account for the statistically significantly higher VTC_{sat} for teachers in the renovated schools in comparison with the non-renovated schools.

Teachers' well-being perception ratings were not statistically significantly different across the three strata of schools. The statistically insignificant difference in well-being perception and the statistically significant difference in IEQ satisfaction between teachers in the renovated and non-renovated schools suggested that well-being perception and IEQ satisfaction were not similarly affected by IEQ-related renovations. However, the results suggested that personal characteristics such as gender and age may be essential in determining the impact of IEQ-related renovations on occupants' well-being. The test of associations also suggested a plausible indirect impact of school's IEQ-related renovations on teachers' well-being via improved IEQ satisfaction. The most promising indirect positive impact is likely that of IEQ-centered renovations on TPhWB via improvement of their VTC_{sat}. These results confirm that occupants' IEQ satisfaction and their well-being are probably not the same and should, therefore, be assessed separately.

This study used post-renovation data to investigate the impact of IEQ-related renovations on the IEQ satisfaction and well-being of teachers in renovated schools relative to teachers in new and non-renovated schools. The lack of pre-renovation data implies that the actual improvement in IEQ satisfaction and well-being of teachers in the renovated schools were not accounted for in this study. Hence, future studies should adopt a pre-post research design that would account more accurately for actual improvements in IEQ satisfaction and well-being due to specific renovation interventions. Not only was the population for this study limited, but each respondent was assigned the IEQ satisfaction survey in addition to only one of the three well-being surveys deployed as part of this study. This deployment strategy shortened the completion time of the online survey; however, it resulted in fewer respondents completing each of the three well-being surveys which may explain most of the statistically insignificant differences in well-being perception between the three strata of schools. Given that the research used an adapted and refined teachers' IEQ satisfaction survey, and newly developed and refined well-being surveys, future research should deploy these refined surveys to a larger population of teachers to confirm their structural validity and enable the generalization of their results.

5.8 Acknowledgment

This research would not have been possible without the support of the Government of Manitoba Public School Finance Board, the two School Division, and the 32 schools. The authors are particularly grateful to all teachers who participated in the online survey.

5.9 References

Allen, P., & Marples, C. L. (1998). Notched-noise and quiet detection thresholds as early indicators of auditory system damage in school-aged children. *Canadian Acoustics - Acoustique Canadienne, 26*(3), 62-63.

Almeida, R. M. S. F., & de Freitas, V. P. (2014). Indoor environmental quality of classrooms in Southern European climate. *Energy and Buildings, 81*, 127-140. doi: 10.1016/j.enbuild.2014.06.020

Angela, L., Abbas, E., & David, R. (2011). Linking energy and maintenance management for sustainability through three American case studies. *Facilities*, *29*(5/6), 243-254. doi: 10.1108/02632771111120547

ASHRAE. (2010). Thermal Environmental Conditons for Human Occupancy. Atlanta: the American Society of Heating, Refrigerating and Air-Conditioning Engineers.

Bradley, J. S., & Sato, H. (2008). The intelligibility of speech in elementary school classrooms. *The Journal of the Acoustical Society of America, 123*(4), 2078-2086. doi: doi:http://dx.doi.org/10.1121/1.2839285

Buckley, J., Schneider, M., & Shang, Y. (2005). Fix it and they might stay: School facility quality and teacher retention in Washington, DC. *The Teachers College Record, 107*(5), 1107-1123.

Eweda, A., Zayed, T., & Alkass, S. (2015). Space-Based Condition Assessment Model for Buildings: Case Study of Educational Buildings. *Journal of Performance of Constructed Facilities, 29*(1), 04014032. doi: doi:10.1061/(ASCE)CF.1943-5509.0000481

Exner, D., D'Alonzo, V., Paoletti, G., Pascual, R., & Pernetti, R. (2017). *Building-Stock Analysis for the Definition of an Energy Renovation Scenario on the Urban Scale*. Paper presented at the SSPCR 2015, the 1st International Conference on Smart and Sustainable Planning for Cities and Regions, Bolzano, Italy.

Field, A. (2005). *Discovering statistics using SPSS statistics* (2 ed.). London: Sage Publication.

Földváry, V., Bukovianska, H. P., & Petráš, D. (2015). Analysis of Energy Performance and Indoor Climate Conditions of the Slovak Housing Stock Before and After its Renovation. *Energy Procedia, 78*, 2184-2189. doi: http://dx.doi.org/10.1016/j.egypro.2015.11.314

Gaudreault, V., Overton, D., & Trstenjak, J. (2009). Age of education infrastructure: recent trends (11-621-M, no. 81). Retrived from http://www.statcan.gc.ca/pub/11-621-m/11-621-m2009081-eng.pdf

Ghita, S. A., & Catalina, T. (2015). Energy efficiency versus indoor environmental quality in different Romanian countryside schools. *Energy and Buildings, 92*, 140-154.

Harris, D. N., & Sass, T. R. (2014b). Skills, productivity and the evaluation of teacher performance. *Economics of Education Review, 40*, 183-204.

Hongisto, V., Haapakangas, A., Varjo, J., Helenius, R., & Koskela, H. (2016). Refurbishment of an open-plan office - Environmental and job satisfaction. *Journal of Environmental Psychology, 45*, 176-191. doi: 10.1016/j.jenvp.2015.12.004

Langevine, R., Allouche, M., & AbouRizk, S. (2006a). *Decision support tool for the maintenance management of buildings*. Paper presented at the Joint International Conference on Computing and Decision Making in Civil and Building Engineering, Montréal, Canada.

Liu, L., Rohdin, P., & Moshfegh, B. (2015). Evaluating indoor environment of a retrofitted multi-family building with improved energy performance in Sweden. *Energy and Buildings, 102*, 32-44. doi: http://dx.doi.org/10.1016/j.enbuild.2015.05.021

Madureira, J., Alvim-Ferraz, M. C. M., Rodrigues, S., Gonçalves, C., Azevedo, M. C., Pinto, E., & Mayan, O. (2009). Indoor Air Quality in Schools and Health Symptoms among Portuguese Teachers. *Human and Ecological Risk Assessment: An International Journal, 15*(1), 159-169.

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.

Nielsen, A. N., Jensen, R. L., Larsen, T. S., & Nissen, S. B. (2016). Early stage decision support for sustainable building renovation–A review. *Building and Environment, 103*, 165-181.

Noris, F., Adamkiewicz, G., Delp, W. W., Hotchi, T., Russell, M., Singer, B. C., . . . Fisk, W. J. (2013). Indoor environmental quality benefits of apartment energy retrofits. *Building and Environment, 68*, 170-178. doi: 10.1016/j.buildenv.2013.07.003

Ott, W., & Bolliger, R. (2015). Pitfalls in the Economic and Ecological Evaluation of Energy Related Building Renovation Strategies and Measures. *Energy Procedia, 78,* 2340-2345.

Salleh, N. M., Kamaruzzaman, S. N., Riley, M., Ahmad Zawawi, E. M., & Sulaiman, R. (2015). A quantitative evaluation of indoor environmental quality in refurbished kindergarten buildings: A Malaysian case study. *Building and Environment, 94*, 723-733. doi: 10.1016/j.buildenv.2015.11.002

Schreuder, E., van Heel, L., Goedhart, R., Dusseldorp, E., Schraagen, J. M., & Burdorf, A. (2015). Effects of newly designed hospital buildings on staff perceptions: A pre-post study to validate design decisions. *Health Environments Research and Design Journal, 8*(4), 77-97. doi: 10.1177/1937586715573736

Singh, M. K., Attia, S., Mahapatra, S., & Teller, J. (2016). Assessment of thermal comfort in existing pre-1945 residential building stock. *Energy, 98*, 122-134. doi: http://dx.doi.org/10.1016/j.energy.2016.01.030

Singh, M. K., Mahapatra, S., & Teller, J. (2014). Relation between indoor thermal environment and renovation in liege residential buildings. *Thermal Science, 18*(3), 889-902. doi: 10.2289/TSCI1403889S

Statistics Canada. (2016, May 10, 2016). Capital and repair expenditures by North American Industry Classification System (NAICS), Canada. Retrieved 24 October 2016, from http://www5.statcan.gc.ca/cansim/a26

Tabachnick, B. G., & Fidell, L. S. (2001). *Using multivariate statistics* (4 ed.). Needham Height, MA: Allyn & Bacon.

Tanner, C. K. (2008). Explaining relationships among student outcomes and the school's physical environment. *Journal of Advanced Academics, 19*(3), 444-471.

Thomsen, K. E., Rose, J., Mørck, O., Jensen, S. Ø., Østergaard, I., Knudsen, H. N., & Bergsøe, N. C. (2016). Energy consumption and indoor climate in a residential building before and after comprehensive energy retrofitting. *Energy and Buildings, 123*, 8-16. doi: http://dx.doi.org/10.1016/j.enbuild.2016.04.049

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.

van Bommel, W. J. M. (2006b). Non-visual biological effect of lighting and the practical meaning for lighting for work. *Applied Ergonomics, 37*(4), 461-466. doi: http://dx.doi.org/10.1016/j.apergo.2006.04.009

Veitch, J. A., Charles, K. E., Farley, K. M. J., & Newsham, G. R. (2007). A model of satisfaction with open-plan office conditions: COPE field findings. *Journal of Environmental Psychology, 27*(3), 177-189. doi: 10.1016/j.jenvp.2007.04.002

Wells, E. M., Berges, M., Metcalf, M., Kinsella, A., Foreman, K., Dearborn, D. G., & Greenberg, S. (2015). Indoor air quality and occupant comfort in homes with deep versus conventional energy efficiency renovations. *Building and Environment, 93, Part 2*, 331-338. doi: http://dx.doi.org/10.1016/j.buildenv.2015.06.021

Witterseh, T., Wyon, D. P., & Clausen, G. (2004). The effects of moderate heat stress and open-plan office noise distraction on SBS symptoms and on the performance of office work. *Indoor air, 14*(s8), 30-40.

Zinzi, M., Agnoli, S., Battistini, G., & Bernabini, G. (2016). Deep energy retrofit of the TM Plauto School in Italy—A five years experience. *Energy and Buildings, 126*, 239-251.

Connecting Section

The previous chapter, chapter 5, assessed differences in teachers IEQ satisfaction and well-being in new, renovated, and non-renovated schools using scores of the refined IEQ satisfaction survey and the refined and validated well-being surveys from chapter 4. The results showed statistically significant differences in IEQ satisfaction scores between the renovated and non-renovated schools, and between the new and non-renovated schools. However, differences in IEQ satisfaction between the renovated and new schools were statistically insignificant. The physical conditions of the renovated schools were like the non-renovated school prior to the IEQ-related renovations described in chapter 3. The results, therefore, suggested that the IEQ-related renovations of the renovated schools resulted in improved occupants' IEQ satisfaction. None of the differences in well-being scores between the three school strata were statistically significant and thus seem to support the conclusion in chapter 4 that the impact of IEQ on well-being is likely indirect through occupants' IEQ satisfaction. Chapter 5 addressed objective three of this thesis.

The next chapter, chapter 6, integrated the data from SLCA, IEQ field measurements, and occupants' survey to assess the impact of the physical conditions of classrooms space enclosing elements on IEQ parameters and subsequently on teachers' IEQ satisfaction and well-being. The methods section of chapter 6 includes summaries of the SLCA, IEQ field measurement protocol, and occupants' surveys only, given that these were extensively described in chapter 3. Chapter 6 addresses objective four of this thesis.

CHAPTER 6: Conditional Effects of Indoor Environmental Quality Parameters on Occupants' Satisfaction Based on Defects of School Building Envelope Elements

A version of this chapter was submitted to the "Indoor Air" Journal.

Sadick, A.-M., & Issa, M. H. (2018). Occupants' indoor environmental quality satisfaction factors as measures of school teachers' well-being. Indoor Air.

The first author was responsible for the conception and design of the work, the data collection, data analysis and the drafting of the journal paper. The second author supervised the work and critically revised the paper.

6.1 Abstract

There is limited empirical evidence on how the physical conditions of building envelope elements moderate the impact of indoor environmental quality parameters on building occupants. Therefore, this research aimed to investigate the conditional effects of indoor environmental quality parameters on teachers' indoor environmental quality satisfaction based on the physical conditions of school building elements. This research involved snapshot field measurements of the indoor environmental quality parameters of thermal comfort, indoor air quality, lighting and acoustics in 52 classrooms in 10 schools in Southern Manitoba. An online occupants' survey was also administered to the teachers in those schools to investigate their indoor environmental quality satisfaction. An indoor environmental quality-related building condition assessment was also conducted to assess defects in the physical condition of the building envelope element of those schools' classrooms. Moderation analyses showed statistically significant conditional effects of particulate matter on teachers’ ventilation and thermal comfort satisfaction based on indoor air quality-related finishes and electrical defects. Additionally, a statistically significant conditional effect of daylight factor on lighting satisfaction was found due to lighting-related openings defects. Findings of this research should be of interest school divisions looking to develop operation and maintenance strategies to sustain quality indoor environments and minimize negative impacts on occupants.

Keywords: indoor environmental quality, building condition assessment, moderation analysis, school buildings, occupants’ satisfaction, teachers

6.2 Introduction

A significant proportion of human activities takes place indoors, thus supporting the plethora of research exploring the human-indoor environment interaction (e.g. Boerstra, Beuker, Loomans, & Hensen, 2013; Mendell et al., 2015; Norbäck, Hashim, Hashim, & Ali, 2017). IEQ researchers have investigated different aspects and variables that influence the human-indoor environment interaction, particularly in office buildings (e.g. Kolarik, Toftum, Olesen, & Shitzer, 2009; Sakellaris et al., 2016; Tanabe, Nishihara, & Haneda, 2007). Studies that investigated IEQ in schools mainly focused on its impact on students (e.g. Evans, Yoo, & Sipple, 2010; Wargocki & Wyon, 2007). Given the reported potential benefits of improving IEQ, several studies investigated building renovations aimed at improving IEQ and their impact on building occupants (Sadick & Issa, 2017a; Zinzi et al., 2016). These renovation studies usually focused on the IEQ outcomes of the renovations and not on the physical conditions of building elements that occasioned them. Although the issue of mounting deferred maintenance of school buildings is well reported in the literature (Filardo, 2008; Filardo, Bernstein, & Eisenbrey, 2011; Gaudreault et al., 2009), the impact of school building elements' defects on IEQ and subsequently occupants have received less research attention. Therefore, there is limited empirical evidence to guide strategic operation and maintenance decision-making by school managers looking to maintain their buildings with limited resources.

This research was conducted in collaboration with the Government of Manitoba Public School Finance Board and two Manitoba School Division as part of a larger initiative aimed at investigating schools' physical and IEQ conditions in relation to teachers' satisfaction and well-being. The aim of this research was to investigate the impact of the physical condition of key school building envelope elements on IEQ parameters and subsequently on teachers' IEQ satisfaction. This research had three main components. Firstly, field measurements of thermal comfort, indoor air quality, lighting, and acoustics were conducted in 52 classrooms in 10 schools in Southern Manitoba. Secondly, the physical conditions of the space envelope elements of those 52 classrooms were assessed using the SLCA developed as part of the larger initiative. Lastly, the IEQ satisfaction and well-being of teachers in the schools were assessed using surveys developed and administered online via Qualtrics. All three components were conducted in the winter of 2016. This research should be of interest to school divisions and managers looking to develop operation and maintenance strategies to sustain quality indoor environments in schools and enhance school occupants' satisfaction and well-being. Moreover, the findings of this research will be of interest to IEQ researchers looking to investigate building envelope elements in relation to IEQ conditions and occupants' IEQ satisfaction. They will also be of interest to building managers, in general, looking to prioritize operation and maintenance activities, improve IEQ, and minimize the risk of complaints and potential lawsuits by tenants due to poor indoor environments. This chapter addresses objective four of this research presented in chapter 1.

6.3 Background information

Building occupants' subjective assessment of their indoor environment is one of the primary and most employed methods to assess buildings' IEQ (Fadeyi, 2014; Lan, Lian, & Pan, 2010; Sakellaris et al., 2016). The subjective assessment of IEQ usually gives an indication of how occupants' interaction with their indoor environment affects their comfort given the considerable time they spend indoors (Muhič & Butala, 2004). This satisfaction has been found in general to be below recommended levels in the literature (Brager, Zhang, & Arens, 2015; Sadick & Issa, 2017a). Several studies showed that occupants' IEQ satisfaction is influenced by several known and unknown factors including individual control of the environment, personal characteristics, and building characteristics. For example, Boerstra et al. (2013) found a substantial relationship between occupants' perceived control of their indoor environment and indoor air quality satisfaction in office buildings, with those with the highest perceived control being the most satisfied (Boerstra et al., 2013). Brager and Baker (2009) found that occupants of office and educational buildings with mixed-mode ventilation system were satisfied with thermal comfort and indoor air quality due to their ability to access and control operable windows. Choi and Moon (2017) found that junior and middle-aged office building occupants preferred a working plane with higher illuminance and higher air velocity than senior occupants (Choi & Moon, 2017). Additionally, office workers in perimeter workstations preferred higher air velocity and illuminance than those with workstations at the core of the building (i.e. spatial factor) (Choi & Moon, 2017).

A significant proportion of human activities in all domains of life take place within indoor spaces enclosed by building envelope elements including walls, floors, and ceilings. Therefore, the environmental quality of these indoor spaces and occupants' satisfaction with it will plausibly depend on the physical conditions of the enclosing elements. Schreuder et al. (2015) reported significant improvements in IEQ satisfaction and well-being for workers who moved from 11 old conventional office buildings to three new green office buildings. Hongisto et al. (2016) found significant improvements in occupants' IEQ and job satisfaction following the refurbishment of an open-plan office. Brager and Baker (2009) concluded that occupants of newer mixed-mode office and educational buildings were most satisfied than those in older buildings. The literature showed that school buildings' renovations aimed at improving IEQ can also have a positive effect on occupants. Ghita and Catalina (2015) reported that students in new and renovated school buildings were more satisfied with thermal comfort than students in an old school. Zinzi et al. (2016) found substantial increases in the number of students satisfied with thermal comfort, indoor air quality, daylight, and acoustics following school building renovations. Evans et al. (2010) found that school buildings' physical condition substantially affected students' performance, with that effect highest in schools with high student mobility (i.e. students who changed schools frequently).

Despite the reported benefits of school buildings' renovations focused on improving IEQ, school buildings generally have a history of deferring maintenance due to limited maintenance budgets (Cash & Twiford, 2009; Lavy & Nixon, 2017; Uline & Roberts, 2009). Deferred maintenance has, therefore, resulted in poor school building conditions globally (Borge & Hopland, 2017; Hunter, 2009; Xaba, 2012). To illustrate, a school building condition survey in the

United States in 2014 estimated that US$200 billion was required to renovate deteriorated schools to avoid deferring maintenance (Conlin & Thompson, 2017). Additionally, the Australian government in 2009 committed approximately A$15 billion to the renewal of primary schools nationwide (McShane, 2012). Most studies (Durán-Narucki, 2008; Lavy & Nixon, 2017; Maxwell, 2016) that investigated school building condition focused on its impact on students' academic achievement. For example, both Maxwell (2016) and Durán-Narucki (2008) found that school buildings' condition was a statistically significant predictor of students' academic achievements. Although there has been limited focus on teachers, Earthman and Lemasters (2009) found that teachers in schools with satisfactory building condition ratings perceived their classrooms to be suitable for teaching and learning while those in unsatisfactory schools had a contrary perception of their classrooms.

The literature generally supports targeted building renovations aimed at improving IEQ as an effective strategy to enhance occupants' satisfaction and performance (e.g. Hongisto et al., 2016; Schreuder et al., 2015). However, studies that investigated the IEQ benefits of renovations (e.g. Thomsen et al., 2016; Zinzi et al., 2016) did not account for the effect of the physical conditions of space envelope elements on IEQ parameters (i.e. daylight, temperature, and relative humidity) and subsequently building occupants, thus highlighting their limitation. Similarly, the studies that investigated the conditions of school buildings on occupants' satisfaction and performance, did not account for their impact on IEQ parameters. These limitations emphasize the need to investigate how the physical conditions of building elements moderates the effects of IEQ parameters on occupants to enable strategic renovation decision-making. For example, the impact of indoor air temperature fluctuations on occupants' thermal comfort satisfaction and performance would likely be influenced by cracked glazed windows and damp walls, albeit to different degrees. This makes it important for building owners or managers, especially school divisions operating several buildings with mounting deferred maintenance and limited resources to prioritize building upgrades to improve their IEQ.

6.4 Methods

This research is part of a larger two-staged initiative conducted in collaboration with the Government of Manitoba Public School Finance Board and two Manitoba school divisions in Canada. Stage one focused on developing teachers' well-being surveys and a teachers' IEQ satisfaction survey as shown in chapter 4 as well as the SLCA for schools as shown in chapter 3. Stage two involved deploying the instruments developed in stage one in addition to field IEQ measurements of thermal comfort, indoor air quality, lighting, and acoustics parameters in 32 schools in Southern Manitoba as shown in chapter 3. The 32 schools were stratified into new, renovated, non-renovated schools. Details of the stratification strategy and strata descriptions are given in chapter 3. This research reports on stage two, in particular on how the physical condition of building elements enclosing classrooms moderates the impact of classroom IEQ parameters on teachers' IEQ satisfaction.

6.4.1 IEQ-related building condition assessment

The IEQ-related BCA was conducted at the classroom level using the SLCA developed for this research. The SLCA has four hierarchical levels and five main components at the highest level (i.e. level 4) including main envelope, openings, finishes, electrical, and mechanical. Each of these five components has three sub-levels. Level 3 represent sub-components of level 4 (e.g. wall, floor, and ceilings for main envelope), level 2 represent the defects of level 3 components, and level 1 represent the defect severities of level 2 defects. The assessments are conducted at level 1 and aggregated for scores at each level. The SLCA scores range from 1 to 16 and are subdivided into four regions as follows: $1 \leq SLCA \leq 4$ (low), $4 < SLCA \leq 8$ (medium), $8 < SLCA \leq 12$ (high), and $12 < SLCA \leq 16$ (very high). These regions correspond to the expected impact of IEQ. The level 2 SLCA defects were categorized into four depending on the IEQ factor they were likely to influence the most. Therefore, each of the five level 4 components had a thermal comfort, indoor air quality, lighting, and acoustics-related SLCA scores where applicable. Details of the development, validation, and results of the SLCA are given in chapter 3. The SLCA was conducted in 52 classrooms in 10 of the 32 schools. These 10 schools consisted of three new, three renovated, and four non-renovated schools.

6.4.2 Field measurements of IEQ

Field measurements of thermal comfort, indoor air quality, lighting, and acoustics parameters were conducted in all of the 10 schools and 52 classrooms where the SLCA was conducted. The thermal comfort parameters were air temperature and relative humidity. The indoor air quality parameters were CO_2, CO, TVOC, and particulate matter (i.e. $PM_{2.5}$ and PM_{10}). The acoustics parameters were background noise (A and C weighted), reverberation time (RT60 at 500 Hz, 1 KHz, 2 KHz), and apparent sound transmission class (ASTC). For lighting, only daylight factor was measured. Each of these parameters was measured only once in each of the 52 classrooms and a minimum of five classrooms was measured in each school. Details of their measurement protocols and results were reported in chapter 3.

6.4.3 Occupants' survey

The occupant survey consisting of an adapted teachers' IEQ satisfaction survey and the newly developed teachers psychological, social, and physical well-being surveys was administered online using Qualtrics. A total of 234 responses were received from the 32 schools within the two school divisions. However, only the 75 responses from teachers in the 10 schools that participated in the SLCA and IEQ field measurements were considered in this research. Details of the teachers' IEQ satisfaction and well-being survey development, validation, and results are given in chapter 4. Factor analysis of the adapted IEQ satisfaction survey responses resulted in three latent factors: ventilation and thermal comfort, lighting, and acoustics and privacy satisfaction as shown in chapter 4. In an earlier analysis of total survey responses shown in chapter 4, the results suggested that the impact of schools' indoor environment on teachers' well-being indirectly depended on their satisfaction with IEQ. Additionally, the randomization strategy employed in administering the online survey as explained in chapter 4 resulted in relatively lower responses for the well-being surveys. Therefore, the well-being survey responses from the 10 schools were not included in this research. Only the teachers' IEQ satisfaction survey responses from the 10 schools were analyzed in this chapter.

6.4.4 Data analysis

The SLCA, IEQ field measurement, and IEQ satisfaction data for the 10 schools were analyzed together and not with respect to the strata of schools. Findings from earlier analyses of this data shown in chapter 3 suggested that the new schools had the most preferred indoor conditions followed by the renovated and non-renovated schools respectively. However, the indoor conditions of some non-renovated schools were comparable to or even exceeded the indoor conditions of the renovated schools, whereas the indoor conditions in some new schools were below those of the renovated schools. Therefore, analyzing all 10 schools together increased the variability of the data and minimized the risk of accepting a statistically insignificant alternative hypothesis in place of the null.

This research aimed to determine how the physical conditions of building elements influenced the effect of IEQ parameters on teachers' IEQ satisfaction. The premise of this research was that the effects of IEQ parameters on teachers' IEQ satisfaction will be dependent on the level of SLCA scores. Thus, SLCA scores in the low region would likely lead to a positive effect of IEQ parameters on teachers' satisfaction while SLCA scores in the high region would lead to a negative effect. Therefore, moderation analyses were conducted with teachers' IEQ satisfaction factors as the dependent variables (Y), IEQ parameters as the independent variables (X), and level 4 SLCA scores as the moderators (M) (Hayes, 2013). The graphical and statistical moderation models are shown in Figure 6.1.

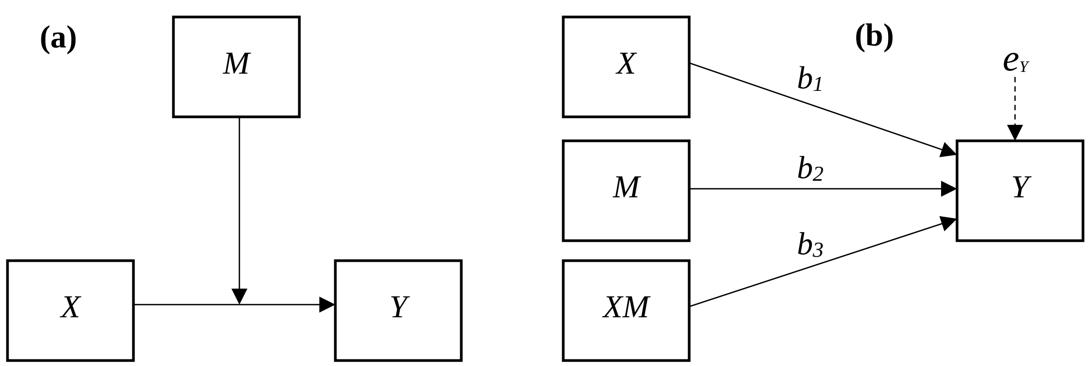

Figure 6.1: Moderation models: (a) graphical model; (b) statistical model

The interaction variable (XM) in the statistical moderation model assessed the conditional effect of IEQ parameters on teachers' IEQ satisfaction based on the SLCA scores. The parameters b_1, b_2, and b_3 as shown in Figure 6.1 are the conditional coefficients and e_Y is the error term. A statistically significant b_3 (i.e. $p \leq 0.05$) indicated a statistically significant moderation effect. The Johnson-Neyman significance region was determined for each statistically significant interaction variable to establish the range of SLCA scores within which the conditional effect of an IEQ parameter on teachers' satisfaction was statistically significantly different from zero (Hayes, 2013). The moderation analyses were conducted using the "PROCESS" v2.16.3 program for IBM SPSS Statistics version 23 (Hayes, 2013). Heteroscedasticity, which can lead to an incorrect statistically significant inference was mitigated by using the heteroscedasticity-consistent standard error estimator, HC3, recommended for samples not exceeding 250 (Long & Ervin, 2000).

6.5 Results

This section presents the descriptive statistics for the IEQ teacher satisfaction factors, the SLCA scores, and the IEQ field measurements. Additionally, this section reports on the results of the moderation analyses. Only statistically significant moderations are presented starting with the one for ventilation and thermal comfort satisfaction and ending with the one for lighting satisfaction.

6.5.1 Descriptive statistics

Table 6.1 presents the mean, standard deviation, minimum, and maximum values for the IEQ satisfaction factors, the SLCA scores, and the IEQ field measurements. The table aggregates descriptive statistics for the 10 schools where IEQ field measurements were conducted.

Table 6.1: Descriptive statistics

	Mean	Standard deviation	Minimum	Maximum
IEQ satisfaction				
Lighting satisfaction (L_{sat})	5.064	1.400	1.000	7.000
Ventilation and thermal comfort satisfaction (VTsat)	4.264	1.471	1.000	7.000
Privacy and acoustics satisfaction (PAsat)	4.990	1.075	2.500	7.000
SLCA scores, thermal comfort-related				
Openings	1.136	0.292	1.000	2.100
Main envelope	1.409	0.683	1.000	5.000
Finishes	1.425	0.465	1.000	2.500
Mechanical	1.000	0.000	1.000	1.000
SLCA scores, indoor air quality-related				
Openings	1.772	0.780	1.000	3.444
Main envelope	1.409	0.683	1.000	5.000
Finishes	2.125	0.886	1.000	4.222
Electrical	5.230	4.501	1.000	16.000
Mechanical	5.365	3.445	1.000	8.500
SLCA scores, acoustics-related				
Openings	1.033	0.196	1.000	2.375
Main envelope	2.666	0.641	1.600	5.600
Finishes	4.005	1.777	1.750	10.000
Mechanical	6.192	7.205	1.000	16.000
SLCA scores, lighting-related				
Openings	2.187	1.089	1.000	8.500
Main envelope	2.201	1.791	1.000	8.000
Finishes	2.865	2.187	1.000	7.500
Electrical	3.451	2.435	1.000	8.500
IEQ field measurements				
TVOC ($\mu g/m^3$)	413.2	118.9	244.603	822.393
CO2 (ppm)	1052.613	237.372	653.089	1644.384
CO (ppm)	0.814	0.154	0.462	1.232
RH (%)	27.039	6.639	16.976	39.573
$PM_{2.5}$ ($\mu g/m^3$)	19.025	15.803	3.059	81.275
PM_{10} ($\mu g/m^3$)	55.237	34.318	14.562	173.226
Air temperature (^oC)	22.140	0.996	19.192	24.066
Radiant temperature (^oC)	22.408	0.982	19.435	24.373
Average background noise (dB-A weighted)	27.618	3.246	22.825	35.609
Average background noise (dB-C weighted)	33.459	3.795	28.041	45.860
RT60 at 500Hz	0.569	0.179	0.250	1.080
RT60 at 1kHz	0.525	0.184	0.280	1.100
RT60 at 2kHz	0.474	0.098	0.300	0.750
ASTC	40.904	5.064	29.000	50.000

Daylight factor	1.049	0.869	0.010	4.125

6.5.2 Moderation for ventilation and thermal comfort satisfaction

The effect of $PM_{2.5}$ on teachers' ventilation and thermal comfort satisfaction (VTC_{sat}) was found to be statistically significantly dependent on indoor air quality-related finishes defects, b_3 = 0.038, t = 2.042, p = 0.045. This moderation effect alone accounted for 9.5% of the variance in teachers' VTC_{sat} scores. Therefore, indoor air quality-related finishes defects including "painting appearance", "ceiling finishes appearance" and "deteriorated/damaged painting" statistically significantly influenced the effect of PM2.5 on VTC_{sat}. Figure 6.2 shows a graphical depiction of the moderation effect of indoor air quality-related finishes defects on the relationship between $PM_{2.5}$ and teachers' VTC_{sat}. For the 10^{th} (6.418 µg/m^3), 25^{th} (9.256 µg/m^3), and 50^{th} (13.922 µg/m^3) percentiles of $PM_{2.5}$ concentrations, Figure 6.2 shows that the moderation effect of indoor air quality-related finishes defects would likely result in lower VTC_{sat}. Classrooms with $PM_{2.5}$ concentrations not exceeding the 50^{th} percentile (i.e. 13.922 µg/m^3) were the cleanest. Therefore, an increase in their airborne $PM_{2.5}$ resulting from dusty painting and ceiling finishes is likely to decrease VTC_{sat}. The 75^{th} percentile concentration was 23.228 µg/m^3 and the moderation effect of indoor air quality-related finishes defects showed a positive impact on VTC_{sat}. The 75^{th} percentile concentration was below the World Health Organization's recommended maximum threshold of 25 µg/m^3 for $PM_{2.5.}$ Additionally, Figure 6.2 shows that most of the indoor air quality-related finishes defects scores were within the low region of the SLCA scale where the expected impact on the indoor environment and by extension teachers' satisfaction was expected to be low or negligible. Therefore, the moderation effect of indoor air quality-related finishes defects on VTC_{sat}

for the 75th percentile $PM_{2.5}$ concentration is less likely to be negative considering the expected low impact. A steeper positive effect on VTC_{sat} is observed for the 90th percentile $PM_{2.5}$ concentration (39.516 µg/m^3). The concentrations of $PM_{2.5}$ in the classrooms within the 90th percentile range were higher than classrooms within the 75th percentile range. Therefore, minimal increase in $PM_{2.5}$ concentrations of classrooms within the 90th percentile range due to low air-quality related finishes defects would have a less negative impact on VTC_{sat} compared to classrooms within the 75th percentile range.

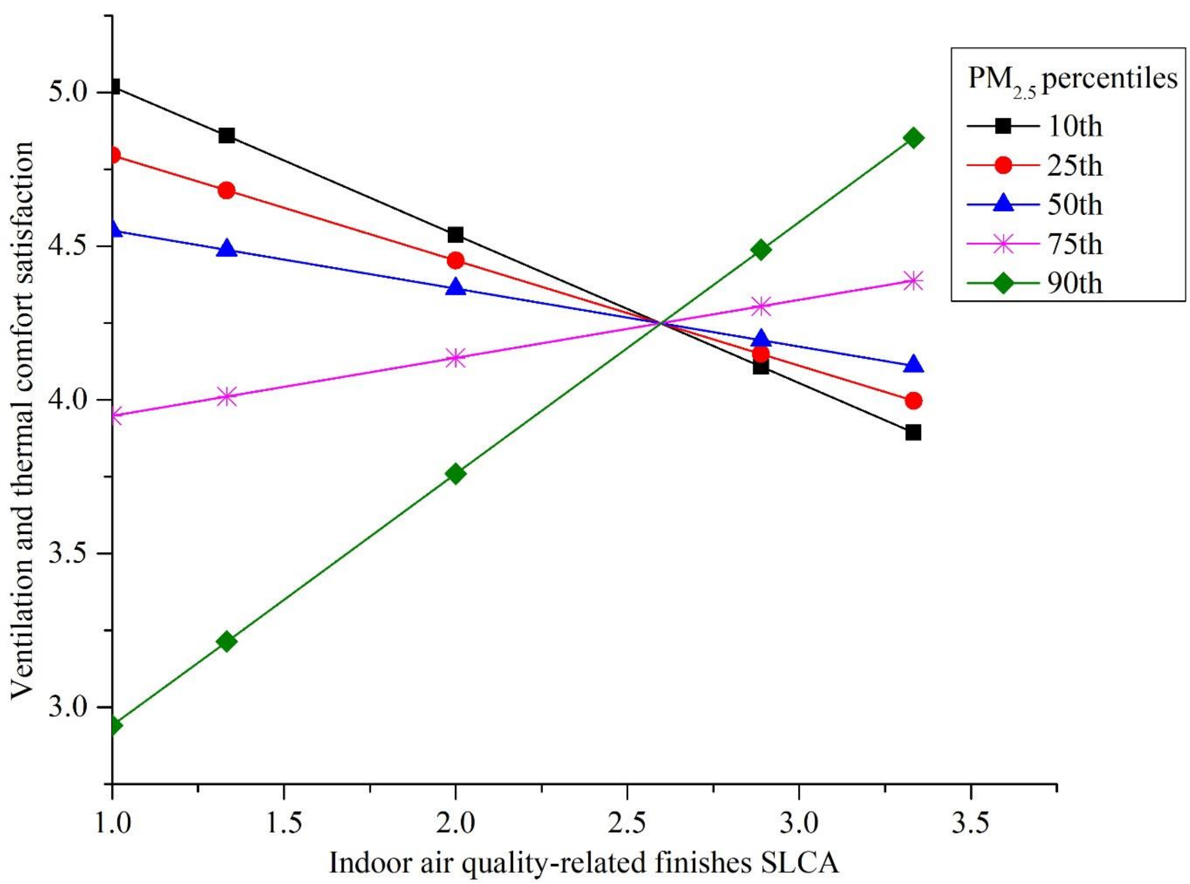

Figure 6.2: Effect of $PM_{2.5}$ on VTC_{sat} moderated by indoor air quality-related finishes SLCA

Figure 6.3 shows the Johnson-Neyman significance region (i.e. light grey region) for the moderation effect of the indoor air quality-related finishes defects scores. The figure shows that the conditional effect of $PM_{2.5}$ on VTC_{sat} was statistically significant for indoor air quality-related finishes defects scores ≤ 1.625. The significance region shows that the conditional effect of $PM_{2.5}$ on VTC_{sat} was negative and was expected given that about 50% of the classroom had $PM_{2.5}$ concentrations less than half of the WHO recommended limit. Therefore, the slightest increase in $PM_{2.5}$ concentration from dusty painting and ceiling finishes would likely have a negative effect on teachers' VTC_{sat}.

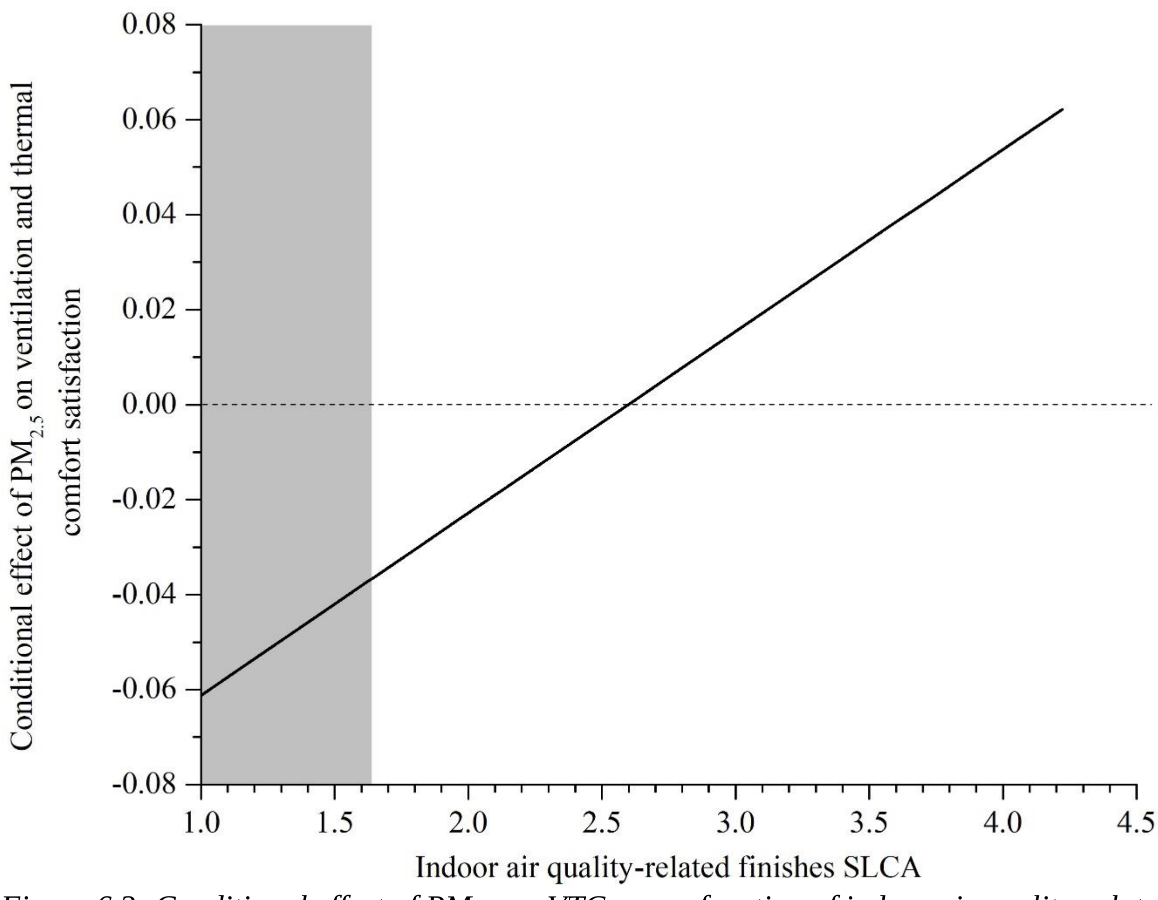

Figure 6.3: Conditional effect of $PM_{2.5}$ on VTC_{sat} as a function of indoor air quality-related finishes SLCA

Figure 6.4 illustrates the moderation effect of indoor air quality-related electrical defects on the relationship between PM_{10} and teachers' VTC_{sat}. The moderation was statistically significant, $b_3 = 0.003$, $t = 2.749$, $p = 0.009$, and accounted for 12.5% of the variance in VTC_{sat} scores. Figure 6.4 shows that the moderation effect on VTC_{sat} was negative for the 10^{th} (22.243 $\mu g/m^3$), 25^{th} (32.922 $\mu g/m^3$) and 50^{th} (42.048 $\mu g/m^3$) percentiles respectively in descending order. Additionally, the figure shows that the indoor air quality-related electrical defects which were mainly "dust particles on luminaires and lamps" ranged from the low to very high region of the SLCA scale. Therefore, PM_{10} concentration in classrooms within the 10^{th} and 25^{th} percentile range would be the most affected, thus explaining their steeper slopes relative to other percentile values. For the 75^{th} percentile PM_{10} concentration, the moderation effect of indoor air quality-related electrical defects on VTC_{sat} was negligible as demonstrated by the nearly flat slope in Figure 6.4. The 75^{th} percentile concentration of 69.143 $\mu g/m^3$ slightly exceeded the WHO recommended limit of 50 $\mu g/m^3$ for PM_{10} concentration (WHO, 2006); therefore, the negligible moderation effect is tenable. The 90^{th} percentile PM_{10} (i.e. 97.587 $\mu g/m^3$) was approximately twice the WHO recommended threshold; hence, classrooms within this range were the most polluted. If teachers in those classrooms had prolonged exposure to those high PM_{10} concentrations, then the slightly positive effect of indoor air quality-related electrical defects on VTC_{sat} is logical. Compared to the moderation effect of low indoor air quality-related finishes defects on the relationship between $PM_{2.5}$ and VTC_{sat} in Figure 6.2, the slope of the 90^{th} percentile PM_{10} in Figure 6.4 is less steep. Therefore, the slopes of the 90^{th} percentile $PM_{2.5}$ and PM_{10} concentrations suggest that the moderation effect on VTC_{sat} resulting from the increased concentration of particulate matter would be negative.

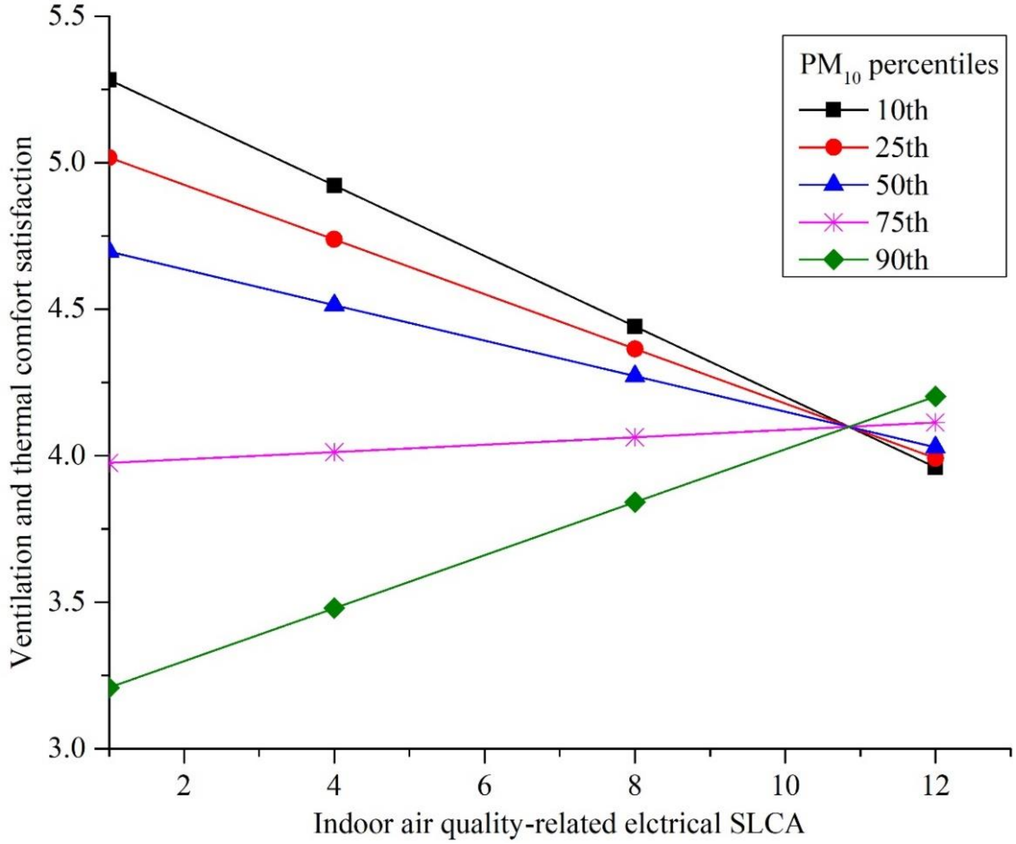

Figure 6.4: Effect of PM_{10} on VTC_{sat} moderated by indoor air quality-related electrical SLCA

Figure 6.5 shows the Johnson-Neyman significance region (light grey region) for the conditional effect of PM_{10} on teachers' VTC_{sat} based on indoor air quality-related electrical defects. The significance region shows that the conditional effect of PM_{10} on VTC_{sat} was negative and statistically significant for indoor air quality-related electrical defect scores ≤ 6.849 (i.e. low to medium region of the SLCA scale).

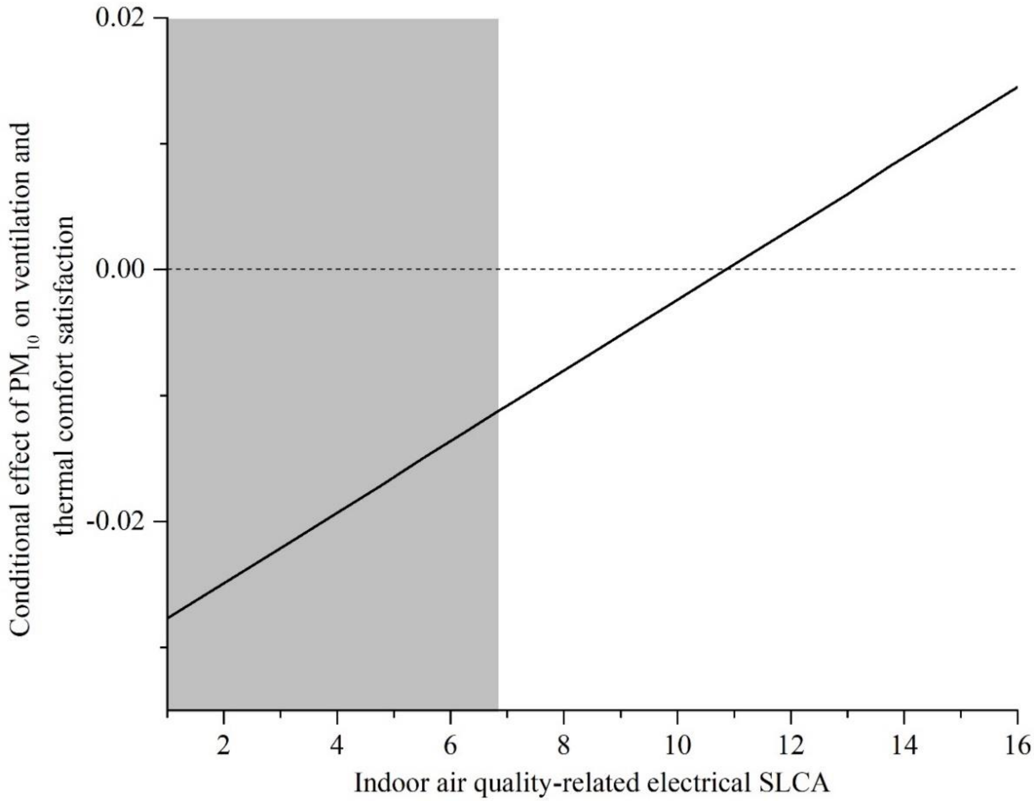

Figure 6.5: Conditional effect of PM10 on VTC_{sat} as a function of indoor air quality-related electrical SLCA

6.5.3 Moderation of lighting satisfaction

Lighting-related openings defects was found to be a statistically significant moderator of the effect of daylight factor on lighting satisfaction (L_{sat}), $b_3 = -0.618$, $t = -2.491$, $p = 0.016$. The moderation effect of lighting-related openings defects including "stained window glazing" and "damaged screen/blinds" accounted for approximately 8% of the variance in the L_{sat} scores. Figure 6.6 illustrates the moderation effect of lighting-related openings defects on the relationship between daylight factor and L_{sat}.

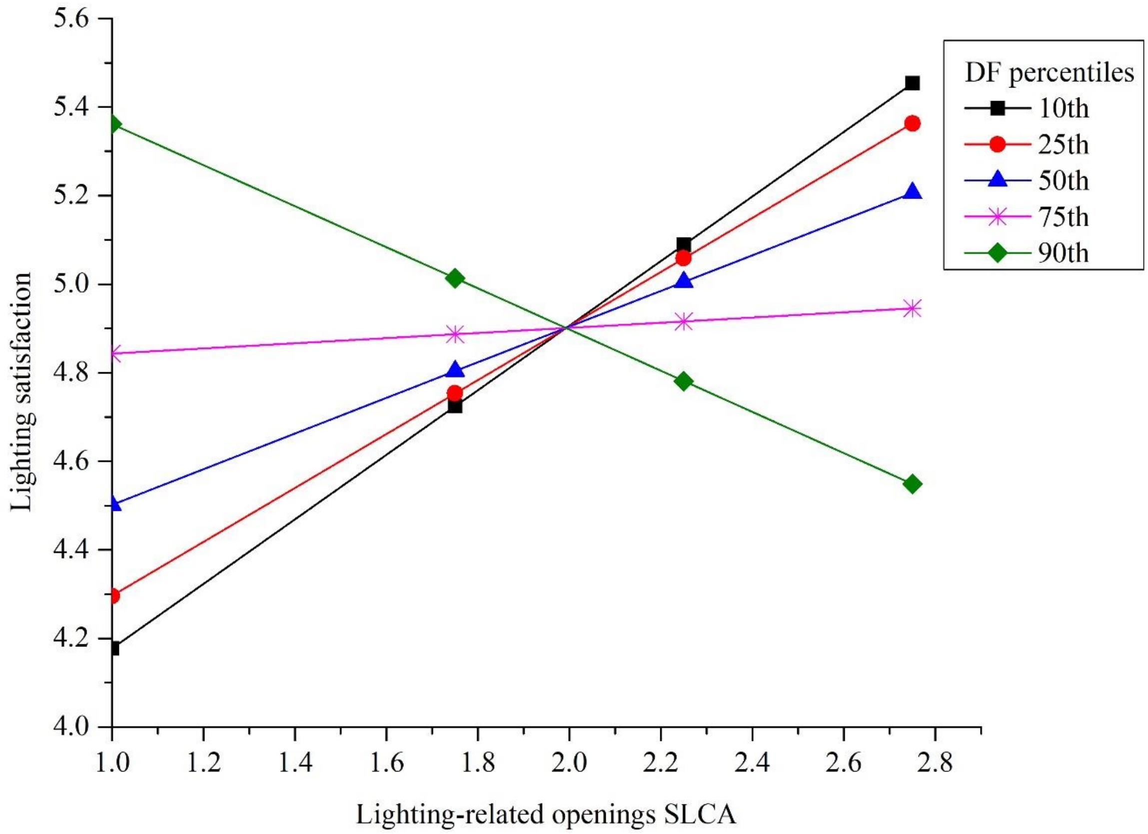

Figure 6.6: Effect of daylight factor on L_{sat} moderated by lighting-related openings SLCA

Figure 6.6 shows that the moderating effect of lighting-related openings defects on L_{sat} was positive for the 10th (0.236), 25th (0.486), and 50th (0.772) percentile daylight factors. The 10th to 50th percentile daylight factors were substantially below the recommended minimum threshold of 2% below which electric light is required for satisfactory vision (İnan, 2013). Most of the lighting-related openings defects scores (see Figure 6.6 and Figure 6.7) with “stained window glazing” as the leading defect were generally within the low to medium region of the SLCA scale. Therefore, lighting-related openings defects were less likely to have a negative moderating effect on L_{sat} for classrooms with daylight factors within the range of the 10th to 50th percentiles as teachers in those classrooms most likely used electric lighting most of the time. The positive moderating effect for the 10^{th} to 50^{th} percentile daylight factors is probably indicative of the positive effect of electric light on L_{sat} for classrooms with low daylight penetration. The 75^{th} percentile daylight factor was 1.313% and the moderating effect of lighting-related openings defects was negligible. Classrooms with daylight factor within the range of the 75^{th} percentile would require complementary electric lighting, thus supporting the negligible moderating effect of lighting-related openings defects on L_{sat}. The 90^{th} percentile daylight factor was 2.423%; thus, classrooms within this range would not require complementary electric lighting when there is a reasonable amount of daylight outdoors. Therefore, lighting-related openings defects especially translucent or opaquely stained window glazing would likely reduce the amount of daylight transmitted indoors and negatively affect L_{sat} as shown in Figure 6.6 for teachers who usually rely on daylight in class.

Figure 6.7 shows the Johnson-Neyman significance regions (light grey regions) for the conditional effect of daylight factor on L_{sat} as a function of lighting-related openings defects. The conditional effect was statistically significant for lighting-related openings defect scores from 0 to 1.174 and from 3.917 to 8.500. The significance regions show a positive moderating effect of low lighting-related openings defects on L_{sat} and a negative effect for medium to high lighting-related openings defects.

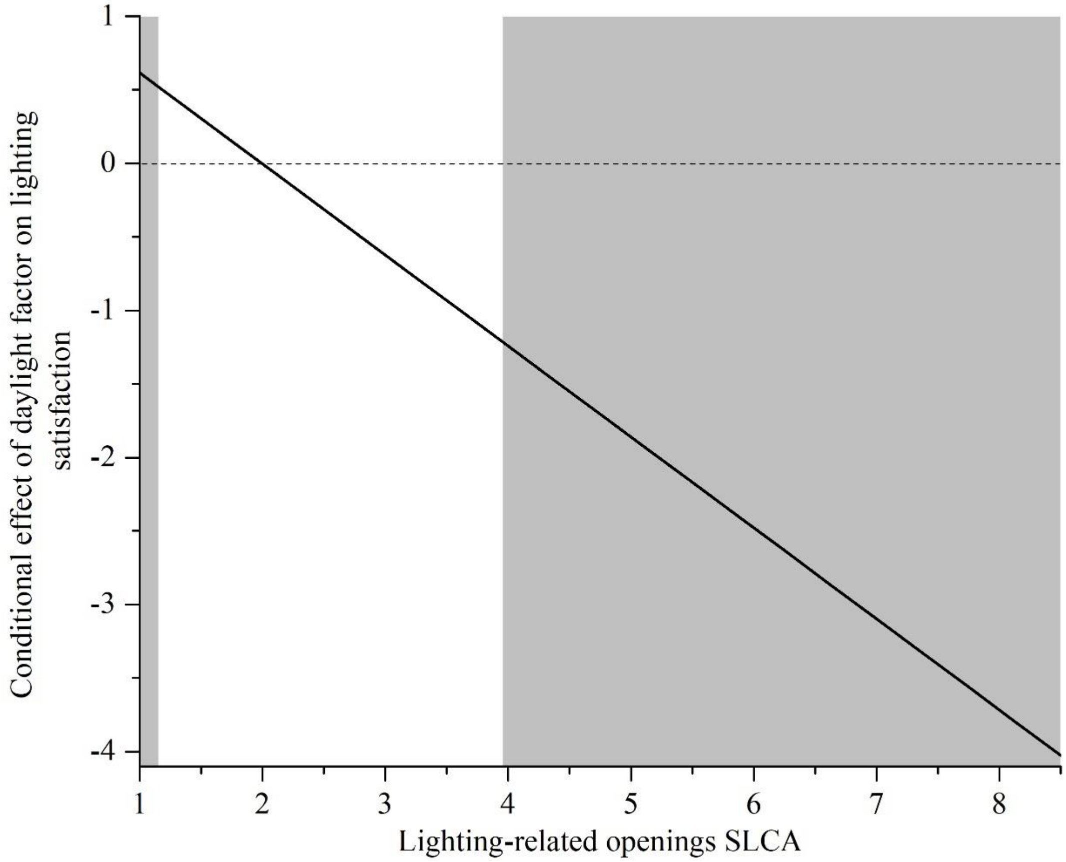

Figure 6.7: Conditional effect of daylight factor on L_{sat} based on lighting-related openings SLCA

6.6 Discussion

Although most of the moderation analyses conducted in this exploratory study were not statistically significant, the proportion of variance explained (i.e. 8 – 12.5%) by each of the three statistically significant interaction variables were reasonably substantial. This justifies investigating the moderation effect of building envelope elements' physical condition on the interaction between building occupants and IEQ parameters. The three statistically significant results support the hypothesis that the effect of IEQ parameters on occupants' satisfaction may depend on the level of defects of building envelope elements. However, the two IEQ parameters with statistically significant moderated effects on VTC_{sat} did not support the SLCA logic that low and high scores would lead to a positive and negative impact on IEQ satisfaction respectively. The moderation effect of $PM_{2.5}$ on teachers' VTC_{sat} was a function of indoor air quality-related finishes defects, the SLCA scores of which were mainly in the low region. Therefore, the impact on teachers in classrooms with $PM_{2.5}$ concentrations within the range of the 10^{th} to 50^{th} percentiles was expected to be positive. However, the results showed a negative impact although the $PM_{2.5}$ concentrations in those classrooms were substantially below recommended limits by the WHO. The moderation effect of $PM_{2.5}$ concentration in classrooms within the range of the 90^{th} percentile on VTC_{sat} was positive although those concentrations substantially exceeded the WHO threshold. A similar pattern of moderation effect is observed for PM_{10} although its moderation effect on VTC_{sat} was a function of indoor air quality-related electrical defects. For PM_{10}, the indoor air quality-related electrical defect scores ranged from low to very high on the SLCA scale; therefore, the negative impact on PM_{10} within range of the 10^{th} to 50^{th} percentile concentration was logical. However, the slight positive impact on VTC_{sat} at the 90^{th} percentile was not expected.

Findings of this research lead to the conclusion that the smallest increase in PM concentration of clean spaces would likely have the most substantial negative impact on VTC_{sat} relative to considerable increases in less clean spaces. Additionally, PM concentrations above the recommended threshold may not result in increased negative impact on occupants' VTC_{sat}, especially if the PM concentration does not inhibit occupants from completing their indoor activities. This conclusion is similar to Ghita and Catalina (2015) who investigated IEQ in old, new, and renovated schools and found that students were satisfied with indoor air quality although CO_2 concentration levels substantially exceeded the recommended threshold for classrooms. The main issue with both indoor air quality-related finishes and electrical defects for $PM_{2.5}$ and PM_{10}

respectively was dust particles. The concentrations of fine dust particles within the range of $PM_{2.5}$ and PM_{10} may not have the same immediate negative effect on occupants' VTC_{sat} compared to air temperatures above the recommended threshold. However, the potential health consequences of exposure to high concentrations of $PM_{2.5}$ and PM_{10} could be substantial. Results of the moderation analysis for $PM_{2.5}$ and PM_{10} point to the potential benefits of cleanliness on occupants' VTC_{sat}. The results suggest that regular cleaning of luminaires, lamps, and finishes (on walls, floors, and ceilings) as part of planned classroom maintenance could enhance teachers' VTC_{sat}. This research agrees with Sediso and Lee (2016) who found statistically significant correlations between cleanliness and occupants' IEQ satisfaction in both green certified and conventional office buildings.

The conditional effect of daylight factor on teachers L_{sat} based on lighting-related openings defects was opposite to the conditional effect of PM on VTC_{sat}. The impact of moderation on teachers' L_{sat} in classrooms with daylight factors within the 10^{th} to 50^{th} percentiles was positive. The 10^{th} to 50^{th} percentile daylight factors were less than half of the recommended daylight factor below which electric light would be needed; therefore, teachers in those classrooms most likely used electric light most of the time. Hence, a substantial decrease in the amount of daylight indoors resulting from low to medium translucent stains on window glazing may not be noticed. For teachers in classrooms within the range of the 90^{th} percentile daylight factor, the amount of daylight indoors would most of the time be adequate without the need for electric light. Additionally, the SLCA scores for lighting-related openings defects which ranged from low to medium implied that some classrooms within the range of the 90^{th} percentile probably had higher daylight factors prior to the defects. Therefore, a decrease in the amount of daylight indoors to levels close to the recommended threshold especially during the winter season (i.e. the study period) may be noticeable and have a negative effect on L_{sat}. The transmittance of window glazing was not measured in this study; therefore, the low levels of daylight in some of the classrooms could not be fully explained given that the lighting-related openings scores were below the high range. However, the amount of daylight indoors has been associated with students' performance in schools (Tanner, 2008) and office workers' health (Boubekri, Cheung, Reid, Wang, & Zee, 2014). Therefore, having the right-sized glazed windows with high daylight transmittance that are strategically located in external walls to let in more daylight is essential. Nevertheless, the results of this study suggest that regular cleaning of window glazing as part of planned classroom maintenance would be an effective strategy to enhance teachers' satisfaction.

This exploratory research used snapshot measurements of IEQ parameters to determine their moderated effects on teachers' IEQ satisfaction factors. Because snapshot measurements of IEQ parameters may be very different from long-term measurements, they may not fully characterize the IEQ performance of the classrooms assessed in this research. Long-term measurements of IEQ parameters may have resulted in most of the moderations analyses being statistically significant and thus led to different results and conclusions. However, the three statistically significant results reported in this research using snapshot measurements explain how the physical conditions of building envelope elements are likely to moderate the impact of IEQ parameters on occupants' IEQ satisfaction. Although the occupant satisfaction surveys were all completed within the study period, they were not completed on the same day of the field measurements in each of the 10 schools, which may explain the statistically insignificant results for most of the moderation analyses. Due to the number of schools that participated in the SLCA, only level 4 scores (i.e. the highest level) were used in the moderation analyses. Level 2 scores for specific defects and level 3 scores for the subcomponents of level 4 were less varied due to the limited sample of schools and classrooms evaluated. Using the level 2 scores would have associated specific defects with moderations of occupants' satisfaction factors. However, the limited variability of the level 2 scores would have increased the likelihood of statistically insignificant results becoming statistically significant, leading to wrong interpretations of moderation effects on teachers' IEQ factors. Level 4 scores that were averaged scores from levels 2 and 3 were therefore used to minimize the risk of wrong inference.

Although the results of this exploratory study are not generalizable to all schools, it highlights the potential benefits of IEQ-related building condition assessment. All 10 schools that participated in this study were cleaned daily; however, the cleaning focused mainly on floor and classroom furniture. The results of this study suggest that luminaires and lamps, window glazing, wall and ceilings finishes were not cleaned frequently in most schools, resulting in statistically significant moderations of ventilation and thermal comfort and lighting satisfaction. The Johnson-Neyman significant regions identified values of SLCA scores where defects of space envelope elements had substantial positive and negative effects on teachers' IEQ satisfaction. Therefore, a study with a large sample of schools would lead to establishing threshold values that can be used to plan and develop effective operation and maintenance strategies that would enhance occupants' IEQ satisfaction.

6.7 Conclusion

The aim of this research was to assess the conditional effects of IEQ parameters on teachers' IEQ satisfaction factors as a function of the physical conditions of school building envelope elements. Although only three of the moderation analyses were statistically significant, they support the thesis that buildings' operation and maintenance with IEQ enhancement as its underpinning is an effective strategy. No statistically significant moderation effect was found on any of the acoustics parameters in this research. This does not imply that the effect of acoustic parameters on teachers cannot be influenced by the physical condition of building envelope elements. The lack of statistical significance, in this case, may be due to the limited sample of schools and classrooms investigated.

This research was conducted in the winter season; therefore, future research should focus on replicating it in other seasons since this may lead to different results and conclusions. Future research should also repeat the SLCA and IEQ field measurements together with the occupant survey more than once for confirmatory validation of results. This will add to the IEQ literature and body of knowledge by providing empirical evidence on how the physical conditions of building envelope elements are likely to moderate the impact of IEQ parameters on occupants' IEQ satisfaction. It should motivate similar moderation studies in schools and other building types that use large building samples in different climates. This is to establish benchmarks for these moderation effects and threshold values that would facilitate strategic operation and maintenance decision-making.

The SLCA instrument was conceptualized based on defects and key building envelope elements observed in schools and especially classrooms. However, the premise of its development was to improve IEQ and by extension teachers' IEQ satisfaction. Therefore, the instrument can be easily adapted and used for other buildings types. The results of the study suggest that knowledge of the moderation effects of the physical conditions of building envelope elements on occupants' satisfaction will likely lead to the development of operation and maintenance practices that affect building occupants positively. Therefore, this type of moderation studies should be of interest to school divisions and other building owners and managers conducting renovations that aim to improve their buildings' IEQ performance and their occupants' satisfaction. It should also be of interest to owners and managers of buildings with acceptable or superior indoor environments and that are looking to improve their management of the operation and maintenance of these indoor environments in order to make them more sustainable.

6.8 Acknowledgments

The authors are grateful to the Government of Manitoba Public School Finance Board, the two school divisions, and the 32 schools for agreeing to participate in this research and facilitating access to the schools and the data collection. The authors are also grateful to Md Anamul Hasan, Joshua Boateng Akom, and Katia Cavalcanti Parpinelli for their assistance with data collection. This research was funded by a Discovery Grant (RGPIN 418532-2012) from the Natural Sciences and Engineering Research Council of Canada.

6.9 References

Boerstra, A., Beuker, T., Loomans, M., & Hensen, J. (2013). Impact of available and perceived control on comfort and health in European offices. *Architectural Science Review, 56*(1), 30-41. doi: 10.1080/00038628.2012.744298

Borge, L.-E., & Hopland, A. O. (2017). Schools and public buildings in decay: the role of political fragmentation. *Economics of Governance, 18*(1), 85-105.

Boubekri, M., Cheung, I. N., Reid, K. J., Wang, C.-H., & Zee, P. C. (2014). Impact of Windows and Daylight Exposure on Overall Health and Sleep Quality of Office Workers: A Case-Control Pilot Study. *Journal of Clinical Sleep Medicine : JCSM : Official Publication of the American Academy of Sleep Medicine, 10*(6), 603-611. doi: 10.5664/jcsm.3780

Brager, G., & Baker, L. (2009). Occupant satisfaction in mixed-mode buildings. *Building Research & Information, 37*(4), 369-380. doi: 10.1080/09613210902899785

Brager, G., Zhang, H., & Arens, E. (2015). Evolving opportunities for providing thermal comfort. *Building Research & Information, 43*(3), 274-287. doi: 10.1080/09613218.2015.993536

Cash, C., & Twiford, T. (2009). Improving student achievement and school facilities in a time of limited funding. *International Journal of Educational Leadership Preparation, 4*(2), 1-9.

Choi, J.-H., & Moon, J. (2017). Impacts of human and spatial factors on user satisfaction in office environments. *Building and Environment, 114*, 23-35. doi: http://dx.doi.org/10.1016/j.buildenv.2016.12.003

Conlin, M., & Thompson, P. N. (2017). Impacts of New School Facility Construction: An Analysis of a State-Financed Capital Subsidy Program in Ohio. *Economics of Education Review*.

Durán-Narucki, V. (2008). School building condition, school attendance, and academic achievement in New York City public schools: A mediation model. *Journal of Environmental Psychology, 28*(3), 278-286. doi: https://doi.org/10.1016/j.jenvp.2008.02.008

Earthman, G. I., & Lemasters, L. K. (2009). Teacher attitudes about classroom conditions. *Journal of Educational Administration, 47*(3), 323-335.

Evans, G. W., Yoo, M. J., & Sipple, J. (2010). The ecological context of student achievement: School building quality effects are exacerbated by high levels of student mobility. *Journal of Environmental Psychology, 30*(2), 239-244. doi: http://dx.doi.org/10.1016/j.jenvp.2010.01.001

Fadeyi, M. O. (2014). Initial study on the impact of thermal history on building occupants' thermal assessments in actual air-conditioned office buildings. *Building and Environment, 80*, 36-47. doi: http://dx.doi.org/10.1016/j.buildenv.2014.05.018

Filardo, M. (2008). Good buildings, better schools. *Economic Policy Institute Briefing Paper, 216*, 3.

Filardo, M., Bernstein, J., & Eisenbrey, R. (2011). Creating Jobs Through FAST!, a Proposed New Infrastructure Program to Repair America's Public Schools. *Washington: Economic Policy Institute*.

Gaudreault, V., Overton, D., & Trstenjak, J. (2009). Age of education infrastructure: recent trends (11-621-M, no. 81). Retrived from http://www.statcan.gc.ca/pub/11-621-m/11-621-m2009081-eng.pdf

Ghita, S. A., & Catalina, T. (2015). Energy efficiency versus indoor environmental quality in different Romanian countryside schools. *Energy and Buildings, 92*, 140-154.

Hayes, A. F. (2013). *Introduction to mediation, moderation, and conditional process analysis: A regression-based approach*. New York: Guilford Press.

Hongisto, V., Haapakangas, A., Varjo, J., Helenius, R., & Koskela, H. (2016). Refurbishment of an open-plan office - Environmental and job satisfaction. *Journal of Environmental Psychology, 45*, 176-191. doi: 10.1016/j.jenvp.2015.12.004

Hunter, R. C. (2009). The Public School Infrastructure Problem: Deteriorating Buildings and Deferred Maintenance. *School Business Affairs, 75*(2), 10-12.

İnan, T. (2013). An investigation on daylighting performance in educational institutions. *Structural Survey, 31*(2), 121-138. doi: doi:10.1108/02630801311317536

Kolarik, J., Toftum, J. r., Olesen, B. W., & Shitzer, A. (2009). Occupant Responses and Office Work Performance in Environments with Moderately Drifting Operative Temperatures (RP-1269). *HVAC&R Research, 15*(5), 931-960. doi: 10.1080/10789669.2009.10390873

Lan, L., Lian, Z., & Pan, L. (2010). The effects of air temperature on office workers' well-being, workload and productivity-evaluated with subjective ratings. *Applied Ergonomics, 42*(1), 29-36. doi: http://dx.doi.org/10.1016/j.apergo.2010.04.003

Lavy, S., & Nixon, J. L. (2017). Applications, Enrollment, Attendance, and Student Performance in Rebuilt School Facilities: A Case Study. *International Journal of Construction Education and Research, 13*(2), 125-141. doi: 10.1080/15578771.2016.1245687

Long, J. S., & Ervin, L. H. (2000). Using heteroscedasticity consistent standard errors in the linear regression model. *The American Statistician, 54*(3), 217-224.

Maxwell, L. E. (2016). School building condition, social climate, student attendance and academic achievement: A mediation model. *Journal of Environmental Psychology, 46*, 206-216. doi: https://doi.org/10.1016/j.jenvp.2016.04.009

McShane, I. (2012). Learning to share: Australia's Building the Education Revolution and shared schools. *Journal of Educational Administration and History, 44*(2), 105-119. doi: 10.1080/00220620.2012.658766

Mendell, M. J., Eliseeva, E. A., Spears, M., Chan, W. R., Cohn, S., Sullivan, D. P., & Fisk, W. J. (2015). A longitudinal study of ventilation rates in California office buildings and self-reported occupant outcomes including respiratory illness absence. *Building and Environment, 92*, 292-304. doi: https://doi.org/10.1016/j.buildenv.2015.05.002

Muhič, S., & Butala, V. (2004). The influence of indoor environment in office buildings on their occupants: expected–unexpected. *Building and Environment, 39*(3), 289-296.

Norbäck, D., Hashim, J. H., Hashim, Z., & Ali, F. (2017). Volatile organic compounds (VOC), formaldehyde and nitrogen dioxide (NO2) in schools in Johor Bahru, Malaysia: Associations with rhinitis, ocular, throat and dermal symptoms, headache and fatigue. *Science of The Total Environment, 592*(Supplement C), 153-160. doi: https://doi.org/10.1016/j.scitotenv.2017.02.215

Sadick, A.-M., & Issa, M. H. (2017a). Differences in teachers’ satisfaction with indoor environmental quality and their well-being in new, renovated and non-renovated schools. *Indoor and Built Environment*, 1420326X17717074. doi: 10.1177/1420326X17717074

Sakellaris, I. A., Saraga, D. E., Mandin, C., Roda, C., Fossati, S., de Kluizenaar, Y., . . . Szigeti, T. (2016). Perceived indoor environment and occupants’ comfort in European “modern” office buildings: the OFFICAIR study. *International journal of environmental research and public health, 13*(5), 444.

Schreuder, E., van Heel, L., Goedhart, R., Dusseldorp, E., Schraagen, J. M., & Burdorf, A. (2015). Effects of newly designed hospital buildings on staff perceptions: A pre-post study to validate design decisions. *Health Environments Research and Design Journal, 8*(4), 77-97. doi: 10.1177/1937586715573736

Sediso, B. G., & Lee, M. S. (2016). Indoor environmental quality in Korean green building certification criteria—certified office buildings—occupant satisfaction and performance. *Science and Technology for the Built Environment, 22*(5), 606-618. doi: 10.1080/23744731.2016.1176849

Tanabe, S.-i., Nishihara, N., & Haneda, M. (2007). Indoor Temperature, Productivity, and Fatigue in Office Tasks. *HVAC&R Research, 13*(4), 623-633. doi: 10.1080/10789669.2007.10390975

Tanner, C. K. (2008). Explaining relationships among student outcomes and the school's physical environment. *Journal of Advanced Academics, 19*(3), 444-471.

Thomsen, K. E., Rose, J., Mørck, O., Jensen, S. Ø., Østergaard, I., Knudsen, H. N., & Bergsøe, N. C. (2016). Energy consumption and indoor climate in a residential building before and after comprehensive energy retrofitting. *Energy and Buildings*, *123*, 8-16. doi: http://dx.doi.org/10.1016/j.enbuild.2016.04.049

Uline, C. L., & Roberts, L. W. (2009). Measuring school facility conditions: An illustration of the importance of purpose. *Journal of Educational Administration, 47*(3), 368-380.

Wargocki, P., & Wyon, D. P. (2007). The Effects of Moderately Raised Classroom Temperatures and Classroom Ventilation Rate on the Performance of Schoolwork by Children (RP-1257). *HVAC&R Research*, *13*(2), 193-220. doi: 10.1080/10789669.2007.10390951

WHO. (2006). *WHO Air quality guidelines for particulate matter, ozone, nitrogen dioxide and sulfur dioxide: Global update 2005 summary of risk assessment*. Geneva: World Health Organization

Xaba, M. (2012). A qualitative analysis of facilities maintenance-a school governance function in South Africa. *South African Journal of Education, 32*(2), 215-226.

Zinzi, M., Agnoli, S., Battistini, G., & Bernabini, G. (2016). Deep energy retrofit of the TM Plauto School in Italy—A five years experience. *Energy and Buildings*, *126*, 239-251.

Connecting Section

Chapters 3, 4, 5 and 6 presented detailed findings for the three major components of this thesis including SLCA, IEQ field measurement, and occupants' surveys. The previous chapter, chapter 6, integrated data from chapters 3, and 4 to investigate the impact of the physical conditions of classrooms space enclosing elements on IEQ parameters and subsequently on teachers' IEQ satisfaction and well-being. The statistically significant results reported in chapter 6 supported the idea that physical conditions of space enclosing elements are likely to influence IEQ and subsequently occupants IEQ satisfaction.

The next chapter, chapter 7, summarizes the research findings from chapters 3, 4, 5, and 6. Additionally, the chapter presents the contributions of this research to the body of knowledge, the key limitations of this research, and recommendations for future research.

CHAPTER 7: Conclusion

This chapter presents a summary of the research findings in chapters 3, 4, 5 and 6 and its contributions. The chapter concludes with a discussion of the research limitations, recommendations for future research and concluding remarks.

7.1 Summary of research findings

This thesis involved investigating the impact of school buildings' physical and indoor environmental conditions on school teachers' IEQ satisfaction and well-being. Chapter 3 addressed objective one of this thesis by reporting on the conceptualization of the SLCA and results of applying the SLCA and IEQ field measurements to evaluate schools' physical and indoor environmental conditions. The results of the SLCA showed that scores were consistently lower in the new schools relative to both the renovated and non-renovated schools. The highest number of statistically significant differences (i.e. 8 out of 17) in IEQ-related SLCA scores was between the new and non-renovated schools. At least one statistically significant difference was found for thermal comfort, indoor air quality, acoustics, and lighting-related SLCA. The lowest number of statistically significant differences (i.e. 1 out of 17) was between the renovated and non-renovated schools and was for indoor air quality-related SLCA only. For the new and renovated schools, four statistically significant differences were found between their IEQ-related SLCA scores with at least one statistically significant difference for indoor air quality, acoustics, and lighting-related SLCA except for thermal comfort. Contrary to the results of IEQ satisfaction factors in chapter 5, the results in chapter 3 suggest that the IEQ-related renovations of the renovated schools did not lead to substantial differences between renovated and non-renovated schools with regards to their physical conditions. Additionally, the results also suggest that the IEQ-related renovations did not lead to statistically insignificant differences in the physical conditions of the new and renovated schools. The fact that the renovated schools were the ones renovated instead of the other schools suggests that their physical conditions were probably the worst of all schools prior to these renovations. Therefore, the IEQ-related renovations could have led to substantial improvements in their physical conditions without those improvements leading to statistically significant differences in the scores of IEQ-related SLCA between the renovated and non-renovated schools. Chapter 3 shows that the pattern of results for IEQ field measurements was not like IEQ-related SLCA. Firstly, statistically significant differences were found for three of 12 IEQ parameters between new and non-renovated schools, with at least one statistically significant difference for all four IEQ factors except lighting. Secondly, two statistically significant differences were found between the renovated and non-renovated schools for acoustics parameters only. Lastly, at least one statistically significant difference was found between the new and renovated schools for thermal comfort and indoor air quality parameters only. Although the pattern of results for scores of the IEQ-related SLCA and IEQ field measurements were not similar, at least one statistically significant and theoretically relevant association was found between both assessments and each of the four IEQ factors. Firstly, for thermal comfort, a strong positive association ($r = 0.860$, $p = 0.000$) was found between main envelope SLCA and relative humidity in non-renovated schools. Secondly, for indoor air quality, CO_2 was significantly associated with mechanical SLCA in renovated schools, $r = 0.590$, $p = 0.020$. Thirdly, for acoustics, A-weighted background noise significantly correlated with mechanical SLCA in non-renovated schools, $r = 0.551$, $p = 0.010$. Lastly, for lighting, daylight factor and openings SLCA were significantly correlated in new schools, $r = -0.727$, $p = 0.002$. These medium to high significant correlations support the logic of the SLCA's defect severities; therefore, chapter 3 concluded that the SLCA was suitable for IEQ-related building condition assessments in schools.

Chapter 4 addressed objective two of this thesis which entailed developing surveys to assess teachers' well-being in a school context and assessing the extent to which teachers' IEQ satisfaction factors were direct measures of their well-being. Association analyses between the three newly developed teachers' well-being surveys and their corresponding existing validated well-being surveys in the literature supported the validity of the three new surveys. The association coefficients were 0.40 ($p = 0.001$), 0.30 ($p = 0.018$), and 0.47 ($p = 0.000$) for TPWB, TSWB, and TPhWB respectively. These weak to moderate positive coefficients supported that the respective well-being surveys were valid for the intended subdivision of personal well-being. Additionally, the coefficients also attested to the uniqueness and contextual relevance of the surveys for teachers in schools in comparison to the existing validated well-being surveys in the literature that were all context-free. The α value for TPWB, TSWB, and TPhWB was 0.87, 0.90, and 0.80 respectively, exceeding the recommended threshold of 0.70 and thus indicating that the newly developed and validated well-being surveys were likely to produce consistent results when administered in the future. The NRC IEQ satisfaction survey developed for office building occupants was adapted to assess the extent to which IEQ satisfaction factors were direct measures of teachers' well-being. Results of the CFA showed that the 18 items three-factor solution of IEQ satisfaction developed by the NRC did not fit teachers' IEQ satisfaction. However, results of the EFA showed that teachers' IEQ satisfaction consisted of 12 items with three latent factors. The three latent factors (i.e. VTC_{sat}, L_{sat}, and AP_{sat}) had satisfactory reliability and internal consistency values (i.e. 0.81, 0.82, and 0.79 respectively). The results showed very weak and statistically insignificant associations between each of the three refined IEQ satisfaction factors and the existing validated well-being surveys except between VTC_{sat} and the RAND 36 physical well-being components. Therefore, the chapter concluded that VTC_{sat} was the most statistically significant direct measure of physical well-being with a weak to moderate association coefficient of 0.341 ($p = 0.012$), while L_{sat} and AP_{sat} were statistically insignificant direct measures of either psychological, social, or physical well-being.

Chapter 5 related to objective three of this thesis and addressed the impact of school buildings' condition as new, renovated, and non-renovated on teachers IEQ satisfaction factors and well-being. The results showed teachers in the new schools were the most satisfied with VTC_{sat}, L_{sat}, and AP_{sat} followed by teachers in the renovated and non-renovated ones respectively in descending order. Additionally, the results showed statistically significant differences in scores of all three IEQ satisfaction factors between the new and non-renovated schools, and between the renovated and non-renovated schools. However, the differences in scores of all three IEQ satisfaction factors between the new and renovated schools were statistically insignificant. This suggested the IEQ-related renovations conducted in the renovated schools significantly improved their IEQ conditions, leading to the statistically insignificant difference between teachers in the new and renovated schools. For well-being, the pattern of scores was not like IEQ satisfaction factors. The scores of TPWB, TSWB, and TPhWB were not consistently highest in the new schools followed in descending order by the renovated and non-renovated schools. For example, the TSWB ratings were 5.22, 5.09, and 4.96 in the renovated, non-renovated, and new schools respectively. Additionally, no statistically significant differences were found in the scores of TPWB, TSWB, and TPhWB between any pairs of school strata. The results, therefore, suggested that the impact of IEQ conditions on teachers' well-being in the new, renovated, and non-renovated schools were dissimilar from their impact on IEQ satisfaction factors. The results of the association analysis between well-being subdivisions and IEQ satisfaction factors confirmed this dissimilarity. TSWB significantly correlated with both VTC_{sat} ($r = 0.485$, $p = 0.000$) and AP_{sat} ($r = 0.351$, $p = 0.005$) while TPhWB significantly correlated with L_{sat} ($r = 0.348$, $p = 0.010$), VTC_{sat} ($r = 0.582$, p 0.000), and AP_{sat} ($r = 0.383$, $p = 0.004$). TPWB did not significantly correlate with any of the three factors of IEQ satisfaction. These weak to moderate statistically significant correlations supported the inconsistent pattern of results for the scores of well-being and IEQ satisfaction factors given that the highest proportion of variance explained by the associations (i.e. between TPhWB and VTC_{sat}) was approximately 34% only. The associations suggested the impact of IEQ on well-being was indirect through IEQ satisfaction.

Chapter 6 addressed objective four of this thesis by reporting on the conditional effects of IEQ parameters on teachers IEQ satisfaction based on SLCA scores. Statistically significant moderations were found for VTC_{sat} and L_{sat} only. The impact of $PM_{2.5}$ on VTC_{sat} was significantly moderated by indoor air quality-related finishes defects, $b_3 = 0.038$, $t = 2.042$, $p = 0.045$. Additionally, the impact of PM_{10} on VTC_{sat} was significantly moderated by indoor air quality-related finishes defects, $b_3 = 0.003$, $t = 2.749$, $p = 0.009$. For both significant moderations, the results suggested that the impact on VTC_{sat} were negative for the 10^{th} to 50^{th} percentile concentrations of $PM_{2.5}$ (i.e. 6.418 – 13.922 $\mu g/m^3$) and PM_{10} (i.e. 22.243 - 42.048 $\mu g/m^3$) respectively. In addition, the results suggested a positive impact on VTC_{sat} for the 75^{th} to 90^{th} percentile concentrations of $PM_{2.5}$ (23.228 - 39.516 $\mu g/m^3$) and PM_{10} (69.143 - 97.587 $\mu g/m^3$) respectively. The 10^{th} to 50^{th} percentile concentrations for both $PM_{2.5}$ and PM_{10} were below the

WHO recommended maximum thresholds of 25 μg/m^3 and 50 μg/m^3 respectively. The 75th to 90th percentile concentrations were generally above the WHO threshold for both $PM_{2.5}$ and PM_{10} respectively. Therefore, results suggested that the impact of $PM_{2.5}$ and PM_{10} on VTC_{sat} as a function of indoor air quality-related finishes and electrical defects respectively would be detrimental for teachers in the cleaner classrooms (i.e. 10th to 50th). However, in the least clean classrooms (75th to 90th percentile), the conditional effect on VTC_{sat} may be less detrimental if the higher concentrations of $PM_{2.5}$ and PM_{10} have remained for long. The pattern of daylight factor effects on L_{sat} based on lighting-related openings defects was contrary to the moderation effects of $PM_{2.5}$ and PM_{10} on VTC_{sat}. The effects on L_{sat} were negative for the 90th percentile daylight factor (i.e. 2.423%) and negligible for the 75th percentile daylight factor (i.e. 1.313%). For the 10th to 50th percentile daylight factors (0.236 - 0.772%), the moderation effects on L_{sat} based on lighting-related openings defects was positive. The 10th to 50th percentile daylight factors were substantially below the recommended threshold of 2% below which electric light is required to aid vision. Therefore, the results suggested that the impact of daylight factor on L_{sat} as a function of lighting-related openings defects would be negative for teachers who probably relied on daylight frequently (i.e. 90th classrooms). For teachers in the 10th to 50th percentile daylight factor classrooms, the moderation effect was positive considering those teachers most likely used electric light nearly all the time. The significant moderations reported in chapter 6 accounted for substantial proportions (i.e. 8 – 12.5%) of the variance in the scores of teachers' VTC_{sat} and L_{sat}. Therefore, chapter 6 concluded that the physical parameters of IEQ (e.g. $PM_{2.5}$ and daylight factor) and subsequently occupants IEQ satisfaction are most likely substantially dependent on the physical conditions of space envelope elements.

7.2 Contributions to the body of knowledge and implications of this research

- Development and validation of the SLCA for IEQ-related building condition assessment

The SLCA developed for the IEQ-related BCA of schools in this research is the first of its kind in the IEQ literature. While field observation methods and practices in the IEQ literature focus on observing the presence or absence of key building elements and their usage pattern, the SLCA goes a step further to assess the physical conditions of key space envelope elements. Current IEQ field observations also contribute to identifying causes of occupants' dissatisfaction with IEQ. However, the SLCA goes a step further by providing objective data for strategic IEQ-related operation and maintenance decision making. Although the SLCA was developed for schools, it can be easily adapted and used in other buildings considering that its main components (i.e. main envelop, openings, finishes, electrical, and mechanical) are common to all building types.

- Adaptation and refinement of an existing IEQ satisfaction survey for assessing teachers' IEQ satisfaction in school context, and development and validation of teachers' TPWB, TSWB, and TPhWB surveys

The NRC's IEQ satisfaction survey adapted and refined in this research demonstrated the importance of contextual issues when assessing IEQ satisfaction given that only 12 out of the 19 adapted items were found to be relevant for teachers in schools. Using the refined IEQ satisfaction survey for teachers in schools will most likely lead to a realistic assessment of teachers' IEQ satisfaction. Moreover, using multiple items for assessing IEQ satisfaction factors like lighting will minimize the subjectivity related to using a single item. The teachers' well-being surveys developed and validated in this research will enrich the IEQ literature with regards to the investigation of the intricate interactions between building occupants and their indoor environments. Use of these surveys in this research has provided empirical evidence suggesting that occupants' IEQ satisfaction should not be interpreted as occupants' well-being. Occupants' well-being is a broad concept which includes IEQ satisfaction and other essential elements including occupants' ability to physically complete their indoor tasks and their interactions with other occupants within their indoor space. Therefore, assessing occupants' well-being independent of IEQ satisfaction will likely lead to new insights on the impact of IEQ parameters on occupants. The well-being surveys developed and validated in this research will help assess the benefits of IEQ improvement interventions in schools. They can also be used by researchers in other disciplines including the social sciences to assess teachers' well-being in schools.

- Evidence supporting the relevance of IEQ-related renovations

This exploratory research provides empirical evidence supporting renovation interventions aiming to improve IEQ with the goal of improving occupants' satisfaction in schools. However, results of this research suggested that the moderation effects of the physical conditions of space envelop elements on occupants' satisfaction are complex and will most likely vary for different IEQ parameters. For example, results of this research showed that the conditional effect of $PM_{2.5}$ and PM_{10} on VTC_{sat} depended on indoor air quality-related finishes and electrical defects are likely to be positive. The positive impact on VTC_{sat} does not imply that classrooms with high concentrations of $PM_{2.5}$ and PM_{10} are a good working condition for teachers. Rather, it implies that teachers may not be dissatisfied with high concentrations of $PM_{2.5}$ and PM_{10} despite their potential long detrimental health effects on teachers. More IEQ research studies incorporating these developed methods should contribute to establishing benchmarks in the form of critical cut-off values or ranges for the physical condition of space envelope elements. These benchmarks would help in developing decision support tools to enable strategic operation and maintenance of school buildings.

- Relevant body of knowledge for school managers, building design and engineering professional, and IEQ researchers

The instruments and knowledge generated through this research should be of interest to governments and school divisions considering the substantial cost of school buildings' repair and their mounting deferred maintenance. This knowledge should be instrumental in developing new maintenance strategies or retooling existing ones to enhance the environmental conditions of schools given the reported link between educational achievements and schools' environmental condition. Findings of this research should also be relevant to building designers, engineers, and managers interested in school buildings. They should inform the design and construction of school buildings (e.g. material selection) that provide comfortable and healthy indoor environments that promote effective teaching and learning. These instruments and knowledge would also be relevant to IEQ researchers focusing on schools and other building types. These researchers can use the new instruments and report on their confirmatory validity and on required future improvements to them. Researchers interested in other building types can also adapt the SLCA for IEQ-related BCA to investigate the moderation effects of the physical conditions of space envelope elements in offices and homes for example on IEQ parameters and occupants' satisfaction and well-being. The well-being surveys developed and validated in this research will be relevant to key stakeholders in the sustainable building industry who are interested in assessing the benefits of sustainable buildings especially schools. For example, routine deployment of these surveys in both green and non-green schools may lead to identifying building design and maintenance strategies to maximize occupants' well-being.

7.3 Limitations

- Focus on visually observable defects of space enclosing elements

The SLCA was developed to enable quick and less costly IEQ-related BCA and thus focused mainly on visually observable defects. Invisible defects such as large internal cracks in walls and other space envelope elements were not captured even though they were likely to have a significant impact on IEQ conditions and thus subsequently on occupant' satisfaction and well-being. Moreover, the assessment of electrical and mechanical components focused on the physical condition of their visible elements within indoor spaces. Therefore, defects within ducts and the air handling units of HVAC systems were not accounted for by the SLCA even though they are likely to have a significant impact on thermal comfort and indoor air quality. Furthermore, the SLCA did not consider the assessment of the operation and maintenance of HVAC systems even though this significantly impacts IEQ. The SLCA does not, therefore, lead to a comprehensive condition assessment of school buildings.

- Use of a cross-sectional research design (i.e. SLCA, IEQ field measurements, and occupants' surveys deployed only once)

The SLCA and IEQ field measurements were conducted only once in each of the 52 classrooms. The IEQ field measurements were short-term measurements only (i.e. approximately 15 minutes sampling time per parameter) and the 10 schools were all assessed on different days within the measurement period. Therefore, results of the IEQ field measurements in this research were not representative of the daily variations in IEQ conditions experienced by teachers in schools. The IEQ satisfaction and well-being surveys were also administered only once. Because the SLCA, IEQ field measurements, and occupants' surveys were deployed in the winter season only, their results are not representative of other seasons.

- Use of a deductive process in developing teachers' IEQ satisfaction survey

The IEQ satisfaction survey used in this research was originally developed for office building occupants and was adapted and refined for teachers in schools. Although this adapted survey enabled the meeting of the goal and objectives of this research, it likely excluded other essential dimensions of IEQ satisfaction that are unique to teachers in schools. For example, the original NRC survey did not include a separate item for daylight as part of lighting satisfaction. The adapted survey used in this research included a separate item for assessing satisfaction with the amount of daylight in classrooms which emerged as the most significant item of the L_{sat} latent factor for teachers in a school context.

- Conflicting assessment of occupants' control of indoor environment

The VTC_{sat} factor in the refined IEQ satisfaction survey included the item "Your ability to alter or control physical conditions (such as temperature, light etc.) in your classroom". This item loaded significantly to the VTC_{sat} with a factor loading of 0.72 suggesting that most of the teachers who completed the survey associated the item with VTC_{sat}. However, the wording of the item shows that control of lighting and acoustics parameters were included as part of it. This is likely to make the assessment of these parameters more subjective and cause confusion when interpreting its results.

- Exclusion of other school building occupants (i.e. beyond teachers) and other indoor spaces (i.e. beyond classrooms)

Both the IEQ satisfaction and well-being surveys in this research focused on teachers only given that most of the previous IEQ research in schools focused on students. Therefore, the findings of this research are not considered representative of all school building occupants. Besides students, other non-teaching staff including office managers, custodians, and librarians in schools play significant roles that support the teaching and learning process. The impact of school buildings' physical and IEQ conditions on these occupants was not captured in this study. The assessment conducted in this study focused on classrooms given that teachers spend the greatest proportion of their school time in classrooms. Additionally, classrooms represent the greatest proportion of indoor space relative to other indoor spaces in school buildings and can, therefore, be considered representative of these schools. Other indoor spaces like corridors, library, and staff rooms were not accounted for in this study even though they may significantly influence the impact of school buildings' physical and indoor environmental conditions on teachers' IEQ satisfaction and well-being.

- Inability to identify survey responses from classrooms where the SLCA and IEQ field measurements were conducted

The surveys were not limited to teachers in classrooms where the SLCA and IEQ field measurements were conducted. Therefore, the moderation analysis presented in chapter 6 included IEQ satisfaction responses of teachers in other classrooms of the same schools where the SLCA and IEQ field measurements were not conducted. This limitation probably explains why most of the moderation analyses were not statistically significant.

- Not accounting for other relevant factors in this research

The quality of building's indoor environment and occupants' well-being can be influenced by several factors including outdoor weather conditions, environmental noise, and occupants' use of environmental control features. This research, however, focused on investigating how the physical conditions of building elements are likely to influence IEQ and subsequently occupants IEQ satisfaction and well-being. Other parameters like outdoor air temperature, outdoor humidity, and outdoor noise levels that could have influenced schools' IEQ were not accounted for due to resource limitation. This research excluded work-related factors within a school context such as job satisfaction, job recognition, and occupational hazards that can affect teachers' well-being. Additionally, relevant personal factors including medical health conditions, health status, and allergens that could have influenced teachers' well-being and IEQ satisfaction in schools were not captured in this research. The impact of these work-related and personal factors may exceed the potential direct and indirect impact of IEQ on teachers' well-being in a school context.

- Use of relatively small samples and of less stringent statistical methods to analyze the data

The sample sizes in this research were relatively small; therefore, the results will not be generalizable to schools beyond the study population. The SLCA was applied in 52 classrooms in 10 schools out of the 32 schools in the two school divisions that participated in this research. Additionally, the number of survey responses used in developing the IEQ satisfaction and well-being surveys were adequate; however, they may not be representative of IEQ satisfaction and the well-being manifestations of teachers beyond the study population. This research used several statistical methods to analyze the data collected. Although the methods were appropriate for this research, future research should consider the following key points. The analysis of differences in physical and IEQ conditions between the new, renovated, and non-renovated schools were conducted using the Kruskal-Wallis H test: the non-parametric less stringent alternative to the parametric One-Way Analysis of Variance test due to the limited sample sizes of the school strata. The factor structures of the teachers' IEQ satisfaction, psychological, social, and physical well-being surveys developed in this research using exploratory factor analysis were not confirmed with another sample of teachers who did not participate in this research.

7.4 Recommendations

- Capture of non-visible defects of space enclosing elements

Other advanced condition assessment equipment like thermal cameras that can capture non-visible defects should be employed to complement the SLCA for detailed condition assessments of schools and other building types. Capturing non-visible defects will be instrumental in finding the sources of adverse IEQ conditions and making informed operation and maintenance decisions to enhance IEQ.

- Use of a longitudinal research design (i.e. long-term IEQ field measurements, repeated SLCA, and repeated occupants' surveys)

Future IEQ studies should employ longitudinal research designs incorporating repeated SLCA, long-term IEQ field measurements, and repeated occupants' surveys across different weather seasons. This will lead to generating a significant amount of data to assess how seasonal variations are likely to influence the impact of school buildings' physical and indoor conditions on teachers' satisfaction and well-being.

- Development of an IEQ satisfaction survey using an inductive process

Future IEQ studies should consider developing IEQ satisfaction surveys using an inductive approach to produce surveys with content that is relevant to the context of building occupants. Use of content-relevant IEQ satisfaction surveys will lead to realistic assessments that will inform decisions to enhance occupants' satisfaction.

- Assessment of occupants' control of indoor environments

Occupants' limited control of their indoor environment has been identified in the literature as one of the leading causes of occupants' dissatisfaction. Therefore, future IEQ satisfaction surveys should assess occupants' ability to control the parameters of different IEQ factors by using a different item for every IEQ factor.

- Inclusion of other school building occupants (i.e. beyond teachers) and other indoor spaces (i.e. beyond classrooms)

Future studies should consider all school building occupants and other indoor spaces beside classrooms to enable a comprehensive assessment of how school buildings' physical and indoor conditions affect teaching and learning in schools. Extending IEQ research to capture the different categories of school building occupants and indoor spaces will be key in developing comprehensive IEQ enhancement strategies in schools.

- Use of sampling strategies that link specific survey responses to SLCA and IEQ field measurements

Future studies should explore sampling and survey deployment strategies that will make it possible to link specific survey responses to SLCA and IEQ field measurements without compromising the privacy of respondents. This will improve the assessments of the likely impact of IEQ parameters on building occupants subject to the physical conditions of space enclosing elements.

- Accounting for other relevant factors

Future IEQ studies should make provision for monitoring outdoor environmental conditions to investigate their influence on indoor conditions relative to the physical conditions of space enclosing elements. Additionally, future studies in schools and other building types should also include relevant work and personal factors in assessing occupants' well-being in relation to their indoor environment.

- Using larger samples and more stringent statistical methods to validate findings

Future confirmatory studies with larger samples of schools and classrooms are required to confirm the logic of the SLCA instrument. Differences in SLCA and IEQ field measurements between different school building types should be assessed using one-way analysis of variance. Additionally, future studies with larger samples of teachers are required to confirm the validity of the teachers' IEQ satisfaction and well-being surveys developed using confirmatory factor analysis and to suggest further improvements.

- Using the right terminology to qualify building occupants' surveys

Findings of this research suggested that occupants' IEQ satisfaction and occupants' well-being were different but related concepts with IEQ satisfaction being an aspect of occupants' well-being. Therefore, IEQ researchers who focus on assessing occupants' satisfaction with IEQ factors should use the correct terminology and interpret their findings as occupants' IEQ satisfaction and not occupants' well-being given that the latter includes other dimensions beyond satisfaction with IEQ factors. Measuring occupants' IEQ satisfaction and referring to it as occupants' well-being would be misleading and could, therefore, derail efforts to enhance occupants' well-being through IEQ improvements.

7.5 Concluding remarks

There is growing interest in the built environment sector to minimize the environmental and social impact of constructed structures. The quality of indoor environments in offices, school, homes, and other building types is gaining significant academic and industry interest due to the reported potential impact of adverse indoor environments on the satisfaction, well-being, health, and performance of building occupants. For schools, the IEQ literature strongly suggests that poor indoor environments will lead to poor academic achievements. However, authorities in charge of school buildings' operation and maintenance, especially in Canada are faced with mounting deferred maintenance due to resource limitations. This differed maintenance will likely affect the physical and IEQ conditions of schools and subsequently of occupants' satisfaction, well-being, and performance. The body of knowledge generated from this exploratory research should contribute to developing decision support tools for the strategic operation and maintenance of school buildings that would ensure sustained quality indoor environments. Maintaining comfortable and healthy indoor environments is likely to affect buildings' energy consumption through the operation of HVAC systems and subsequently the operation and maintenance budget. Therefore, future research should explore ways to maintain quality indoor environments without increasing buildings' energy consumption and its contribution to greenhouse gas emission.

Appendix A: Space level condition assessment instrument

1 MAIN ENVELOPE

1.1 Walls (indoor)

4	3	2	1
1.1.1 Damaged internal wall(s) [T/AQ/AC]			
☐Cracks/Missing units/ Holes/ Separations though thickness	☐Cracks/Missing units/Holes/ Separations not through thickness	☐N/A	☐No visible defects
1.1.2 Damaged external wall(s) [T/AQ/AC]			
☐Cracks/Missing units/ Holes/ Separations though thickness	☐Cracks/Missing units/Holes/ Separations not through thickness	☐N/A	☐No visible defects

1.2 Floor

4	3	2	1
1.2.1 Damaged floor [T/AQ/AC]			
☐Cracks/Holes though thickness	☐Cracks not through thickness	☐N/A	☐No visible defects

1.3 Ceiling

4	3	2	1
1.3.1 Damaged concrete ceiling [T/AQ/AC]			
☐Cracks/Holes though thickness	☐Spalling/Cracks not through thickness	☐N/A	☐No visible defects
1.3.2 Damaged suspended ceiling [AQ/AC/L]			
☐Cracks/Missing units/Holes though thickness	☐Cracks not through thickness	☐N/A	☐No visible defects

2 OPENINGS

2.1 Doors

4	3	2	1
2.1.1 Damaged door frame [T/AQ/AC]			
☐Missing frames	☐Warped/Gaps between frame and wall	☐N/A	☐No visible defects
2.1.2 Damaged door leaves [T/AQ/AC]			
☐Holes/Cracks/Separation through thickness	☐Warped	☐N/A	☐No visible defects
2.1.3 Broken/damaged door glazing [T/AQ/AC]			
☐Missing/Shattered panes	☐Cracked/Holes through thickness	☐Surface cracks	☐No visible defects
2.1.4 Functionality of door hardware [T/AQ/AC]			

☐Missing/ Broken	☐Damaged	☐Malfunctioning	☐No visible defects
2.1.5 Mold damage/damp doors [T/AQ]			
☐Rotten, fluffy, dark discoloration etc.	☐Damp	☐Damp stains	☐No visible defects

2.2 Windows			
4	3	2	1
2.2.1 Missing/damaged window frames [T/AQ/AC]			
☐Missing frame	☐Cracks/Warped/ Displaced frames	☐N/A	☐No visible defects
2.2.2 Stained window glazing [L]			
☐Opaquely stained	☐Translucently stained	☐Transparently stained	☐No visible stains
2.2.3 Broken/damaged window glass [T/AQ/AC/L]			
☐Missing/Shattered panes	☐Cracks/Holes through thickness	☐Surface cracks	☐No visible defects
2.2.4 Damaged/deteriorated window caulk or seal [T/AQ]			
☐Missing caulk or seal	☐Crumples and flakes when touched	☐Visible cracks	☐No visible defects
2.2.5 Functionality of window hardware (i.e. controls, hinges etc.) [T/AQ/AC]			
☐Broken	☐Damaged	☐Malfunctioning	☐No visible defects
2.2.6 Mold damage/damp windows [T/AQ]			
☐Rotten, fluffy, dark discoloration etc.	☐Damp	☐Damp stains	☐No visible defects

2.3 Sunscreen			
4	3	2	1
2.3.1 Damaged screen/blinds [L]			
☐Missing units/ Holes	☐N/A	☐N/A	☐No visible defects
2.3.2 Functionality of screen/blinds control [L]			
☐Missing/Broken units	☐Damaged units	☐Malfunctioning	☐No visible defects
2.3.3 Appearance of screens/blinds [AQ]			
☐76 – 100% are dusty	☐51 – 75%	☐26 – 50%	☐25% and below

3 FINISHES

3.1 Finishes, wall surface (indoor)			
4	3	2	1
3.1.1 Damaged render/stucco [T/AQ/AC]			
☐Spalling/Holes	☐ Deep cracks	☐N/A	☐No visible defects
3.1.2 Deteriorated/damaged painting [AQ]			

☐Chalking/Peeling/Flaking	☐Deep cracks without flakes	☐N/A	☐No visible defects
3.1.3 Painting appearance [AQ/L]			
☐Dirty	☐Worn-out	☐N/A	☐No visible defects
3.1.4 Mold damage/damp wall surfaces [T/AQ]			
☐Rotten, fluffy, dark discoloration etc.	☐Damp	☐Damp stains	☐No visible defects
3.1.5 Coverage of sound absorbing items – wall [AC]			
☐76 – 100% of surface	☐51 – 75%	☐26 – 50%	☐25% and below
3.2 Finishes, floor			
4	3	2	1
3.2.1 Damaged floor finish [T/AQ/AC]			
☐Missing units/Holes/ through thickness	☐Deep Cracks/Cuts	☐N/A	☐No visible defects
3.2.2 Mold damage/damp floor finishes [T/AQ]			
☐Rotten, fluffy, dark discoloration etc.	☐Damp walls	☐Damp stains	☐No visible defects
3.2.3 Floor finishes appearance [AQ]			
☐Dirty	☐Worn-out	☐N/A	☐No visible defects
3.2.4 Coverage of sound absorbing floor finishes [AC]			
☐76 – 100% of surface	☐51 – 75%	☐26 – 50%	☐25% and below
3.3 Finishes, ceiling			
4	3	2	1
3.3.1 Damaged Ceiling Finish (render/stucco) [AQ/L]			
☐Spalling/Holes through thickness	☐Deep cracks	☐N/A	☐No visible defects
3.3.2 Deterioration of Ceiling Finishes (Painting) [AQ/L]			
☐Chalking/Peeling/Flaking	☐Deep cracks without flakes	☐N/A	☐No visible defects
3.3.3 Mold damage/damp ceiling finishes [T/AQ/AC]			
☐Rotten, fluffy, dark discoloration etc.	☐Damp walls	☐Damp stains	☐No visible defects
3.3.4 Ceiling finishes appearance [AQ/L]			
☐Dirty/ dusty surface	☐N/A	☐N/A	☐No visible defects
3.3.5 Coverage of sound absorbing ceiling finishes [AC]			
☐76 – 100% of surface	☐51 – 75%	☐26 – 50%	☐25% and below

4 ELECTRICAL

4.1 Lumps and luminaries

4	3	2	1
4.1.1 Functionality of lamps [L]			
☐Lamps are functioning	☐N/A	☐N/A	☐Not functioning
4.1.2 Appearance of luminaires/lamps [AQ/L]			
☐Dusty/Dirty	☐N/A	☐N/A	☐Not dusty/dirty

5 MECHANICAL

5.1 Air inlet

4	3	2	1
5.1.1 Functionality of air inlets [T/AQ]			
☐Inlets are functioning	☐N/A	☐N/A	☐Not functioning
5.1.2 Appearance of air inlet (diffuser) [AQ]			
☐Dusty/Dirty	☐N/A	☐N/A	☐Not dusty/dirty
5.2 HVAC system			
5.2.1 Vibration and abnormal HVAC noise [AC]			
☐Yes	☐N/A	☐N/A	☐No

Appendix B: Ethics approval certificate 1

UNIVERSITY OF MANITOBA | Research Ethics and Compliance
Office of the Vice-President (Research and International)

Human Ethics
208-194 Dafoe Road
Winnipeg, MB
Canada R3T 2N2
Phone +204-474-7122
Fax +204-269-7173

APPROVAL CERTIFICATE

June 11, 2015

TO: **Abdul-Manan Sadick** [redacted] (Advisor M. Issa)
Principal Investigator

FROM: **Lorna Guse, Chair**
Education/Nursing Research [redacted])

Re: **Protocol #E2015:045**
"Evaluation of school buildings physical and indoor environmental quality in relation to teachers' well-being"

Please be advised that your above-referenced protocol has received human ethics approval by the **Education/Nursing Research Ethics Board**, which is organized and operates according to the Tri-Council Policy Statement (2). **This approval is valid for one year only**.

Any significant changes of the protocol and/or informed consent form should be reported to the Human Ethics Secretariat in advance of implementation of such changes.

Please note:

- **If you have funds pending human ethics approval, please mail/e-mail/fax (261-0325) a copy of this Approval (identifying the related UM Project Number) to the Research Grants Officer in ORS in order to initiate fund setup. (How to find your UM Project Number: http://umanitoba.ca/research/ors/mrt-faq.html#pr0)**

- **if you have received multi-year funding for this research, responsibility lies with you to apply for and obtain Renewal Approval at the expiry of the initial one-year approval; otherwise the account will be locked.**

The Research Quality Management Office may request to review research documentation from this project to demonstrate compliance with this approved protocol and the University of Manitoba *Ethics of Research Involving Humans*.

The Research Ethics Board requests a final report for your study (available at: http://umanitoba.ca/research/orec/ethics/human_ethics_REB_forms_guidelines.html**) in order to be in compliance with Tri-Council Guidelines.**

umanitoba.ca/research

Appendix C: Invitation email from Principal Investigator to Teachers

Sent: mm, dd, yyyy
From:
To:
Subject: Research on Indoor Environmental Quality in Relation to Teachers' Well-Being

This email is on behalf of Abdul-Manan Sadick, the principal investigator from the University of Manitoba.

You are invited to participate in an interview to evaluate teachers' well-being as it pertains to schools specifically. This interview is part of a larger study by the University of Manitoba and the <insert name of School Division> with the goal of evaluating the impact of school buildings' physical and indoor environmental conditions on teachers' well-being. In addition, the study will establish a relation between teachers' well-being and the quality school buildings' indoor environment. This relationship will help the school division to effectively prioritize school buildings' maintenance strategies to provide a healthy indoor working environment in schools.
The interview will be conducted in your school on a date and time that is convenient to you and will take about 45 to 60 minutes. The interview is anonymous and you will not be required to disclose any personal information during the interview. In addition, the interview will be conducted in an enclosed private space with only you and the principal investigator in attendance. Your participation is voluntary and you can withdraw from this study at any time.

This research has been approved by the Education/Nursing Research Ethics Board. If you have any concerns or complaints about this project you may contact any of the above-named persons or the Human Ethics Coordinator at 474-7122 or email Margaret.Bowman@umanitoba.ca.
To participate in this interview, please contact the principal investigator, Abdul-Manan Sadick at sadicka@myumanitoba.ca. You will be required to read and sign an informed consent on the appointed date prior to the start of the interview.

We look forward to meeting you and learning about your perception of teachers' well-being in schools specifically.

Best wishes
Abdul-Manan Sadick
The Principal Investigator

Appendix D: Open-ended interview questions

Section 1: Psychological Well-being

1. Describe what psychological well-being means to you.
2. How would you rate your level of psychological well-being at work (e.g. satisfactory, not satisfactory etc.)?
3. Can you describe recent situations or incidents at work in the past four weeks that you feel has influenced your level of psychological well-being (in harmony with yourself, happy)?
   (Note: situations can be related to students, colleagues, superiors, and parents of students)

Section 2: Social well-being

1. Describe what social well-being means to you.
2. How would you rate your level of social well-being at work (e.g. satisfactory, not satisfactory etc.)?
3. Can you describe recent situations or incidents at work in the past four weeks that you feel has influenced your level of social well-being (for example feeling of belongingness, feeling of being valued, that you have something to contribute)?
   (Note: situations can be related to students, colleagues, superiors, and parents of students)

Section 3: Physical well-being

1. The physical activities many teachers typically engage in include walking, standing, and demonstrating. Do you regularly engage in other activities? If so, what are those other activities?
2. Thinking of a typical workday in your school, estimate the percentage of your workday you are engaged in these activities.
3. Did you engage in extra-curricular or voluntary activities in your school over the last four weeks? If yes, what were those activities, and what was your motivation for engaging in those activities?
4. Which of your regular work activities in your school do you enjoy the most? Please explain why you enjoy these activities?

Appendix E: Informed Consent – stage one

UNIVERSITY OF MANITOBA

Faculty of Engineering
Department of Civil Engineering

Room E1-368A
Engineering
15 Gillson Street
Winnipeg, Manitoba
Canada R3T 5V6
Tel (204) 474-8212
Fax (204) 474-7513

Research Project Title: Evaluation of school buildings physical and indoor environmental quality in relation to teachers' well-being

Principal Investigator and contact information: Abdul-Manan Sadick, PhD candidate, Room E1-368A Engineering, 15 Gillson St, University of Manitoba, Winnipeg, MB R3T 5V6 Canada, email: sadicka@myumanitoba.ca

Advisor and contact information: Dr. Mohamed Issa, Assistant Professor, Construction Engineering and Management, Department of Civil Engineering, University of Manitoba, E3-589, EITC, 15 Gillson Street, Winnipeg, MB, R3T 2N2, email: Mohamed.Issa@umanitoba.ca

Sponsor (if applicable): Natural Sciences and Engineering Research Council of Canada

This consent form, a copy of which will be left with you for your records and reference, is only part of the process of informed consent. It should give you the basic idea of what the research is about and what your participation will involve. If you would like more detail about something mentioned here, or information not included here, you should feel free to ask. Please take the time to read this carefully and to understand any accompanying information.

Why have you been invited to participate?
You are being invited to participate in the first stage of a two-stage study aiming to investigate teachers' well-being in the context of school environments specifically. Please read this consent form carefully before deciding on whether or not to participate in this study. Your participation in this project is voluntary and you may withdraw from the project at any time prior to the completion of this interview. Your decision to participate or not will be kept in confidence by the researchers (see project team below) and will not be shared with the school division or your school principal.

Project team
The project team includes Abdul-Manan Sadick and Dr. Mohamed Issa.
Mr. Abdul-Manan Sadick is a PhD candidate at the University of Manitoba and is supervised by Dr. Mohamed Issa. This interview is part of Mr. Sadick's PhD research.

Why is the study being done?
Research suggests that improvements to schools' indoor environments could enhance teachers' well-being and by extension the quality of teaching and learning in schools. The outcome of this study will allow for the development of a contextualized teachers' well-being evaluation model that will be used to assess the impact of schools' indoor environmental quality and physical conditions on teachers' well-being. This study is the first stage of a two-stage study. The essence of this stage is to develop the preliminary well-being models that will be deployed and validated in the second stage.

What are you asked to do?
You are asked to participate voluntarily in an interview to explore the manifestations of psychological, social, and physical well-being of school teachers as it pertains to schools specifically. Your responses should draw from your experiences with other teachers, students, superiors, or parents of students as it pertains to your school environment. They interview should take a maximum of 60 minutes of your time. You will be asked to complete a short demographics survey prior to the actual interview.

Potential harm/ benefits
There is no known harm or direct benefits to participating in the study. However, your participation will help us better understand teachers' well-being in the context of school environments specifically.

Privacy and confidentiality
The interview will be recorded with an audio electronic recording device. You are asked not to mention your name or refer to other colleagues or students by name or using any other identifiable information throughout your interview. Please use generic words to refer to them. The recorded interview will be transcribed and a copy forwarded to you for verification and for your record. Only the principal investigator and the advisor (i.e. supervisor) will have access to all the information that will be collected for the study. All information gathered from you will be strictly confidential. The information will be completely anonymized and coded to ensure that your responses do not reveal your identity. Recorded interviews, demographic data, interview transcripts, and identification codes will be kept in a locked cabinet accessible only by the principal

investigator. Direct responses from this interview will not be included in any reports or research publications. Your employer will not have access to any of the data collected for this study. In addition, your employer will not be given any report with respect to the outcome of this stage of the study, given that the findings will be validated in the second stage.

At the end of January 2016, the recorded interview will be permanently deleted from the electronic audio recording device and the transcribed interviews will also be permanently destroyed. This data will not be stored in any format by the researchers.

Dissemination
Your direct responses to the interview questions will not be included in any report or scientific publication. Your responses will be analyzed for the purpose of developing and administering a survey in the second phase of this study to evaluate teachers' well-being as it pertains to schools specifically. A copy of the transcribed interview will be forwarded to you for verification and your records. You can request a copy of the survey that will be developed at the end of this stage of the study; see details below.

Risk and Benefits
You are not required to answer any question in the interview you may find distressing. You do not have to answer every question to be able to participate in this study.

You have the right to change your mind
By signing this Informed Consent, you agree to the information contained in inhere and to participating in the study. In no way does this waive your legal rights nor release the researchers, or your employer from their legal and professional liabilities. You are free to withdraw from the study at any time, and to refrain from answering any questions without prejudice or consequence. You will not be required to provide an explanation for doing so. To withdraw from this study, please contact the principal investigator at sadicka@myumanitoba.ca. In addition, you can also withdraw from this study by informing the principal investigator in person before, during or after the interview. Upon withdrawing from this study, your information will be permanently destroyed. If you decide to withdraw your information after you have provided it, you can do so by informing the principal investigator Abdul-Manan Sadick at sadicka@myumanitoba.ca. The principal investigator will permanently destroy your information. Alternatively, your information will be returned to you if requested in your email to the principal investigator; your information will not be duplicated for used in this study.

Can you request a summary of the study results?
You can request a summary of the study results either in electronic or printed version. This summary will be the preliminary teachers' well-being evaluation survey that should be available by the end of December 2015. To request a summary of the study results, or to ask questions about this study, please contact the principal investigator Abdul-Manan Sadick at sadicka@myumanitoba.ca and provide your preferred contact details.

Should you have any questions or concerns regarding this research project, you are welcome to contact the Chair of the University of Manitoba's Department of Civil Engineering as follows:

Dr. Ahmed Shalaby, Ph.D., P.Eng.
Professor and Head
Department of Civil Engineering
University of Manitoba
15 Gillson Street, EITC E1-368
Winnipeg, MB R3T 5V6
p: (204) 474-6818
e: Ahmed.Shalaby@umanitoba.ca

Ethics review

This research has been approved by the University of Manitoba Education/Nursing Research Ethics Board. If you have any concerns or complaints about this study you may contact any of the above-named persons or the Human Ethics Coordinator (HEC) at 474-7122 or email Margaret.Bowman@umanitoba.ca. A copy of this consent form has been given to you to keep for your records and reference.

How to participate

If you agree to participate in this survey and agree to the information contained herein, please inscribe your signature on the dotted line below.

Your signature on this form indicates that you have understood to your satisfaction the information regarding participation in the research project and agree to participate as a subject. In no way does this waive your legal rights nor release the researchers, sponsors, or involved institutions from their legal and professional responsibilities. You are free to withdraw from the study at any time, and /or refrain from answering any questions you prefer to omit, without prejudice or consequence. Your continued participation should be as informed as your initial consent, so you should feel free to ask for clarification or new information throughout your participation.

The University of Manitoba may look at the research records to see that the research is being done in a safe and proper way.

Participant's Signature …………………………….. Date……………………….

Researcher's Signature ……………………………… Date………………………..

Appendix F: Demographic information – stage one

1. What is your gender?

☐Male ☐Female

2. What is your age?

☐18 – 29 ☐30 – 39 ☐40 – 49 ☐50 – 59 ☐60 or over

3. How many years have you been teaching for?

☐ Less than 10 ☐ 10 - 20 ☐ 20 or over

4. Which grade(s) do you teach? ______________________________

Appendix G: Adapted teachers' IEQ satisfaction survey

Appendix G1: Demographic Information

1. What is the name of your school?

2. Which Division do your belong to?
   ☐ Hanover ☐ Seine River

3. For how long have you been working in this school?
   ☐ Less than 1 year ☐1 – 2 years ☐3 – 5 years ☐ More than 5 years

4. What is your gender?
   ☐ Female ☐Male

5. What is your age?
   ☐ 18 – 29 ☐30 – 39 ☐40 – 49 ☐50 – 59 ☐60 or over

6. Which grade levels do you teach (please select all that applies)?
   - ☐Kindergarten ☐Grade 7
   - ☐Grade 1 ☐Grade 8
   - ☐Grade 2 ☐Grade 9
   - ☐Grade 3 ☐Grade 10
   - ☐Grade 4 ☐Grade 11
   - ☐Grade 5 ☐Grade 12
   - ☐Grade 6

7. How many hours do you spend in the classroom per week?
   ☐Less than 10 ☐11 – 20 ☐21 – 30 ☐More than 30

8. Which of the following best describe your role in the school?
   ☐ Teacher
   ☐Teacher (Physical Education)
   ☐Teacher (Music/Band)
   ☐Counsellor
   ☐Principal/Vice Principal
   ☐Administrative Assistant

☐Secretary
☐Librarian
☐Educational Assistant
☐Custodian/Assistant Custodian

Appendix G2: Environmental Feature Rating

For each of the following, please select the appropriate check box that best expresses your level of satisfaction with the ……

1. Temperature in the classroom(s) where you teach regularly

Very Unsatisfactory	Unsatisfactory	Somewhat Unsatisfactory	Neutral	Somewhat Satisfactory	Satisfactory	Very Satisfactory
☐	☐	☐	☐	☐	☐	☐

2. Amount of daylight in your classroom
3. Amount of electric light in your classroom
4. Overall air quality in your classroom (i.e. smells bad, stuffy, stale air etc.)
5. Aesthetic appearance of your classroom(s)
6. Level of privacy for both teaching and non-teaching related conversations in your classroom
7. Level of visual privacy within your classroom
8. Amount of noise from other people's conversations in nearby classrooms and corridors while you are in your classroom
9. Size of your personal workspace to accommodate your work and materials
10. Amount of background noise (i.e. not speech) you hear in your classroom
11. Amount of light for computer work in your classroom
12. Amount of reflected light or glare in your classroom
13. Air movement in your classroom(s)
14. Your ability to alter or control physical conditions (such as temperature, light etc.) in your classroom
15. Your access to a view of outside from your classroom(s)
16. Distance between you and other people you work with
17. Quality of lighting (both electric and daylight) in your classroom
18. Frequency of distractions from other people outside your class
19. Degree of enclosure of your work area by walls, screens or furniture

Appendix H: Preliminary teachers' well-being surveys

Appendix H1: Preliminary teachers' psychological well-being

Instructions: For each statement below, indicate which answer best describes your present agreement or disagreement with each statement.

1. High background noise affects my concentration and workflow in class (-)

Strongly Disagree	Disagree	Slightly Disagree	Slightly Agree	Agree	Strongly Agree
☐	☐	☐	☐	☐	☐

2. High or low temperature in my classroom affects my work (-)
3. I am able to cope with everyday interactions with students in class
4. I am able to deal with difficult situations in school
5. I am always optimistic, even when I am not sure how to resolve issues in school
6. I am happy because I feel valued in my school
7. I am happy because I control air temperature in my classroom
8. I don't feel alone in my school
9. I establish and sustain relationships with my students
10. I express my thoughts and feelings in school
11. I feel eager to make a difference in my school
12. I feel secured to perform my duties as a teacher
13. I feel that I am reaching my students
14. I get all the supported I need to do my work in school
15. I get frustrated when electronic technology in the classroom do not work (-)
16. I get frustrated when students are not succeeding in my class (-)
17. I have adequate workspace to do my work in school
18. I help my students to get the support they need
19. I know my responsibilities as a teacher in school
20. I learn from different situations I experience in school
21. I like the occasional compliments and feedback from my colleagues
22. I love my job and the idea that I am making a difference
23. I see my students participating in class and I feel I can do more
24. It is part of my job to figure out the needs of all my students
25. My classroom is not fit for teaching and learning (-)
26. My role is respected in my school
27. My state of mind has no influence on my students in class (-)
28. My students appreciate my support
29. My students' personal problems are mine too
30. My work load in school is too much (-)
31. Poor environmental conditions of my classroom are a source of distraction (-)
32. Sometimes, I feel I have lost control of my class (-)
33. The achievements of my students are gratifying

34. The amount of daylight in my class affects my mood

Appendix H2: Preliminary teachers' social well-being

Instructions: For each statement below, indicate which answer best describes your present agreement or disagreement with each statement.

1. High background noise in class affects my interaction with students (-)

Strongly Disagree	Disagree	Slightly Disagree	Slightly Agree	Agree	Strongly Agree
☐	☐	☐	☐	☐	☐

2. I am able to anticipate problems in my classroom
3. I am able to identify issues that affect socialization in my school
4. I contribute to the social development of my students
5. I enjoy the company of people in my school
6. I feel a strong sense of connection with my students
7. I feel comfortable expressing my feelings to some people in school
8. I feel connected to my colleagues in school
9. I get close and have conversation with students
10. I get to laugh with my students as a group in class
11. I have a strong sense of belonging in my school
12. I have meaningful relationships in school
13. I have mutually trusting relationships in school
14. I have positive interactions with people in my school
15. I know I am supported by my colleagues in school
16. I know that I have something important to contribute to my school
17. I purposely plan for classroom social interactions
18. In my school, I am tolerated and not accepted (-)
19. In my school, learning is a collective responsibility
20. In my school, my concerns are not ignored
21. In my school, my voice matters
22. In my school, you see people caring about other people
23. It is important to acknowledge the efforts of your students in class
24. My school is not part of my social network (-)
25. My students share some details of their life with me
26. People do not have the time to socialize in school (-)
27. There is a positive atmosphere in my school
28. There is a sense of peace and calm in my school due to our relationships
29. There is mutual respect amongst people in my school
30. We figure out a way to work through our differences together
31. We get to interact and laugh together as colleagues
32. When I get the chance, I sit with my colleagues to have conversations

Appendix H3: Preliminary teachers' physical well-being

Instructions: For each statement below, indicate which answer best describes your present agreement or disagreement with each statement.

1. I always feel tired in class (-)

Strongly Disagree	Disagree	Slightly Disagree	Slightly Agree	Agree	Strongly Agree
☐	☐	☐	☐	☐	☐

2. I am comfortable with lifting, moving, or displaying my teaching materials
3. I don't have to be active to get my job done in school (-)
4. I engage in fun activities with my students in school
5. I feel alert and energetic in my classroom
6. I feel comfortable standing, bending, kneeling, or sitting on the floor to help my students
7. I feel exhausted at the end of the day (-)
8. I feel uncomfortable due to the level of air temperatures in my classroom (-)
9. I frequently get running nose, dry throat and lips, or watery eyes in school (-)
10. I frequently raise my voice in class due to high background noise (-)
11. I get allergic reactions in school due to conditions of my work environment (-)
12. I get bodily pains from standing and movements in class (-)
13. I get headache in school due to environmental conditions of my workspace (-)
14. I have bodily pains that affect my work in school (-)
15. I have less time to complete all my tasks in school (-)
16. I make time to engage in extracurricular activities in school
17. I spend nearly half of my time in school sitting at my desk (-)
18. I strain my eyes to see in my classroom due to poor lighting (-)
19. I teach from my seat and not on my feet (-)
20. I wish I could do less walking in the classroom (-)
21. In my class, I teach through demonstrations
22. In my classroom, I am constantly on my feet moving around
23. It is soo much fun playing with my students in school
24. Moving in class is good for my general health

Appendix I: Ethics approval certificate 2

UNIVERSITY OF MANITOBA

Research Ethics and Compliance
Office of the Vice-President (Research and International)

Human Ethics
208-194 Dafoe Road
Winnipeg, MB
Canada R3T 2N2
Phone +204-474-7122
Fax +204-269-7173

APPROVAL CERTIFICATE

March 18, 2016

TO: **Abdul-Manan Sadick** (Supervisor: Mohamed Issa)
Principal Investigator [redacted]

FROM: **Zana Lutfiyya, Chair**
Education/Nursing Research Ethics Board (ENREB)

Re: **Protocol #E2016:033 (HS19512)**
"Evaluation of school buildings physical and indoor environmental quality in relation to teachers' well-being"

Please be advised that your above-referenced protocol has received human ethics approval by the **Education/Nursing Research Ethics Board**, which is organized and operates according to the Tri-Council Policy Statement (2). **This approval is valid for one year only and will expire on March 18, 2017**.

Any significant changes of the protocol and/or informed consent form should be reported to the Human Ethics Secretariat in advance of implementation of such changes.

Please note:

- **If you have funds pending human ethics approval, please mail/e-mail/fax (261-0325) a copy of this Approval (identifying the related UM Project Number) to the Research Grants Officer in ORS in order to initiate fund setup. (How to find your UM Project Number: http://umanitoba.ca/research/ors/mrt-faq.html#pr0)**

- **if you have received multi-year funding for this research, responsibility lies with you to apply for and obtain Renewal Approval at the expiry of the initial one-year approval; otherwise the account will be locked.**

The Research Quality Management Office may request to review research documentation from this project to demonstrate compliance with this approved protocol and the University of Manitoba *Ethics of Research Involving Humans*.

The Research Ethics Board requests a final report for your study (available at: http://umanitoba.ca/research/orec/ethics/human_ethics_REB_forms_guidelines.html) in order to be in compliance with Tri-Council Guidelines.

umanitoba.ca/research

Appendix J: Invitation letter from Principal Investigator to Principals – stage two

UNIVERSITY OF MANITOBA

Faculty of Engineering
Department of Civil Engineering

Room E1-368A
Engineering
15 Gillson Street
Winnipeg, Manitoba
Canada R3T 5V6
Tel (204) 474-8212
Fax (204) 474-7513

Subject: Invitation to participate - Research on Indoor Environmental Quality in Relation to Teachers' Well-Being

You recently received an email from the Hanover School Division (or Seine River School) regarding the second stage of this two-stage collaborative study with researchers from the University of Manitoba (U of M). I am pleased to invite your school to participate in the second stage this study. The aim of this study is to evaluate the impact of school buildings' physical and indoor environmental quality (IEQ) on teachers' well-being. The results of this study will provide useful information to our school division and individual schools in the division about how to establish schools with physical conditions that provides conducive environment for teaching and learning. I am a graduate student in the Faculty of Engineering and this research is for my PhD.

This second stage will focus on measuring indoor environmental quality parameters such as air temperature, relative humidity, and carbon dioxide in classrooms with electronic sensor. Only a sample of classrooms will be measured in your school. Selection of classrooms will be based on the following:

1. Building orientation – classrooms will be selected from the north, south, east and west directions of a school building, at least one classroom from each direction.
2. Grade levels – grade levels (i.e. from kindergarten to grade 12) in particular will be considered

Based on the above criteria, a minimum of three and a maximum of six classrooms will be sampled per school. Measurement will be conducted during school day and will take at most two days per school. Air quality and temperature measurements will be taken in selected classrooms when they are occupied and take 15 minutes to complete. The researchers will not be in the classroom during the measurement period. The measurement equipment are custom built and mounted on a mobile carts, hence, there will be no need for additional time to setup and take down the equipment in the classroom. Additionally, an online occupants' survey will be deployed to assess teachers' well-being and satisfaction with classroom indoor environment. The survey will take about 15 minutes to complete. Furthermore, we will also assess the condition of school building elements such glazed windows, walls, and floors.

This second stage will be conducted over the next four months. If you agree for your school to participate in this study, please contact me (Abdul-Manan Sadick - the principal investigator) at sadicka@myumanitoba.ca. By agreeing to participate in this study, you agree to grant us (the U of M researchers) access to your school to conduct this study. After you have agreed to participate, I will forward a participants' invitation email to you to be forwarded to all teachers in your school by your administrative assistant on my behalf; this email will invite teachers in your school to participate in the online survey. The invitation email will have an anonymous link to the online survey. Your decision to participate in this study is voluntary and you can withdraw your school from this study at any time.

The IEQ measurement data, building condition assessment and occupants' survey will all be downloaded and stored a password protected external portable drive. The portable drive will be stored in a locked cabinet. Only the principal investigator will have access to the password and key to the cabinet. Data that contains information that can potentially lead to identification of research participants will be stored separately from anonymized data. Only the principal investigator will have access to the raw data while the PhD advisor will have access to anonymized data. All data collected for this study will be permanently destroyed by the end of September 2017, by which time project will have officially ended. Additionally, the principal investigator is expected to complete his PhD by September 2017. The online survey will be permanently deleted from the Qualtrics online sever whiles the dataloggers and portable external drive will be formatted to permanently destroy all data.

At the end of this study, a detailed report will be prepared and submitted to the two school divisions. The purpose of this report will be to provide the divisions with information required to provide a suitable indoor environment to maximize teachers' well-being and enhance teaching and learning in schools. Further, the key findings and the methods employed will be presented at research conferences and submitted to academic journals for publication. These publications will add to the growing body of literature on IEQ in schools and how it influences well-being of teachers. Additionally, the principal investigator will use the key findings in writing his PhD dissertation.

Should you have any questions or concerns regarding this research project, you are welcomed to contact my PhD Supervisor Dr. Mohamed Issa at Mohamed.Issa@ad.umanitoba.ca or (204) 474-8786

This research has been approved by the Education/Nursing Research Ethics Board of the U of M. If you have any concerns or complaints about this project you may contact the Human Ethics Coordinator at 204-474-7122, or by e-mail at humanethics@umanitoba.ca.

We will be delighted to work with your school on this study. We hope that you will consider participating in this study to make it a success.

Thank you.

Best Regards

Abdul-Manan Sadick

The Principal Investigator

Department of Civil Engineering, University of Manitoba

15 Gillson Street, E3-386, EITC, Winnipeg, MB, R3T 5V6
Email: sadicka@myumanitoba.ca

Appendix K: Occupants' survey invitation email – stage two

Sent: mm, dd, yyyy
From:
To:
Dear Participant

Subject: University of Manitoba Teachers' Well-being and Indoor Environmental Quality Survey

You are invited to participate in an online survey to evaluate your well-being as a teacher and the indoor environmental quality of school buildings, mainly classrooms. This survey is part of a large study by the University of Manitoba and the <*insert name of School Division*> with the goal of evaluating the impact school buildings' physical and indoor environmental condition on the well-being of teachers. I am a graduate student in the Faculty of Engineering and this research is for my PhD.

Participation should take you about 15 minutes. Your participation is voluntary and you can withdraw from this study at any time. Your response will influence future decisions regarding the operation and maintenance of existing schools and the construction of new schools to provide conducive teaching and learning environment.

Should you have any questions or concerns regarding this research project, you are welcomed to contact my PhD Supervisor Dr. Mohamed Issa at Mohamed.Issa@ad.umanitoba.ca or (204) 474-8786.

This research has been approved by the Education/Nursing Research Ethics Board of the U of M. If you have any concerns or complaints about this project you may contact the Human Ethics Coordinator at 204-474-7122, or by e-mail at humanethics@umanitoba.ca.

To participate in this survey, please click the link below to access the survey page. Please note that your responses will be submitted directly to the University of Manitoba Researchers. Upon clicking the link below, you will be presented with an online informed consent from. You will be automatically taken to the online survey page upon agreeing to the informed consent.

We are looking forward to learning from your experience of well-being and the quality of indoor environments in schools.

Occupant survey link: http://www.qualtrics.com/survey/012789635

Best wishes

U of M Research Team

Appendix L: Informed consent – stage two

UNIVERSITY OF MANITOBA
Faculty of Engineering
Department of Civil Engineering

Room E1-368A
Engineering
15 Gillson Street
Winnipeg, Manitoba
Canada R3T 5V6
Tel (204) 474-8212
Fax (204) 474-7513

Informed Consent

Research Project Title: Measuring the Indoor Environmental Quality of Office Buildings and its Impact on Worker Productivity

Why have you been invited to participate?

You are being invited to participate in a study aiming to investigate indoor environmental quality in schools and how it impacts teachers' well-being. Please read this consent form carefully before deciding whether or not to participate in this study. Your participation in this project is voluntary and you may withdraw from the project at any time prior to submitting your responses at the end of the survey. Your decision to participate or not to participate will be kept in confidence by the researchers and will not be shared with your employers.

Project team

The project team includes Dr. Mohamed Issa and Mr. Abdul-Manan Sadick. Mr. Abdul-Manan Sadick is a PhD student at the University of Manitoba and is supervised by Dr. Mohamed Issa.

Why is the study being done?

Research suggests that improvements to the indoor environment of schools could enhance the well-being of teachers and improve their performance. Hence, this research seeks to establish a relationship between teachers' psychological, social, and physical well-being with the quality of classrooms' indoor environment. The outcome of this study can influence design decisions of new schools and operation and maintenance strategies for existing schools to provide indoor environments that enhances teachers' well-being.

What are you asked to do?

You are asked to complete an online survey regarding your satisfaction with the indoor environment and experience of well-being in school. They survey should take about 15 minutes of your time.

Potential harm/ benefits

There is no known harm or direct benefits to participating in the study. However, your participation will help us better identify the physical conditions affecting well-being of teachers and thus contribute to improving those aspects.

Privacy and confidentiality

All data will be transmitted through a secure, encrypted internet connection and stored on secured servers. Only members of the University of Manitoba research team will have access to the raw data. All information gathered from you will be strictly confidential. The information will be completely anonymized to ensure that your responses do not reveal your identity. Reports and research publications resulting from this study will be based on group averages but not individual responses. Your employer will only be given aggregated data.

The IEQ measurement data, building condition assessment and occupants' survey will all be downloaded and stored a password protected external portable drive. The portable drive will be stored in a locked cabinet. Only the principal investigator will have access to the password and key to the cabinet. Data that contains information that can potentially lead to identification of research participants will be stored separately from anonymized data. Only the principal investigator will have access to the raw data while the PhD advisor will have access to anonymized data.

All data collected for this study will be permanently destroyed by the end of September 2017, by which time project will have officially ended. Additionally, the principal investigator is expected to complete his PhD by September 2017. The online survey will be permanently deleted from the Qualtrics online sever whiles the dataloggers and portable external drive will be formatted to permanently destroy all data.

Dissemination

At the end of this study, a report will be prepared using anonymized and aggregated data and submitted to your employer. The purpose of this will be to provide the School Division with the information required to provide a suitable indoor environment in order to enhance teachers' well-being. Further, the key findings and the methods employed will be presented at research conferences and also submitted to academic journals for publication. This will add to the growing body of literature on IEQ in schools and how it influences teachers' wellbeing in school context. Additionally, the principal investigator will use the key findings in writing his PhD dissertation.

Risk and Benefits

You are not required to answer any question in the survey that you find to be distressing. You will be able to submit your responses without having to answer questions you find to be distressing. With the exception of this consent page, none of the questions in the survey has restrictions that require you to answer them before proceeding to other questions or submitting your responses.

You have the right to change your mind

By entering your access code and clicking “start survey” at the end of this form, you agree to the information contained in inhere and to participating in the study. In no way does this waive your legal rights nor release the researchers, or your employer from their legal and professional liabilities. You are free to withdraw from the study at any time, and to refrain from answering any questions, without prejudice or consequence. Simply close your web browser if you decide to do so. You will not be required to provide an explanation for doing so.

Can you request a summary of the study results?

You can request a summary of the study results either in electronic or printed version. This summary will be available by the end of December 2016. To request this summary, or to ask questions about this study, please contact the principal investigator Abdul-Manan Sadick at sadicka@myumanitba.ca.

You can contact my PhD Supervisor Dr. Mohamed Issa at Mohamed.Issa@ad.umanitoba.ca or (204) 474-8786

Should you have any questions or concerns regarding this research project, you are welcomed to contact the Chair of the University of Manitoba’s Department of Civil Engineering as follows:

Dr. Ahmed Shalaby, Ph.D., P.Eng.
Professor and Head
Department of Civil Engineering
University of Manitoba
E1-368 EITC,
15 Gillson Street,
Winnipeg, MB R3T 5V6
p: (204) 474-6818
e: Ahmed.Shalaby@umanitoba.ca

Ethics review

This research has been approved by the Education/Nursing Research Ethics Board of the U of M. If you have any concerns or complaints about this project you may contact the Human Ethics Coordinator at 204-474-7122, or by e-mail at humanethics@umanitoba.ca.

A copy of this consent form has been given to you to keep for your records and reference.

How to participate

If you agree to participate in this survey and agree to the information contained herein, please click the “start survey” button.

Your signature (i.e. clicking the start button) on this form indicates that you have understood to your satisfaction the information regarding participation in the research project and agree to participate as a subject. In no way does this waive your legal rights nor release the

researchers, sponsors, or involved institutions from their legal and professional responsibilities. You are free to withdraw from the study at any time, and /or refrain from answering any questions you prefer to omit, without prejudice or consequence. Your continued participation should be as informed as your initial consent, so you should feel free to ask for clarification or new information throughout your participation.

The University of Manitoba may look at the research records to see that the research is being done in a safe and proper way.

This research has been approved by the Education/ Nursing Research Ethics Board. If you have any concerns or complaints about this project you may contact any of the above-named persons or the Human Ethics Coordinator (HEC) at 474-7122. A copy of this consent form has been given to you to keep for your records and reference.

Start Survey