AMERICAN UNIVERSITY OF BEIRUT

QUANTIFYING OCCUPANT COMFORT AND BEHAVIOR: CASE STUDY OF LEBANESE ACADEMIC BUILDINGS

by

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A thesis
submitted in partial fulfillment of the requirements
for the degree of Master of Engineering
to the Department of Civil and Environmental Engineering
of the Maroun Semaan Faculty of Engineering and Architecture
at the American University of Beirut

Beirut, Lebanon
March 2019

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ACKNOWLEDGMENTS

I would like to address my gratitude to Dr. Hiam Khoury and Dr. Maya Abou Zeid, my thesis advisors and professors, for all the support, guidance and encouragement that led me to finish my thesis.

Special thanks to Dr. Issam Srour and Dr. Aram Yeretzian, my professors and committee members, for their constructive comments that helped me improve my thesis.

I would also like to thank Mr. Khaled Joujou for providing me with all the help and information regarding the study.

Finally, I would like to thank all faculty members, staff and students who accepted to provide time and participate in the survey of this study.

AN ABSTRACT OF THE THESIS OF

Nour Ahmad Fayed for Master of Engineering
Major: Civil Engineering

Title: Quantifying Occupant Comfort and Behavior: Case Study of Lebanese Academic Buildings

Sustainability-focused design of buildings has been the center of attention of researchers and designers in recent years. However, occupants' comfort has not been typically taken into consideration when designing sustainable buildings. As such, energy savings goals have not been generally achieved in these designs due to occupants' behavioral changes in response to satisfaction with the Indoor Environmental Quality. Therefore, Post-Occupancy Evaluation is necessary to understand occupants' comfort and needs to improve the building design and accomplish the sustainability goals.

This study conducts a survey in three academic buildings at the American University of Beirut, Lebanon: an old building (Architecture building), a renovated building (Bechtel building) and a new LEED certified building (IOEC building). The focus of this research is to understand which components of the Indoor Environmental Quality mostly affect the occupants' satisfaction, by targeting students, faculty members and staff. The collected data is first used to quantify the level of satisfaction with each component of the IEQ through a descriptive statistical analysis. Results show that occupants are mostly dissatisfied with the Thermal and Aesthetics, followed by the Indoor Air Quality and Acoustic components. The occupants are satisfied with the Visual level of comfort. Behavior analysis reveals that occupants who are dissatisfied with their thermal comfort and the indoor air quality tend to behave in ways to increase their level of satisfaction which causes dissipation of energy. Therefore, energy savings designs need to be preceded by or informed by studies about occupants' comfort in other similar buildings, to ensure the sustainability goals are met.

A structural equation model is developed based on the collected data from students in classrooms. The results show that the Indoor Air Quality, the Acoustic level of comfort and the Thermal level of comfort predict the Overall Level of Satisfaction in a decreasing order of importance. Different policies are recommended for building managers and owners. Regular maintenance of the different building systems (HVAC) is necessary to ensure a higher level of satisfaction. Thorough design of the interiors and exteriors of a building should be implemented before the construction. Furthermore, providing control to occupants to be able to operate windows, shades and HVAC systems is necessary to allow them to accommodate their needs and comfort.

Findings of this research provide insights on occupants' comfort in buildings and their adaptive behavior. The study proposes policies to improve the Indoor Environmental Quality in buildings, resulting in an increase in occupants' level of satisfaction and ultimately protecting the environment. The developed survey instrument and modeling framework can be used in other types of commercial buildings and residential ones.

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CHAPTER 1

INTRODUCTION

1.1. Background

Sustainability design is an approach intended to significantly reduce energy consumption while maintaining a healthy comfortable environment for building occupants. When designers became aware about the risk of consuming large amounts of energy in buildings and the importance of sustainable design to reduce the negative impact on the environment, they started creating ways of design and construction to improve building performance (Kibert, 2016). As such, “Green Buildings” began to emerge widely. However, drawbacks were encountered during the operation phase of such buildings. The actual energy consumption in these buildings has often turned out to be in large discrepancy from the original estimates. For the most part, designers did not take the occupants’ behavior into consideration while designing, and occupants’ comfort was not well studied. Consequently, change in the occupants’ behavior was inconsistent with the full intentions of decreasing energy consumption. For instance, the creation of a “controlled environment” as part of the sustainable vision to decrease energy consumption left the occupants uncomfortable because of the lack of control over their indoor environment (Lee, 2005). As such, when occupants felt uncomfortable, they behaved in a way to increase their comfort which didn’t allow the saving energy goals to be reached. Consequently, Post-Occupancy Evaluation (POE) has become necessary to study the comfort of occupants to optimize the building design and set policies to reach the ultimate goal of sustainability. POE consists of collecting real data on occupant perception of the Indoor Environmental Quality (IEQ) in a specific building in order to create a feedback loop and improve the well-being of occupants. The IEQ represents the environmental conditions inside a building including air quality, thermal comfort, visual comfort, acoustic comfort, and aesthetics (ASHRAE, 2012).

Studies about performing POE in Lebanese buildings are limited in the literature, indicating that a lot of Lebanese owners and managers don't usually consider occupants' comfort and expected behavior explicitly in building design. This research effort, on the other hand, takes the initial steps and aims at carrying out a POE on Lebanese educational/ academic buildings to evaluate the perceptions of different types of occupants about different components of the IEQ. As a matter of fact, maintaining a satisfactory level of comfort is essential for efficient teaching and learning experiences. Consequently, improvement in the occupants' comfort can take place after studying what factors mostly affect their satisfaction levels.

1.2. Objectives and Research Framework

The overall objective of this research effort is to study the multilevel comfort of different types of occupants and the impact on their behavior in diverse Lebanese educational buildings using Structural Equation Modeling. The specific objectives are:

- Study different types of occupants' satisfaction with the Indoor Environmental Quality (students versus faculty members/staff) by focusing on their characteristics and needs, through a Post-Occupancy Evaluation survey.
- Develop a structural equation model to establish a relationship between the overall occupants' satisfaction and different features of IEQ in buildings including thermal comfort, indoor air quality, visual comfort, acoustic comfort and appearance.
- Compare the level of satisfaction of occupants with IEQ in different types of buildings: old/ renovated/ new LEED-certified.

- Investigate the impact of comfort on the behavior of different types of occupants and its implication for energy consumption.
- Analyze scenarios and propose interventions to improve the level of comfort of occupants while maintaining an energy saving strategy.

For the purpose of this research, a survey was conducted at the Architecture and Engineering Buildings (Dar Al-Handasah, Bechtel and Irani Oxy Engineering Complex) at the American University of Beirut to collect data about occupants' comfort. More specifically, different types of occupants are targeted to capture multiple perspectives and assess their perceptions in relation to their occupation position (student/ faculty member/ staff). The research focuses on studying multi-level comfort variables using a Structural Equation Model (SEM) and evaluating energy-related occupants' behavior. The outcome of this study will help establish policies that would enhance the level of comfort while sustaining the environment.

The framework of the research is presented in Figure 1 below.

Figure 1 – Research framework

1.3. Significance of the Research

Although several types of buildings exist, targeting the commercial type, in particular academic buildings, is of paramount importance, as the occupants seldom have the incentive to reduce their energy consumption (Gul and Patidar, 2015). They usually focus on completing their job tasks rather than saving energy (Andrews et al., 2013).

Students and faculty members spend a lot of time in classrooms and in academic buildings as a whole. However, they are not in full control over the environment and they might not be satisfied with the IEQ. Consequently, their lack of satisfaction might impact their behavior in order to improve the comfort level which, in turn, might change the energy consumption of buildings.

The study targets the different types of occupants in educational buildings to quantify their IEQ satisfaction levels and study their energy-related behavior. Using the results of a SEM, an approach is suggested to improve the occupants' multi-level comfort while maintaining low-energy consumption rates. The research provides examples of initiatives to improve environmentally friendly building systems while taking into consideration occupants' comfort and behavior. It allows better understanding of the needs of academic occupants and serves as an example to managers to improve the buildings under study as well as other buildings in the campus. Furthermore, the proposed policies are not limited to educational buildings but can also be applied in different types of buildings such as offices or residential.

The results can subsequently be used as part of an agent-based model to study and simulate the multi-level comfort and behavior of occupants in an academic building.

CHAPTER 2

LITERATURE REVIEW

Many researchers have studied occupants' behavior and comfort in different types of buildings. The most relevant studies have been collected and the main findings are presented in the following sections. The different components of the Indoor Environmental Quality that were targeted in relevant studies are first presented. Then the literature about occupants' comfort and satisfaction with these components is portrayed including a description of the Post-Occupancy Evaluation methods used in conventional and sustainable buildings. Following that, studies about occupants' comfort and behavior and the relation to energy consumption are discussed. Finally, the different analysis techniques applied in the studies relevant to this research are presented.

2.1. Components of Indoor Environmental Quality

The main variables that represent the IEQ are: thermal comfort, lighting, acoustic and indoor air quality (ASHRAE, 2012). Many studies have targeted these features in addition to other variables like appearance and aesthetics. As an example, Lee et al. (2016) focused on the impact of noise disturbance on workers' satisfaction with the physical environment and health in open-plan offices. It was shown that a negative relationship exists between noise disturbance and satisfaction with the environment and health. In the study conducted by Abduallah et al. (2016), the IEQ was measured through thermal comfort and air quality by the following items: air temperature too cold, air temperature too warm, too little air movement, air too dry, unpleasant odor in air, air too stale, air too dusty. The authors deduced that these items have a significant yet weak impact on Sick Building Syndrome (SBS) but no effect on stress in an office environment. Nevertheless, it was found that SBS and stress are significantly related. Kamaruzzamann et al. (2015) conducted a POE and determined the variables which mostly affect the office workers' satisfaction. The variables were categorized as: air quality and control, intrusion and appearance. The intrusion variables included acoustic, visual and thermal comfort. The air quality and control variables included ventilation, humidity and health comfort. The appearance variables included aesthetics, privacy and availability of working space comfort. It was found that the latter factor, "appearance" of the building, is the most important factor that affects the satisfaction of a worker. On the other hand, El Asmar et al. (2014) compared the IEQ performance in a LEED (Leadership in Energy and Environmental Design) educational campus in the United States and a conventional campus in Lebanon. The survey conducted during the study targeted the satisfaction with space layout and furniture, indoor air quality, acoustic level, thermal comfort, lighting level, water efficiency, maintenance and cleanliness. The results showed that the average satisfaction level was higher in the United States campus than in Lebanon by 17%. Each study focused on specific features depending on the type of building under study.

2.2. Occupants' Comfort and Satisfaction

Post-Occupancy Evaluation (POE) is a widely used method to obtain the perception of building occupants on the IEQ in order to improve building performance or better design future projects. ASHRAE Standard 55 has defined "an acceptable thermal environment as one in which there is 80% overall acceptability", with acceptable temperature for the indoor environment between 18 and 24 degrees Celsius (ASHRAE, 2004).

Preiser et al. (1988) stated that many POEs have been performed on different types of buildings in order to better transfer occupants' perception of their environment to decisionmakers and these were based on surveys. Surveys are considered a common, relatively inexpensive, time-effective and simple method that can be used to collect data about occupants' satisfaction (Zagreus et al., 2004). For instance, in their research, Huizenga et al. (2003) described a web-based occupant satisfaction survey developed by the Center for the Built Environment (CBE) at the University of California, Berkeley. The aim of the survey was to quantify the occupants' level of comfort in relation to the IEQ of a building by studying environmental features including thermal comfort, indoor air quality, lighting and acoustics. In the survey led by Zagreus et al. (2004), the occupants were asked to rate their satisfaction with the indoor air quality, the thermal comfort, lighting and acoustics. Three cases were studied with the purpose of providing data for the facility managers and building owners to enhance the occupants' comfort and improve building technologies. Similarly, Frontczak et al. (2012) and Kamaruzzaman et al. (2015) conducted POE surveys among office building occupants to assess the effect of IEQ parameters and building features on occupants' satisfaction with the workspace. The purpose was to improve the comfort level of workers. In the first study by Frontczak et al., it was shown that satisfaction with amount of space followed by noise level and visual privacy were the most important variables that affect occupants' satisfaction. In the other study by Kamaruzzaman et al., appearance was the most significant factor which impacted occupants' satisfaction.

Some studies of occupant comfort and satisfaction targeted "Green" buildings. Dili et al. (2010) conducted a survey among occupants of traditional and modern buildings by targeting the thermal comfort satisfaction of residents. It was shown that passive mechanical ventilation incorporated in traditional buildings keeps the occupants satisfied throughout the different seasons of the year without having to refer to high energy-consumption methods like HVAC systems and fans. In contrast, occupants of modern buildings rely heavily on intensive energy systems to reach a level of comfort in different seasons.

Moreover, LEED certifications for new constructed and renovated buildings are being widely adopted; however, the impact of these unconventional buildings on the occupants' comfort satisfaction is a new topic of interest among many researchers. Driza and Park (2014) conducted a post-occupancy survey in two LEED-certified higher educational buildings and results of the analysis revealed that thermal comfort satisfaction was less than the recommended value by LEED standards. User control of thermostat and windows in classrooms was not common which reflected the low satisfaction of occupants. The study by El Asmar et al. (2014) revealed that educational buildings which are LEED certified perform better in terms of IEQ and therefore satisfaction of occupants is higher, compared to a conventional educational building. Similarly, Kim et al. (2015) compared the occupants' comfort satisfaction level between LEED-certified hospitals and conventional ones by performing a survey among healthcare staff in both types of hospitals. Results showed that green hospitals offer better IEQ to their staff and therefore provide them with more satisfaction with lighting, air quality and acoustic comfort.

It is important to note that during POE, it is crucial to gather information about the occupants since the characteristics and socio-cultural background of occupants may affect the relationship between IEQ perception and comfort satisfaction level, as suggested by Sakellaris et al. (2016).

The reviewed studies related to occupants' comfort and satisfaction with the Indoor Environmental Quality as well as the variables studied are summarized in Table 1.

2.3. Energy Consumption and Occupants' Behavior

Studying occupants' behavior alone is not sufficient without studying the impact on energy consumption. Several studies have targeted energy related behavior of occupants in buildings, which can affect energy consumption positively or negatively. Kotol (2012) performed a study on occupants' behavior and its effect on energy consumption in Greenlandic buildings. Through a survey, the researcher revealed that most of the dwellings suffer from poor indoor air quality due to lack of ventilation, which leads to more energy consumption of the HVAC systems. The author suggested that user control should be introduced in all HVAC systems among buildings to save on energy consumption. In fact, behavior is somehow manifested by the level of control given to occupants. Zalejska-Jonsson (2014) discusses adaptive comfort strategies depending on the level of control occupants have over their environment. For example, when people are thermally uncomfortable, they would attempt to restore their comfort by behaving in different ways, such as changing a thermostat setting or opening/closing a window. Additionally, the type of building is important to determine whether occupants have full user control over the building features, like in houses, or whether they lack perceived or actual control, like in offices or classrooms which, in turn, impact the way they behave, as suggested by Day (2015). The latter also demonstrates that occupants' behavior and their interaction with the sustainable building may limit the energy saving goals that the building should be reaching. Similarly, Hong et al. (2016) explains that simple energy related occupants' behaviors are crucial to save on energy, like adjusting thermostat temperature, turning on or off HVAC systems, opening or closing windows, turning on or off lights, pulling up or down blinds, etc. It was also shown by Nguyen and Aiello (2013) that careless energy related occupants' behavior can increase a building's energy consumption by one third, whereas “green” or sustainable energy-related behavior can save a third.

Yang et al. (2015) further suggested that the energy consumption bill payment may motivate occupants to change their behavior in terms of energy saving. As such, occupants in educational buildings - or any other institutional or office buildings - tend to ignore energy saving measures since they are not directly responsible for paying the bill.

Table 1 summarizes some of the most relevant studies conducted on occupants’ behavior and energy consumption.

2.4. Statistical Analysis Techniques

For the purpose of studying occupants’ comfort and satisfaction and the impact of adaptive behavior on energy consumption, researchers have used different statistical techniques. Frontczak et al. (2012) applied proportional odds ordinal logistic regression statistical method to understand which variable assessed by the respondents influences the satisfaction level the most. It was found that the amount of space is the most important variable for highest satisfaction with the workspace. Sakellaris et al. (2016) also performed proportional odds ordinal logistic regression analysis in offices to evaluate the relationship between occupants’ perception of the IEQ and their comfort. It was observed that the acoustic feature is the most important variable that impacts the occupants’ overall comfort. The other variables associated with the overall comfort are in the following decreasing order: air quality, visual and thermal satisfaction. Newsham et al. (2009) referred to Mediated Regression Analysis, a logic sequence of multiple regression analyses, to study how satisfaction with lighting affects environmental satisfaction which, in turn, affects job satisfaction. This statistical method doesn’t provide an estimate of the fit for the entire model.

Some other researchers used Structural Equation Modeling (SEM) in their study of occupants' comfort. For instance, Charles et al. (2003) used SEM to confirm the statistical significance of the hypothesis that relates three environmental features (privacy/acoustics, lighting and ventilation) to the overall environmental satisfaction, which in turn is related to job satisfaction. Lee et al. (2016) also used SEM to study the impact of noise on work satisfaction in open-plan offices specialized in research and development and engineering. Results showed a negative relation between noise disturbance (phone ringing, other people talking, etc.…) and workers' satisfaction with the environment and health. In the study by Kamaruzzaman et al. (2015), SEM was also applied to relate the exogenous latent (or unobserved) constructs – "intrusion", "air quality and control" and "appearance" – to the overall occupants' satisfaction with the office environment which was considered as an endogenous latent construct. "Appearance" was found to be the most significant variable which influences occupants' satisfaction. Furthermore, in the study by Abduallah et al. (2016), a survey was conducted among workers in office buildings to study the relationship between IEQ, Sick Building Syndrome and stress. Partial Least Squares SEM was applied, and the hypothesis that related the Indoor Environmental Quality to stress was rejected by the SEM analysis.

The following Table 1 summarizes the most relevant studies indicating which analysis techniques were used.

Table 1 - Literature review table

Author(s)	Year	Title	Survey	Building Type	Analysis Techniques	Variables Studied
C. Huizenga, L. Zagreus, E. Arens, D. Lehrer	2003	Measuring Indoor Environmental Quality: a web-based occupant satisfaction survey	✓	Office	Comparison analysis	Indoor air quality, thermal comfort, lighting, acoustics
L. Zagreus, C. Huizenga, E. Arens, D. Lehrer	2004	Listening to the occupants: a web-based Indoor Environmental Quality survey	✓	Office	Comparison analysis	Thermal comfort, indoor air quality, building maintenance
A.S. Dili, M.A. Naseer, T. Zacharia Varghese	2010	Thermal comfort study of Kerala traditional residential buildings based on questionnaire survey among occupants of traditional and modern buildings	✓	Residential	Comparison analysis	Thermal comfort (temperature, humidity and air flow)
M. Frontczak, S. Schiavon, J. Goins, E. Arens, H. Zhang, P. Wargocki	2012	Quantitative relationships between occupant satisfaction and satisfaction aspects of Indoor Environmental Quality and building design	✓	Office	Proportional Odds Ordinal Logistic Regression	Office layout, office furnishing, thermal comfort, air quality, lighting, acoustic quality, cleanliness and maintenance
M. El Asmar, A. Chokor, I. Srour	2014	Are building occupants satisfied with Indoor Environmental Quality of higher education facilities?	✓	Educational	Comparison analysis Unpaired t-test	Space layout, space furniture, thermal comfort, air quality, lighting, acoustic quality, water efficiency, cleanliness and maintenance
P.J. Driza and N.K. Park	2014	Occupant satisfaction in LEED-certified higher education buildings	✓	Educational	Descriptive statistics and content analysis	Layout, furniture, thermal comfort, indoor air quality, lighting, acoustics, cleanliness and maintenance
S. Kamaruzzaman, C. O. Egbu, E. Marinie, A. Zawawi, S. Bari Abd Karim, C. Jia Woon	2015	Occupants' satisfaction toward building environmental quality: structural equation modeling approach	✓	Office	SEM	Acoustics, lighting, thermal, air quality and control, appearance
S. Kim, Y. Hwang, Y. Lee, W. Corser	2015	Occupant comfort and satisfaction in green healthcare environments: a survey study focusing on healthcare staff.	✓	Healthcare	Pearson correlation & Linear Regression	Temperature, humidity, noise, ventilation, lighting, layout, way-finding, materials and colors, indoor natural settings
N. H. Abdullah, N.A. Abdul Hamid, M. Shahrul, A. Shaif A. Shamsuddin, E. Wahab	2016	Structural model for the effects of perceived indoor work environment on sick building syndrome and stress	✓	Office	Partial Least Square Structural Equation	Indoor work environment, sick building syndrome, stress

Author(s)	Year	Title	Survey	Building Type	Analysis Techniques	Variables Studied
					Modeling (PLS - SEM)	
P. Jik Lee, B. Kwon Lee, J. Yong Jeon, M. Zhang, J. Kang	2016	Impact of noise on self-rated job satisfaction and health in open plan offices a structural equation modelling approach	✓	Office	SEM	Acoustics
I.A Sakellaris, D.E. Saraga, C. Mandin, C. Roda, S. Fossati, Y. de Kluizenaar, P. Carrer, S. Dimitroulopoulou V.G. Mihucz, T. Szigeti, O. Hänninen, E. de Oliveira Fernandes, J. G. Bartzis, P.M. Bluyssen	2016	Perceived Indoor Environment and occupants’ comfort in European “modern” office buildings: the OFFICAIR study	✓	Office	Ordinal Logistic Regression Analyses	Indoor air quality, thermal comfort, lighting, acoustics
M. Kotol	2012	Survey of occupant behaviour, energy use and indoor air quality in Greenlandic dwellings	✓	Residential	Descriptive statistical analysis	Thermal, air quality, sound quality
Q. Zalejska-Jonsson	2014	Parameters contributing to occupants’ satisfaction: Green and conventional residential buildings	✓	Residential	Ordered logistic models	Thermal quality, air quality, sound quality, day light quality
J. Day	2015	Occupant behaviors and energy use: creating high-performance people for high-performance buildings	✓	Office	Qualitative data analysis /Triangulation	Thermal comfort, visual comfort, air quality
T. Hong, S. C. Taylor-Lange, S. D’Oca, D. Yan, S. P. Corgnati	2016	Advances in research and applications of energy-related occupant behavior in buildings	×	All types	Simulation	Thermal comfort, visual comfort, air quality
K. Charles, J. Veitch, K. Farley, G. Newsham	2003	Environmental satisfaction in open-plan environments: 3. Further scale validation	✓	Office	SEM	Ventilation, privacy, lighting

2.5. Gaps in Literature and Study Contributions

Post-Occupancy Evaluation and the study of occupants' needs are very important to improve a building environment. However, the study of occupants' comfort in an old academic building that was renovated has not been extensively found in the literature. In fact, the renovation of buildings has the purpose of increasing the comfort of occupants, and therefore the recently renovated Bechtel building at the American University of Beirut (AUB) was chosen in this study to investigate this statement. Furthermore, some studies have compared occupants' comfort in traditional and new buildings, as well as non-LEED and LEED buildings, but none has performed a comparison of an old, a renovated and a new LEED building, which is the case in the present study. The age of a building is very important when studying the indoor environmental comfort.

Moreover, paper-based or web-based surveys have been extensively used for POE. In the present study, the IEQ survey is conducted using clickers instead of a web-based survey as a more efficient and interesting way to collect the data. Further explanation about the survey methodology is provided in later sections.

Few studies targeted different types of occupants, but none analyzed the difference in perception of IEQ and satisfaction with the level of comfort depending on the respondents' occupation, specifically student versus faculty member and staff. Each type of occupant has different needs and expectations, although they all share the same building. As such, this concept is reflected in the current study in which different types of occupants are targeted.

CHAPTER 3

SURVEY DESIGN

A survey was conducted in classrooms and offices of the American University of Beirut, Lebanon, among students, faculty members and staff members. This chapter discusses how the survey was designed.

3.1. Survey Design

The survey is composed of 38 questions asking the respondents about their satisfaction with the classroom physical environment and their respective behavior. The response rating scale is a 5-point scale, ranging from “very dissatisfied” to “very satisfied” as follows:

A. Very Dissatisfied
B. Dissatisfied
C. Neutral
D. Satisfied
E. Very Satisfied

Long surveys have negative impact on the completion and response rates. Therefore, the survey was designed to last between 15 and 20 minutes, which is acceptable to ensure respondents do not get bored and would answer all questions genuinely. The survey questionnaire is shown in Appendix A.

The survey is composed of seven sections in the following order: Overall Level of Comfort, Participant Information, Thermal Comfort, Indoor Air Quality, Acoustic Comfort, Visual Comfort and Appearance & Layout. The survey starts with general questions about the respondent’s satisfaction with the respective feature in each section (except for the participant information section). In satisfaction surveys, it is typically better to first ask general questions about the overall satisfaction prior to asking more specific questions. According to Aronoff and Kaplan (1995), even if a respondent tries to answer each question independently, his/her answer can, to a certain degree, be influenced by the preceding question.

Following the general questions about the overall level of comfort, respondents' demographic information is gathered, like gender and age bracket, to ensure that the collected data correspond to a representative sample. The professional status of respondents is also specified (undergraduate/graduate student or faculty member) which can be correlated to their satisfaction and behavior. The rest of the survey questions ask respondents about the satisfaction and perception of different features of Thermal Comfort, Indoor Air Quality, Acoustic Comfort, Visual Comfort and Appearance & Layout. Besides, the respondents' energy-related behaviors are identified through preference questions regarding opening/ closing windows, doors and shades, and turning on/off lights and the HVAC system.

A one-to-one interview is conducted with faculty members and staff in their respective offices. It is similar to the classroom survey with some adjustments to reflect satisfaction in the office rather than in the classroom.

CHAPTER 4

DATA COLLECTION

This chapter presents the time and location of the surveys conducted as well as general information about the participants and how the sampling was done. The survey method used in this research is then described.

4.1. Survey Time and Location

The survey was performed during the Fall and Spring Semesters of AY 2016-2017 and Fall semester of AY 2017-2018, to accommodate for different seasons and weather conditions. The survey took place in classrooms and offices of Dar Al-Handasah building (Architecture), Bechtel Engineering building and Irani-Oxy Engineering Complex (IOEC). A layout plan showing the three buildings on campus is presented in Appendix C. The classrooms are located on the 1st and 2nd floors of the Engineering Bechtel building, the 1st and 5th floors of IOEC and the 1st, 2nd and 3rd floors of the Architecture building. An overview of classrooms in Bechtel, IOEC and the Architecture building is presented in Figures 2, 3 and 4 respectively. The architecture classrooms differ from those in Bechtel and IOEC in terms of layout and seat orientation. Architecture classes are mostly "design studios" and therefore students gather and sit around tables in large rooms to work individually or in groups. The engineering classes are mostly "lectures"; thus, classrooms in Bechtel and IOEC are formed of rows of seats facing a board or a projection screen. All classrooms have windows, generally located at the back of the class. Offices are located in the three buildings and they differ in size and number of available windows; some are oriented to the north and some to south. It should be mentioned that the location of the office impacts the occupant's level of satisfaction differently, as the exposure to the sun is longer on one of the façades. But due to the limited sample collected in offices on different facades, this was not part of the research scope.

Figure 2 – Example of Bechtel Classrooms

Figure 3 – Example of IOEC Classrooms

Figure 4 – Example of Architecture Classrooms (During Renovation)

4.1.1. Bechtel Building

Bechtel Engineering building was constructed in 1952 and went through many renovations, the latest of which took place in 2016. An overview of the building is shown in Figure 5.The building is made of five floors; the first and second floors are composed of classrooms, and the rest is composed of offices and meeting rooms. The third floor and some of the offices on the fourth and fifth floors are equipped with a Variable Refrigerant Volume (VRV) HVAC System with one shared compressor which is known to be energy-efficient and provides users with full control over the temperature. It is a very efficient system because it turns on in each room separately whenever occupants switch on the room control unit. Therefore, it controls the volume of refrigerant based on the demand. This system was implemented specifically in the departments' offices and faculty members' offices to allow flexibility in adjusting temperature based on the preference of these occupants. For example, a faculty member might feel hot in winter and would like to turn the HVAC system on in his/her office, and therefore with the VRV system implemented, it is not necessary to turn on the HVAC system for the whole building.

Figure 5 – Bechtel Building

The departments' staff offices are always busy with people coming in and out, so occupancy is always high in these rooms and therefore might need more cooling than other parts of the building, even when the building is operating on heat. In classrooms, occupants' behavior is more predictable and organized, as a large number of students enter the classroom for a specific time and leave all together. Cooling is required most of the time for this reason except for around two to three months per year. Hence, the classrooms and the rest of the building are operating on a central chilled water system. A two-way valve system is implemented in classrooms instead of a three-way valve system for a more energy efficient purpose.

Temperature control is not allowed in classrooms as the room control units are locked. A temperature set point is specified for all classrooms (23 degrees Celsius). In addition, classrooms are equipped with sensors that measure the CO2 level and accordingly valves provide a percentage of fresh air to the room depending on the measured level of CO2. Additionally, a Building Management System (BMS) was introduced lately in the building to control and monitor the HVAC system.

In regard to the acoustic quality of the building, the false ceilings are made of 60x60 acoustic aluminum tiles that are perforated and mounted under a special type of fabric which absorbs the sound waves. Double walls divide the classrooms for acoustic purposes too. Exterior walls were constructed as double walls and the windows were upgraded to double-glazed during the latest renovation.

For lighting control, occupancy sensors are placed in each room of the building which control both the lights and the audiovisual system. Lighting is managed through three electronic switches incorporated in a board panel located at the entrance of each classroom. The faculty member has the freedom to adjust the room lighting according to his/her preference and the time of the day he/she is giving the class.

4.1.2. IOEC Complex

IOEC is a LEED certified building, constructed in 2014. The building is shown in Figure 6. The whole façade is made of glass windows; nevertheless, the windows in this building are inoperable. The HVAC system is a controllable chilled water system similar to the one in Bechtel. Air handling units are present in all rooms on all floors which send fresh air to the building and remove it to create a ventilation cycle. However, this fresh air needs to be cooled through an air handling unit before being distributed. This unit was specifically chosen to be environmentally-friendly and energy-efficient. However, it couldn’t handle the required flow demand for the whole building. Accordingly, to compensate for the amount of fresh air needed, a motor was installed to increase the speed of the air handling unit which caused its malfunction due to the high pressure of flow. Consequently, the unit was shut down and replaced with a conventional ventilation system without saving energy. Furthermore, all rooms in the building lack false ceilings, which causes the sound of the fans to be disturbing when they are set on the high level. Large mechanical shades were incorporated on the outside façade, but they are hardly manipulated; a person from the operation team needs to walk outside of the building on a catwalk to be able to move it.

Figure 6 – IOEC Building

4.1.3. Dar Al-Handasah Architecture Building

Dar Al-Handasah Architecture building was built in the 1940's and an overview of the building is presented in Figure 7. It didn't go through major renovations, but it is currently undergoing renovation. At the time of the study survey, the building is equipped with a basic chilled water HVAC system; occupants can only change the fan speed (low, medium or high) but the temperature cannot be changed manually. The system is always turned on, taking into consideration that architecture students spend more time in the building even after class hours. Acoustic comfort is a major issue in this building since it is located next to the power plant and cooling towers. Although the windows are double-glazed, occupants tend to open them most of the time since the HVAC system is not very efficient.

Figure 7 – Dar Al-Handasah Architecture building

4.2. Survey Participants and Sampling

To ensure that the sample size is representative of the actual population, emails were sent to all faculty members of the Maroun Semaan Faculty of Engineering and Architecture at the American University of Beirut, asking them if they would accept to participate in the survey by allocating a specified time (15 to 20 min) of their class to conduct the survey. Fourteen members accepted to participate in the survey. Eight classes were located in Bechtel building, three in IOEC and three in the Architecture building. Since all classrooms in Bechtel and the

Architecture building are facing North, and all classrooms in IOEC are facing South, the orientation of classes was not taken into consideration while sampling. To ensure that the data collected covers the whole day, the time of day of the classes was noted and it varied between morning (from 8:00 AM to 12:00 PM) and afternoon (from 12:00 PM to 6:00 PM).

Regarding the interview with faculty and staff members, emails were sent to ask for an appointment to visit their offices and conduct the interview. The chosen offices were located on the North and South façades of the three buildings.

The total number of collected surveys in classrooms was 349. However, not all respondents were actively participating, as some did not answer all questions of the survey. Among the survey respondents, 128 were female (37%) and 171 were male (49%) whereas the rest did not specify their gender. Most of the respondents were between 18 and 24 years old since the survey was conducted among students and mainly second- and third-year undergraduate students (77%). On the other hand, 10 staff members were interviewed, and 22 faculty members participated in the survey: 14 were interviewed and the rest conducted the survey in class with their students. However, only 4 of the faculty members who conducted the survey in classrooms answered the whole questionnaire.

4.3. Data Collection Method

In each classroom, Classroom Response Systems (Clickers) (Mayer et al., 2009) were used to conduct the survey among students and one faculty member to collect data about their comfort perception of the IEQ in the respective classroom. Clickers form an efficient way to answer questions simultaneously when a large number of participants are involved. They are composed of small devices with 10 letters (A to J) which send radio-frequency signals to a USB receiver connected to a laptop. The survey questions were presented on PowerPoint slides with multiple choice answers. The software TurningPoint (TurningTechnologies, 2013) was installed on the laptop to collect the survey answers from PowerPoint. It also has the option of generating bar charts that show the responses on the PowerPoint Presentation. Clickers were chosen as a means to ensure a high response rate from students. A web-based survey sent by email may not guarantee a sufficient number of responses since many students ignore such type of emails. Furthermore, when students are in class, participation in the survey is encouraged by the professor which would allow a higher response rate. More importantly, students can answer the survey questions while perceiving the IEQ of the classroom.

CHAPTER 5

STATISTICAL DESCRIPTIVE ANALYSIS

This chapter presents the general statistical descriptive analysis conducted on the collected data after being cleaned, followed by a statistical analysis of the overall level of satisfaction and the satisfaction with each of the Indoor Environmental Quality components.

5.1. Data cleaning

In this chapter, data with missing responses were used whenever possible and when targeting a specific question. The first step was to extract answers of the needed questions, which represent mainly the indicators of the SEM model (see Chapter 7), and these include the following questions:

Q1, Q2, Q4, Q19, Q20, Q21, Q22, Q29, Q30, Q31, Q32, Q24, Q25, Q27, Q28, Q13, Q14, Q15, Q17, Q34, Q35, Q36, Q37, Q38.

Outlier analysis was then conducted. There are two types of outliers in a dataset: univariate and multivariate. A univariate outlier shows an extreme value on one variable whereas a multivariate outlier shows extreme values on different variables (Kline, 2011). The data was checked for multivariate outliers using Cook’s distance test in the software R (Prabhakaran, 2016). Cook’s distance is used to determine influential outliers in each response (row), which might negatively affect the model. The higher the Cook’s distance is, the higher the influence of the specific outlier. In this case, the calculated values that are three times greater than the mean can be classified as outliers. However, for convenience, only the most extreme values were considered, i.e. values that are greater than 6 times the mean.

"The cook's distance for each observation *i* measures the change in Y for all observations with and without the presence of observation *i*, so we know how much the observation *i* impacted the fitted values." (Prabhakaran, 2016)

For more details, the reader is referred to Cook (2000). The test was applied for each of the different dependent variables (indicators) which will be and a plot showing the extreme values was drawn. Figure 8 is an example of the Cook's distance plot for the indicator Q15. The x axis represents the observation row number and the y axis is the calculated Cook's distance. The red line corresponds to the recommended threshold value above which the outliers are considered influential. The corresponding observation row number of the outliers from the data sheet is noted. In this particular plot, the observations with row number 140, 169, 184, 186 and 201 were considered as influential outliers. After conducting the test for all indicators, 18 responses were removed. It should be noted that out of the 18 responses, 9 were located in IOEC, 6 in Bechtel and 3 in the Architecture building.

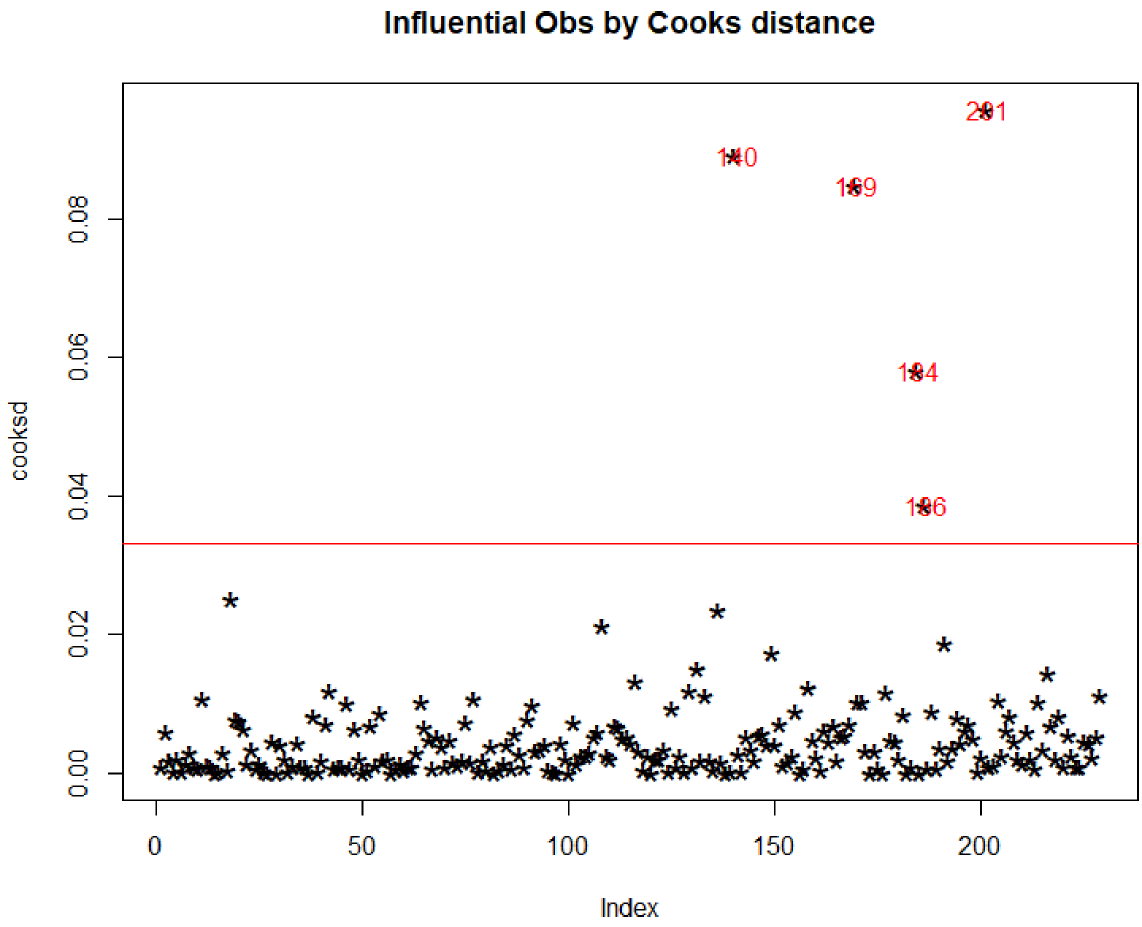

Figure 8 - Cook's distance Plot for Q15

5.2. General descriptive analysis

The data was first cleaned manually to remove any survey with missing answers. Basic statistical descriptive analysis was conducted on the cleaned data excluding the outliers (total of 235 respondents from conducted surveys and interviews) for the different indicators used in the model. The results are presented in Table 2 including the mean and standard error for each indicator for the overall sample and for each building separately.

When the data collected is ordinal, it is assumed to be non-normal (Muthen & Kaplan, 1985). Therefore, the Mann-Whitney-Wilcoxon test is conducted on the data, as an alternative to the t-test, to find whether the populations from each building are significantly different at the 95% confidence level (Siegel, 1956). Furthermore, since the analysis includes three pairwise statistical tests on the same data set, the Bonferroni correction is applied as an adjustment to the p value (Napierala, 2012). Accordingly, the new p value of 0.02 is considered the value below which the populations are statistically different at the 95% level of confidence. Results are presented in Table 2.

Respondents' satisfaction with the overall level of comfort with IEQ (Q1) appears to be different between Bechtel and the two other buildings, but is identical between IOEC and the Architecture building. Additionally, respondents of the Architecture building seem to differently perceive the Relative Satisfaction with IEQ in comparison to other classrooms (Q2) and their State of Health during class (Q4) in comparison to respondents of Bechtel and IOEC. The latter two have similar satisfaction levels regarding Q2 and Q4 indicators. Respondents of the three buildings agree about the Impact of IEQ on the level of concentration (Q3).

Regarding the thermal comfort, respondents seem to assess their satisfaction with thermal comfort (Q13) and with control over temperature (Q14) the same across buildings. However, they differently perceive the temperature when entering the classroom (Q15) and throughout the class (Q17) between IOEC and the other two buildings.

The satisfaction with the Indoor Air Quality (Q19) and the different related indicators (Q20, Q21, Q22) are perceived differently among the three buildings. This can be justified by the fact that each building has its own ventilation and HVAC system as previously discussed, and therefore the IAQ is different and specific to each building.

Respondents of Bechtel and the Architecture buildings assess the satisfaction with Acoustic level of comfort (Q24) differently. Also, noises coming from outside (Q25) are perceived differently between the Architecture building respondents and the two other buildings. This is expected as the Architecture building is located near the generators of the power plant. Furthermore, the estimates of the indicators "Noises coming from mechanical systems (Q27)” and the “Disturbance from other students talking (Q28)” are significantly different between Bechtel and IOEC, and Bechtel and the Architecture building.

The visual comfort (Q29) perception is similar among all the buildings, for all the corresponding indicators. The level of control over lighting (Q30), the amount of light (Q31) and the level of glare (Q32) are similar in all three buildings.

Finally, the aesthetics (Q34) are differently evaluated by the Architecture building respondents and the IOEC respondents. Cleanliness (Q35) is also differently viewed among the Architecture respondents and those from the two other buildings. The distance between respondents (Q36) and whether their seats are comfortable (Q37) are assessed differently between IOEC respondents and the two other buildings. Moreover, the ability to see the board (Q38) is only different between Bechtel and Architecture respondents.

Table 2 – Average means for each IEQ component and building differences

			Overall Mean (Standard error)	Bechtel Mean (Standard error)	IOEC Mean (Standard error)	Archit. Mean (Standard error)	Differences: Bechtel - IOEC Mean (p-value)	Differences: Bechtel - Archi Mean (p-value)	Differences: IOEC - Archi Mean (p-value)
Overall Level of Satisfaction	Q1	Satisfaction with the overall level of comfort with IEQ	2.82 (0.07)	3.07 (0.09)	2.58 (0.14)	2.31 (0.15)	0.52* (0.00)	0.79* (0.00)	0.27 (0.24)
	Q2	Relative Satisfaction with IEQ in comparison to other classrooms	2.67 (0.07)	2.77 (0.08)	2.89 (0.14)	1. 89 (0.16)	-0.12 (0.29)	0.88* (1.8e-06)	1.00* (2.7e-05)
	Q3	Impact of IEQ on level of concentration	3.93 (0.08)	3.98 (0.10)	3.85 (0.16)	3.88 (0.22)	0.13 (0.68)	0.10 (0.89)	-0.03 (0.88)
	Q4	State of health during class	2.69 (0.08)	2.76 (0.10)	2.89 (0.14)	2.03 (0.19)	-0.13 (0.34)	0.73* (0.00)	0.86* (0.00)
Satisfaction with Thermal Comfort	Q13	Satisfaction with thermal comfort	2.26 (0.07)	2.24 (0.10)	2.48 (0.14)	2.11 (0.13)	-0.24 (0.37)	0.13 (0.83)	0.37 (0.33)
	Q14	Satisfaction with control over temperature	1.65 (0.06)	1.62 (0.08)	1.77 (0.13)	1.57 (0.13)	-0.15 (0.46)	0.05 (0.84)	0.20 (0.70)
	Q15	Temperature perception when entering the classroom	3.35 (0.08)	3.10 (0.11)	4.03 (0.12)	3.06 (0.20)	-0.93* (2.50e-07)	0.04 (0.66)	0.97* (4.6e-05)
	Q17	Temperature perception throughout the class	3.34 (0.08)	3.10 (0.11)	4.06 (0.13)	2.94 (0.22)	-0.96* (3.6e-07)	0.16 (0.44)	1.12* (3.7e-05)
Satisfaction with Indoor Air Quality	Q19	Satisfaction with IAQ	2.54 (0.07)	2.50 (0.09)	3.05 (0.13)	1.74 (0.16)	-0.55* (0.00082)	0.76* (7.6e-05)	1.31* (2.3e-07)
	Q20	Freshness of the air	2.23 (0.06)	2.10 (0.07)	2.85 (0.11)	1.54 (0.11)	-0.75* (9.4e-08)	0.56* (0.00)	1.31* (6.6e-10)
	Q21	Ventilation	2.28 (0.07)	2.18 (0.09)	2.75 (0.12)	1.77 (0.14)	-0.57* (0.00)	0.41 (0.04)	0.98* (6.3e-06)
	Q22	Odors	2.69	2.71	3.14	1.74	-0.43*	0.97*	1.40*

			(0.07)	(0.08)	(0.13)	(0.16)	(0.00)	(1.4e-06)	(4.3e-8)
Satisfaction with Acoustic Level of Comfort	Q24	Satisfaction with the acoustic comfort	2.66	2.77	2.69	2.20	0.08	0.57*	0.49
			(0.07)	(0.10)	(0.14)	(0.20)	(0.56)	(0.01)	(0.05)
	Q25	Noises coming from outside	2.69	2.90	2.82	1.66	0.08	1.24*	1.16*
			(0.07)	(0.09)	(0.13)	(0.15)	(0.55)	(9.5e-09)	(5.9e-07)
	Q27	Noises coming from mechanical systems	2.40	2.61	2.12	2.06	0.49*	0.55*	0.06
			(0.08)	(0.11)	(0.13)	(0.17)	(0.00)	(0.02)	(0.83)
	Q28	Disturbance from other students talking	2.71	2.96	2.52	2.03	0.44*	0.93*	0.49
			(0.08)	(0.10)	(0.14)	(0.19)	(0.00)	(2.2e-05)	(0.02)
Satisfaction with Visual Comfort	Q29	Satisfaction with the visual comfort	3.27	3.35	3.15	3.17	0.20	0.18	-0.02
			(0.07)	(0.09)	(0.15)	(0.18)	(0.33)	(0.40)	(0.98)
	Q30	Level of control over lighting	2.99	2.95	2.91	3.31	0.04	-0.36	-0.40
			(0.07)	(0.10)	(0.14)	(0.18)	(0.67)	(0.07)	(0.04)
	Q31	Amount of light	3.37	3.43	3.29	3.29	0.14	0.14	0.00
			(0.07)	(0.08)	(0.13)	(0.18)	(0.33)	(0.38)	(0.95)
	Q32	Level of glare/reflection	2.70	2.79	2.46	2.80	0.33	-0.01	-0.34
			(0.07)	(0.10)	(0.13)	(0.19)	(0.06)	(0.98)	(0.15)
Satisfaction with Appearance & Layout	Q34	Aesthetics of the room	2.40	2.33	2.71	2.05	-0.38	0.28	0.66*
			(0.08)	(0.11)	(0.15)	(0.15)	(0.04)	(0.31)	(0.01)
	Q35	Cleanliness	3.35	3.50	3.77	2.00	-0.27	1.50*	1.77*
			(0.08)	(0.09)	(0.12)	(0.18)	(0.06)	(5.6e-10)	(3.0e-10)
	Q36	Distance between you and others	2.98	2.76	3.51	2.86	-0.75*	-0.10	0.65*
			(0.08)	(0.11)	(0.15)	(0.21)	(7.4e-05)	(0.66)	(0.01)
	Q37	Comfortable seats	2.37	2.50	2.00	2.57	0.50*	-0.07	-0.57*
			(0.08)	(0.10)	(0.16)	(0.18)	(0.00)	(0.73)	(0.00)
	Q38	Ability to see the board/screen	3.13	3.24	3.15	2.66	0.09	0.58*	0.49
			(0.08)	(0.10)	(0.15)	(0.16)	(0.67)	(0.00)	(0.03)

1 = very dissatisfied; 5 = very satisfied
Total respondents = 235; Bechtel respondents =135; IOEC respondents = 65; Architecture respondents = 35
**populations are significantly different at 95% confidence level*

Table 3 presents the mean and standard error for each indicator by gender, as well as the difference between females and males means. Surveys with missing data are included in this analysis: there are 128 females and 171 males in the sample data. In general, female participants are less satisfied than male participants.

Table 3 – Average means and standard errors by gender

			Female Mean (Standard error)	Male Mean (Standard error)	Difference [Female – Male] (p-value)
Overall Level of Satisfaction	Q1	Satisfaction with the overall level of comfort with IEQ	2.67 (0.09)	2.99 (0.08)	-0.32* (0.01)
	Q2	Relative Satisfaction with IEQ in comparison to other classrooms	2.54 (0.10)	2.72 (0.08)	-0.18 (0.18)
	Q3	Impact of IEQ on level of concentration	3.82 (0.12)	4.02 (0.09)	-0.20 (0.28)
	Q4	State of health during class	2.29 (0.10)	2.60 (0.08)	-0.31* (0.01)
Satisfaction with Thermal Comfort	Q13	Satisfaction with thermal comfort	2.12 (0.09)	2.23 (0.08)	-0.11 (0.44)
	Q14	Satisfaction with control over temperature	1.51 (0.07)	1.62 (0.08)	-0.11 (0.76)
	Q15	Temperature perception when entering the classroom	3.35 (0.11)	3.12 (0.09)	0.23 (0.10)
	Q17	Temperature perception throughout the class	3.47 (0.13)	3.07 (0.09)	0.40* (0.01)
Satisfaction with Indoor Air Quality	Q19	Satisfaction with IAQ	2.19 (0.09)	2.54 (0.09)	-0.35* (0.01)
	Q20	Freshness of the air	2.04 (0.08)	2.27 (0.08)	-0.23 (0.07)
	Q21	Ventilation	2.10 (0.09)	2.26 (0.08)	-0.16 (0.19)
	Q22	Odors	2.38 (0.09)	2.79 (0.08)	-0.41* (0.00)
Satisfaction with Acoustic Level of Comfort	Q24	Satisfaction with the acoustic comfort	2.35 (0.10)	2.84 (0.08)	-0.49* (0.00)
	Q25	Noises coming from outside	2.46 (0.10)	2.83 (0.09)	-0.37* (0.01)
	Q27	Noises coming from mechanical systems	2.06 (0.09)	2.45 (0.09)	-0.39* (0.00)
	Q28	Disturbance from other students talking	2.41 (0.11)	2.95 (0.10)	-0.54* (0.00)
Satisfaction with Visual Comfort	Q29	Satisfaction with the visual comfort	2.90 (0.11)	3.24 (0.08)	-0.34* (0.02)
	Q30	Level of control over lighting	2.82 (0.11)	3.05 (0.08)	-0.23 (0.16)

	Q31	Amount of light	3.14 (0.09)	3.38 (0.08)	-0.24 (0.06)
	Q32	Level of glare/reflection	2.50 (0.09)	2.68 (0.09)	-0.18 (0.29)
Satisfaction with Appearance & Layout	Q34	Aesthetics of the room	2.13 (0.10)	2.36 (0.09)	-0.23 (0.12)
	Q35	Cleanliness	3.05 (0.12)	3.65 (0.08)	-0.60* (0.00)
	Q36	Distance between you and others	2.72 (0.12)	2.86 (0.10)	-0.14 (0.35)
	Q37	Comfortable seats	2.33 (0.11)	2.28 (0.09)	0.05 (0.79)
	Q38	Ability to see the board/screen	2.87 (0.10)	3.19 (0.09)	-0.32* (0.02)

1 = very dissatisfied; 5 = very satisfied
Total respondents = 299; Female respondents =128; Male respondents = 171
**populations are significantly different at 95% confidence level*

The means and standard errors by students' class level (years of study) and their differences are presented in Table 4. The first category includes 104 students from the first and second year of the engineering undergraduate level, (E1 and E2), and the other category includes 163 students from the third and fourth year of the engineering undergraduate level (E3 and E4). The graduate students were not studied as a separate category since only 28 graduate respondents participated in the survey. The results show that the older students are generally less satisfied with the Indoor Air Quality (the two categories are statistically different at 95% level of confidence).

Table 4 - Average means and standard errors by undergraduate year level

			E1+E2 Mean (Standard error)	E3+E4 Mean (Standard error)	Difference [E1+E2 – E3+E4] (p-value)
Overall Level of Satisfaction	Q1	Satisfaction with the overall level of comfort with IEQ	2.86 (0.10)	2.79 (0.08)	0.07 (0.41)
	Q2	Relative Satisfaction with IEQ in comparison to other classrooms	2.73 (0.12)	2.58 (0.08)	0.15 (0.32)
	Q3	Impact of IEQ on level of concentration	3.85 (0.13)	3.97 (0.10)	-0.12 (0.44)
	Q4	State of health during class	2.64 (0.11)	2.26 (0.09)	0.38* (0.01)
Satisfaction with Thermal Comfort	Q13	Satisfaction with thermal comfort	2.03 (0.10)	2.21 (0.09)	-0.18 (0.17)
	Q14	Satisfaction with control over temperature	1.64 (0.10)	1.47 (0.07)	0.17 (0.09)
	Q15	Temperature perception when entering the classroom	3.92 (0.10)	2.88 (0.10)	1.04* (0.00)
	Q17	Temperature perception throughout the class	3.99 (0.11)	2.85 (0.10)	1.14* (0.00)
Satisfaction with Indoor Air Quality	Q19	Satisfaction with IAQ	2.80 (0.11)	2.21 (0.08)	0.59* (0.00)
	Q20	Freshness of the air	2.47 (0.10)	2.01 (0.07)	0.46* (0.00)
	Q21	Ventilation	2.44 (0.10)	2.12 (0.08)	0.32* (0.01)
	Q22	Odors	2.92 (0.12)	2.45 (0.08)	0.47* (0.00)
Satisfaction with Acoustic Level of Comfort	Q24	Satisfaction with the acoustic comfort	2.41 (0.11)	2.67 (0.09)	-0.26 (0.07)
	Q25	Noises coming from outside	2.75 (0.12)	2.61 (0.09)	0.14 (0.44)
	Q27	Noises coming from mechanical systems	1.79 (0.09)	2.43 (0.09)	-0.64* (0.00)
	Q28	Disturbance from other students talking	2.56 (0.13)	2.73 (0.11)	-0.17 (0.34)
Satisfaction with Visual Comfort	Q29	Satisfaction with the visual comfort	3.23 (0.13)	3.06 (0.09)	0.17 (0.23)
	Q30	Level of control over lighting	2.96 (0.13)	2.94 (0.08)	0.02 (0.90)
	Q31	Amount of light	3.27 (0.11)	3.32 (0.08)	-0.05 (0.73)
	Q32	Level of glare/reflection	2.57 (0.11)	2.52 (0.09)	0.05 (0.68)
Satisfaction with Appearance & Layout	Q34	Aesthetics of the room	2.22 (0.13)	2.18 (0.09)	0.04 (0.93)
	Q35	Cleanliness	3.31 (0.12)	3.41 (010)	-0.10 (0.47)
	Q36	Distance between you and others	3.49 (0.13)	2.48 (0.10)	1.01* (0.00)
	Q37	Comfortable seats	2.06	2.40	-0.34*

		(0.12)	(0.09)	(0.01)
Q38	Ability to see the board/screen	3.23	3.05	0.18
		(0.12)	(0.08)	(0.17)

1 = very dissatisfied; 5 = very satisfied
Total respondents = 267; (E1+E2) respondents =104; (E3+E4) respondents = 163
**populations are significantly different at 95% confidence level*

Table 5 below presents the means and standard errors by time of the day when the survey was taken: morning (all surveys collected before 12:00 PM) and afternoon (all surveys collected after 12:00 PM). The total number of surveys collected in the morning is 140 and the total number collected in the afternoon is 209. The results in Table 5 show that the time of the day is important with respect to satisfaction. The Acoustic comfort and Appearance are not affected by time of the day. By focusing on values of groups (morning versus afternoon) that are statistically different, it can be seen that people are generally more satisfied in the morning than in the afternoon regarding their thermal comfort (Q15 and Q17). The classrooms in Bechtel are facing North, and so during the early hours of the day, the sunlight doesn’t penetrate the rooms directly, preventing the heat to build up. The case is similar in IOEC classrooms on the first floor which are facing South-West, and they are recessed to the back as can be seen in Figure 6. Regarding the Indoor Air Quality, occupants also show more satisfaction in the morning than in the afternoon (Q19 to Q22). This can be attributed to the fact that by the end of the day, the rooms are stuffier from all the students entering and leaving the classrooms. Regarding the visual component, only Q30 (Level of control over lighting) is statistically different between both groups, but this factor is not related to time of the day.

Table 5 - Average means and standard errors by time of day

			Morning Mean (Standard error)	Afternoon Mean (Standard error)	Difference [Morning – Afternoon] (p-value)
Overall Level of Satisfaction	Q1	Satisfaction with the overall level of comfort with IEQ	2.77 (0.09)	3.14 (0.09)	-0.37 (0.19)
	Q2	Relative Satisfaction with IEQ in comparison to other classrooms	2.78 (0.10)	2.74 (0.09)	0.04 (0.10)
	Q3	Impact of IEQ on level of concentration	3.83 (0.11)	3.85 (0.11)	-0.02 (0.49)
	Q4	State of health during class	2.72 (0.10)	2.48 (0.09)	0.24* (0.00)
Satisfaction with Thermal Comfort	Q13	Satisfaction with thermal comfort	2.10 (0.10)	2.53 (0.09)	-0.43 (0.07)
	Q14	Satisfaction with control over temperature	1.62 (0.09)	1.84 (0.09)	-0.22 (0.35)
	Q15	Temperature perception when entering the classroom	3.84 (0.09)	3.27 (0.10)	0.57* (0.00)
	Q17	Temperature perception throughout the class	3.82 (0.09)	3.37 (0.10)	0.45* (0.00)
Satisfaction with Indoor Air Quality	Q19	Satisfaction with IAQ	2.71 (0.09)	2.56 (0.10)	0.15* (0.00)
	Q20	Freshness of the air	2.63 (0.09)	2.06 (0.08)	0.57* (0.00)
	Q21	Ventilation	2.48 (0.09)	2.20 (0.09)	0.28* (0.00)
	Q22	Odors	2.99 (0.09)	2.61 (0.10)	0.38* (0.00)
Satisfaction with Acoustic Level of Comfort	Q24	Satisfaction with the acoustic comfort	2.64 (0.10)	2.83 (0.09)	-0.19 (0.86)
	Q25	Noises coming from outside	3.01 (0.10)	2.60 (0.10)	0.41* (0.00)
	Q27	Noises coming from mechanical systems	2.02 (0.10)	2.56 (0.09)	-0.54* (0.00)
	Q28	Disturbance from other students talking	2.80 (0.11)	2.71 (0.12)	0.09 (0.17)
Satisfaction with Visual Comfort	Q29	Satisfaction with the visual comfort	3.19 (0.10)	3.11 (0.10)	0.08 (0.35)
	Q30	Level of control over lighting	2.84 (0.10)	3.03 (0.10)	-0.19* (0.04)
	Q31	Amount of light	3.23 (0.09)	3.30 (0.09)	-0.07 (0.42)
	Q32	Level of glare/reflection	2.55 (0.10)	2.60 (0.11)	-0.05 (0.46)
Satisfaction with Appearance & Layout	Q34	Aesthetics of the room	2.02 (0.10)	2.40 (0.10)	-0.38* (0.00)
	Q35	Cleanliness	3.68 (0.10)	3.17 (010)	0.51* (0.00)
	Q36	Distance between you and others	3.04 (0.12)	3.00 (0.12)	0.04* (0.03)
	Q37	Comfortable seats	1.86	2.70	-0.84*

		(0.10)	(0.10)	(0.00)
Q38	Ability to see the board/screen	3.37	2.86	0.51*
		(0.10)	(0.10)	(0.00)

1 = very dissatisfied; 5 = very satisfied
Total respondents = 349; Morning respondents =140; Afternoon respondents = 209
**populations are significantly different at 95% confidence level*

The means and standard errors by seasons and their differences are presented in Table 6. The surveys in classrooms were grouped by season: "Fall" includes surveys conducted in November and early December, and "Spring" includes surveys conducted in April. Regarding the thermal comfort, both groups are statistically different, and in the Spring, occupants are much more dissatisfied. The results are similar for the Indoor Air Quality. Since the survey sample conducted in spring is limited to one day (April 4, 2017), a general conclusion cannot be made as this day could have been very hot or humid. The visual and acoustic components don't show statistical differences between Fall and Spring, but in general occupants are more dissatisfied in Fall.

Table 6 - Average means and standard errors by season

			Fall Mean (Standard error)	Spring Mean (Standard error)	Difference [Fall-Spring] (p-value)
Overall Level of Satisfaction	Q1	Satisfaction with the overall level of comfort with IEQ	2.89 (0.06)	2.71 (0.15)	0.18 (0.30)
	Q2	Relative Satisfaction with IEQ in comparison to other classrooms	2.71 (0.07)	2.18 (0.11)	0.53* (0.00)
	Q3	Impact of IEQ on level of concentration	3.86 (0.07)	3.89 (0.25)	-0.03 (0.40)
	Q4	State of health during class	2.55 (0.07)	1.79 (0.13)	0.76* (0.00)
Satisfaction with Thermal Comfort	Q13	Satisfaction with thermal comfort	2.32 (0.06)	1.32 (0.10)	1.00* (0.00)
	Q14	Satisfaction with control over temperature	1.70 (0.06)	1.19 (0.08)	0.51* (0.00)
	Q15	Temperature perception when entering the classroom	3.47 (0.07)	1.65 (0.10)	1.82* (0.00)
	Q17	Temperature perception throughout the class	3.51 (0.07)	1.46 (0.12)	2.05* (0.00)
Satisfaction with Indoor Air Quality	Q19	Satisfaction with IAQ	2.55 (0.07)	1.9 (0.13)	0.65* (0.00)
	Q20	Freshness of the air	2.30 (0.06)	1.55 (0.10)	0.75* (0.00)
	Q21	Ventilation	2.32 (0.06)	1.47 (0.09)	0.85* (0.00)
	Q22	Odors	2.71 (0.07)	2.22 (0.13)	0.49* (0.00)
Satisfaction with Acoustic Level of Comfort	Q24	Satisfaction with the acoustic comfort	2.63 (0.06)	2.82 (0.15)	-0.19 (0.36)
	Q25	Noises coming from outside	2.70 (0.07)	2.92 (0.13)	-0.22 (0.20)
	Q27	Noises coming from mechanical systems	2.22 (0.07)	2.76 (0.16)	-0.54* (0.00)
	Q28	Disturbance from other students talking	2.66 (0.08)	2.95 (0.17)	-0.29 (0.12)
Satisfaction with Visual Comfort	Q29	Satisfaction with the visual comfort	3.14 (0.07)	2.90 (0.19)	0.24 (0.18)
	Q30	Level of control over lighting	2.96 (0.07)	3.18 (0.14)	-0.22 (0.28)
	Q31	Amount of light	3.26 (0.06)	3.49 (0.13)	-0.23 (0.29)
	Q32	Level of glare/reflection	2.56 (0.07)	2.95 (0.14)	-0.39* (0.03)
Satisfaction with Appearance & Layout	Q34	Aesthetics of the room	2.20 (0.07)	2.49 (0.18)	-0.29 (0.11)
	Q35	Cleanliness	3.28 (0.07)	3.89 (016)	-0.61* (0.00)
	Q36	Distance between you and others	2.94 (0.08)	2.05 (0.15)	-0.89* (0.00)
	Q37	Comfortable seats	2.26	2.45	-0.19

		(0.07)	(0.18)	(0.25)
Q38	Ability to see the board/screen	3.10	2.63	0.47*
		(0.07)	(0.17)	(0.02)

1 = very dissatisfied; 5 = very satisfied
Total respondents = 349; Fall respondents =310; Afternoon respondents = 39
**populations are significantly different at 95% confidence level*

5.3. Analysis of the overall level of satisfaction

As mentioned earlier, data with missing answers were used in the statistical analysis for each respective question. For example, if a respondent answered Q1 but skipped Q13, he/she will still be considered in the Q1 analysis but not in the Q13 analysis. Therefore, the sample size differs for each statistical analysis that will follow, but it will be specified in each analysis (under each graph). It should also be noted that the sample used in statistical analysis includes students, faculty member and staff, and excludes outliers.

The first question in the survey Q1 was “How would you rate your satisfaction with the OVERALL LEVEL OF COMFORT with the Indoor Environmental Quality in this classroom most of the time”, and the results for Bechtel, IOEC and the Architecture buildings are presented separately in Figure 9. It can be concluded that the highest percentage of the participants are neutral about their overall comfort. However, occupants of the Architecture and IOEC buildings are more dissatisfied or very dissatisfied (51% and 35%, respectively) than those in Bechtel (30%). This is further highlighted in Table 2 in Section (5.2), whereby the mean score for Q1 in Bechtel is 3.07, which corresponds to Neutral, and the mean scores in IOEC and the Architecture building are 2.58 and 2.31, respectively, which are closer to dissatisfaction.

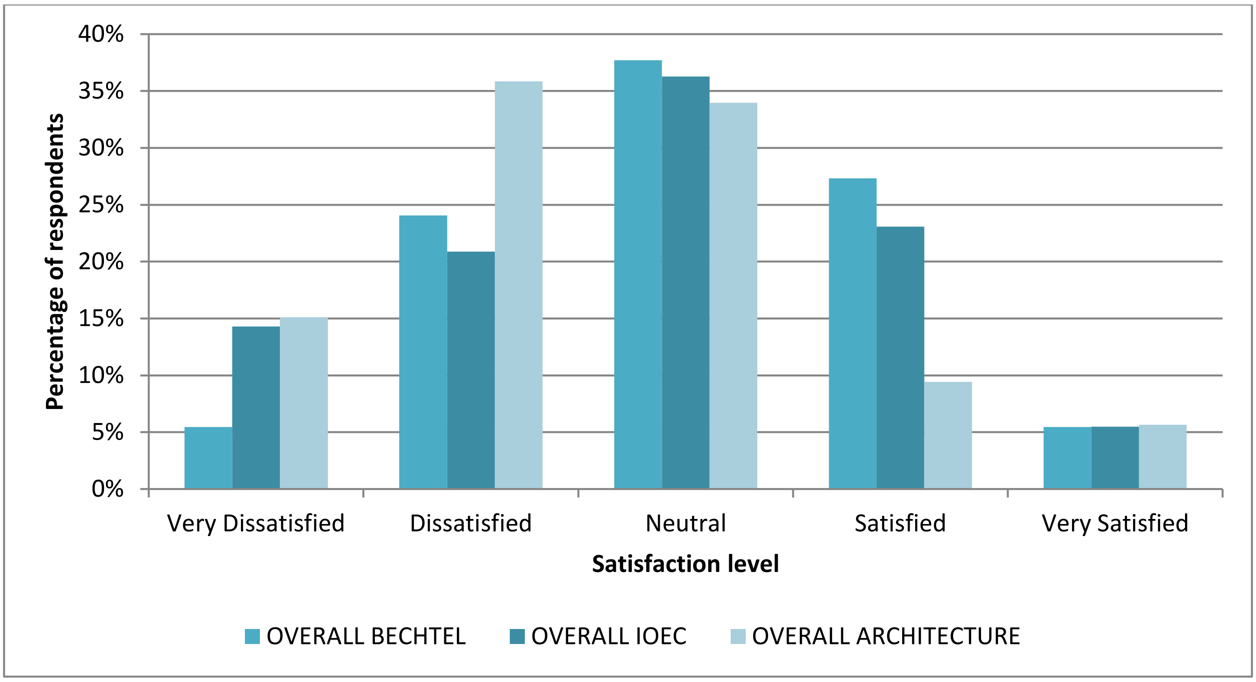

Figure 9 - Overall level of comfort by building (Q1) (sample size = 327)

Furthermore, the overall satisfaction with the level of comfort (Q1) for faculty members and staff versus students is plotted in Figure 10. Students show less satisfaction compared to the faculty members and staff as 36% are dissatisfied or very dissatisfied with the overall comfort versus 19% for faculty members and staff. This can be attributed to the level of control each of the groups has over their environment. For example, Figure 11 depicts the difference of satisfaction level between faculty members/staff and students vis-a-vis the control over temperature whereby 64% of students are very dissatisfied with the control over temperature versus 27% of the faculty members and staff.

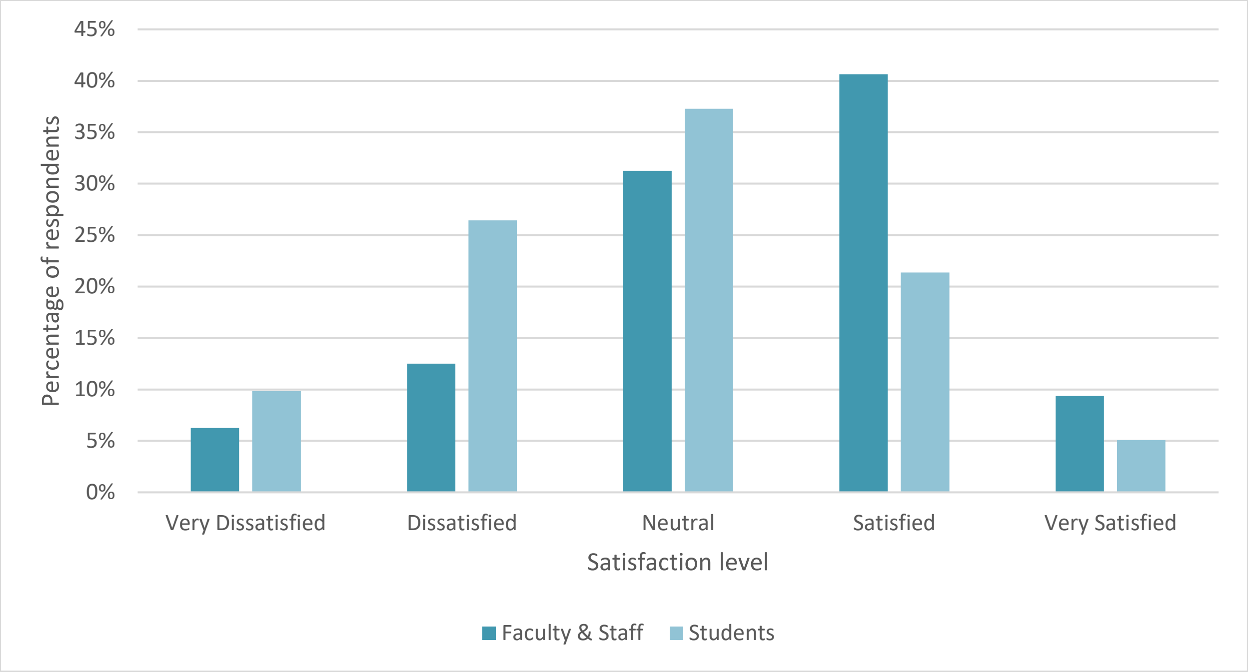

Figure 10 – Overall level of comfort by type of respondent (Q1) (sample size = 327)

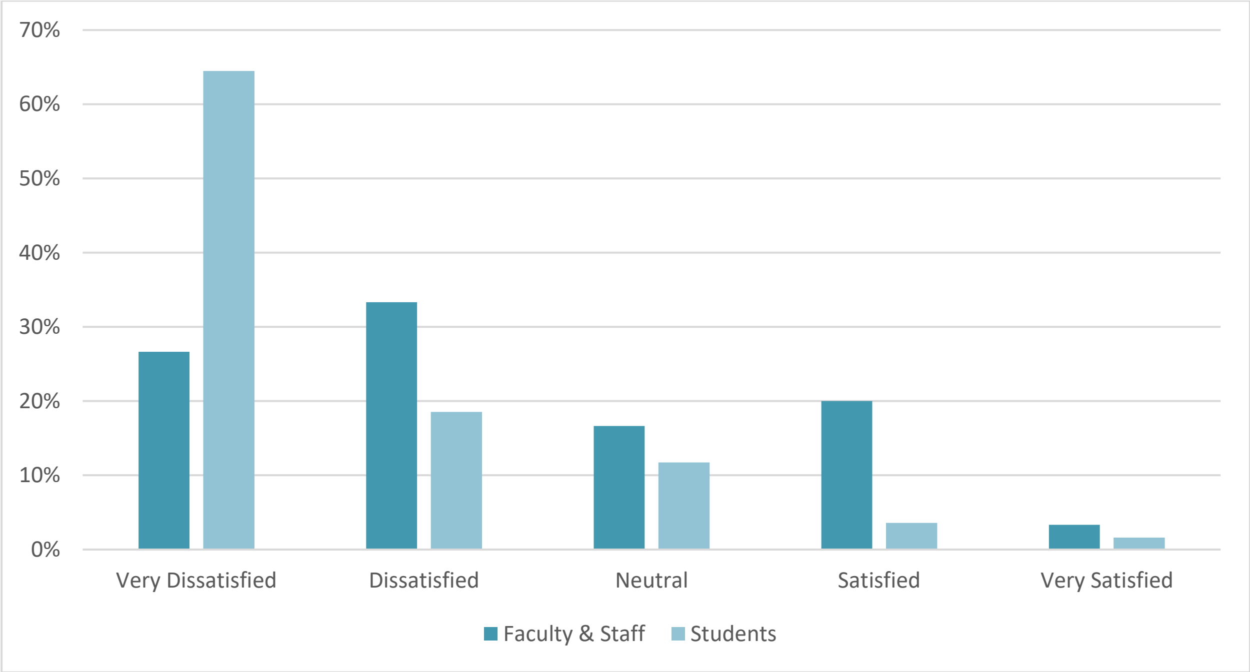

Figure 11 – Satisfaction with level of control over temperature by type of respondent (Q14) (sample size = 337)

5.4. Analysis of the satisfaction with each IEQ component

In this section, the level of satisfaction with each IEQ component is studied. The answers to the general questions "how satisfied are you with…" for the different IEQ variables in all three buildings are plotted in Figure 12, i.e. the answers to the survey questions Q13, Q19, Q24, Q29 and Q34. It can be seen that respondents are generally not satisfied with the thermal comfort, the indoor air quality, acoustic comfort and aesthetics and are mostly satisfied with the visual comfort. It should be noted that the obtained responses might have been affected by asking all respondents upfront to ignore the ongoing construction taking place at the time of the survey next to the Bechtel Building and possibly affecting the operation of other buildings in question.

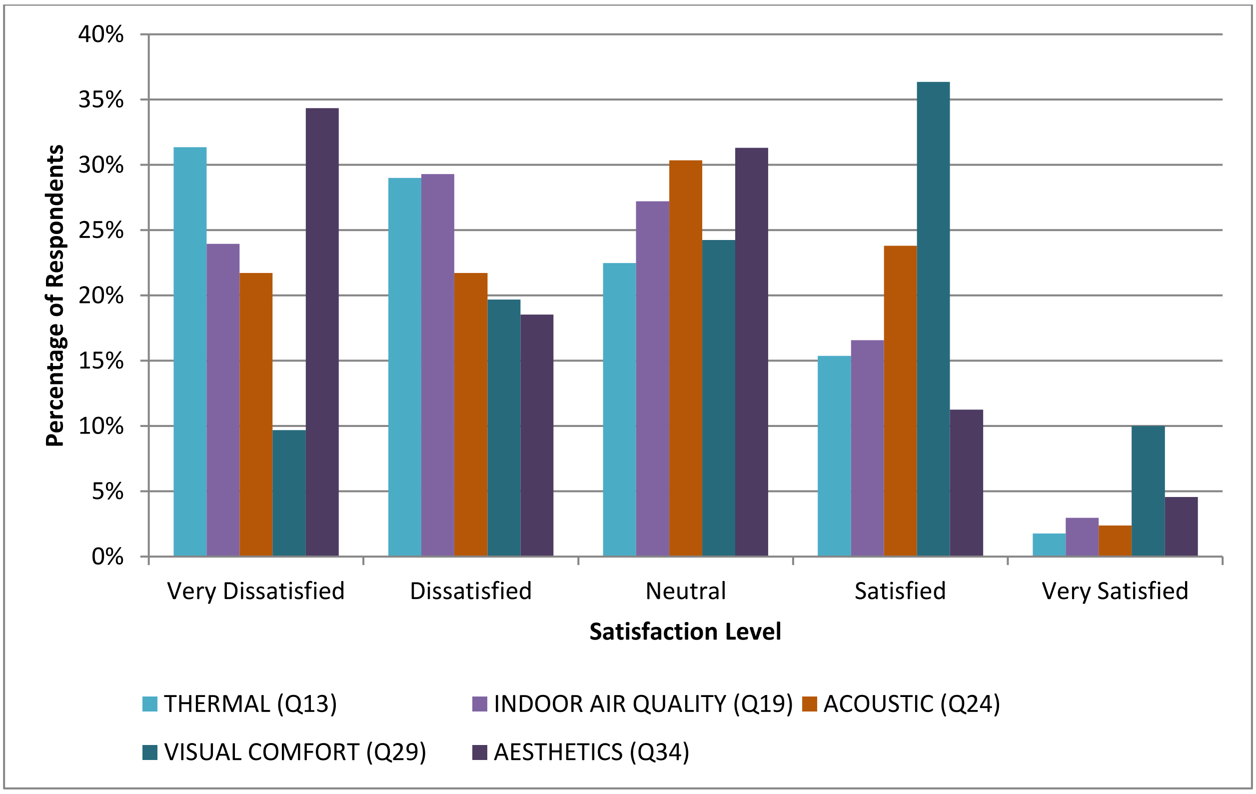

Figure 12 - Satisfaction distribution with the IEQ components

The following subsections illustrate the results pertaining to the general questions on comfort with each IEQ component, for each building and by type of respondent (faculty member and staff versus student).

5.4.1. Thermal Comfort

The satisfaction with thermal comfort is presented in Figure 13 for each building separately as provided by the answers to the question "Q13: How satisfied are you with your THERMAL COMFORT during class?". As per ASHRAE Standard 55 mentioned earlier (ASHRAE, 2004), 80% of the population should be satisfied with the thermal comfort for it to be acceptable. Most of the respondents are dissatisfied or very dissatisfied with the thermal comfort in Bechtel (62%), in IOEC (52%) and in Architecture (70%). On the other hand, Figure 14 shows the distribution of satisfaction responses with thermal comfort for the faculty members and staff versus students. Students show more dissatisfaction with their thermal comfort at 64% for very dissatisfied and dissatisfied levels, whereas faculty and staff members are generally satisfied or very satisfied at 47%. The students' high level of dissatisfaction might be attributed to the fact that the temperature set point is determined in the Bechtel building at 23 degrees Celsius during almost all seasons, without giving any control to students in classrooms. For example, in summer and hot days, occupants might want to feel cooler especially when entering the building from outside, and therefore they would want to decrease the temperature. Faculty and staff members have more control over the temperature in their offices as depicted in Figure 11 and explained in Section (5.3). In the Architecture building, the whole HVAC system is poor and doesn't offer the thermal comfort needed for the occupants. In IOEC, due to the glass façade on the north and south sides and the lack of operable windows, heat builds up in classrooms which makes cooling difficult in hot seasons and during the day. The thermal comfort dissatisfaction is discussed further in the policy analysis section.

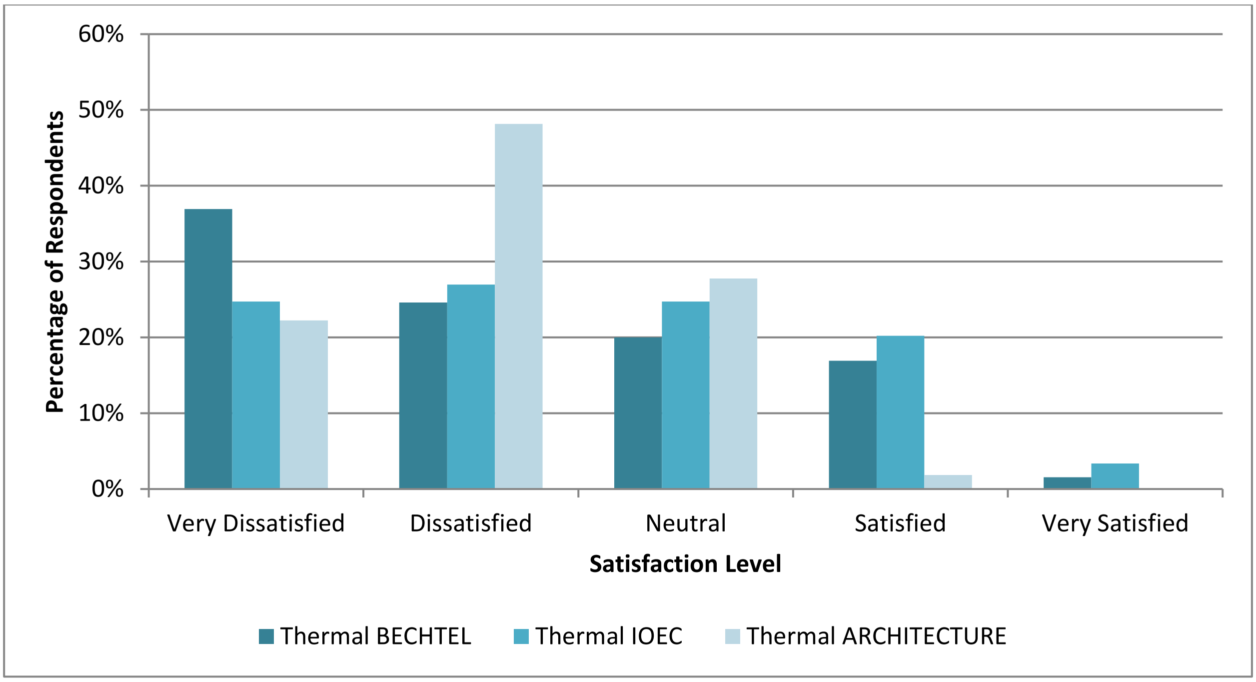

Figure 13 – Satisfaction distribution for thermal comfort by building (Q13)(sample size = 338)

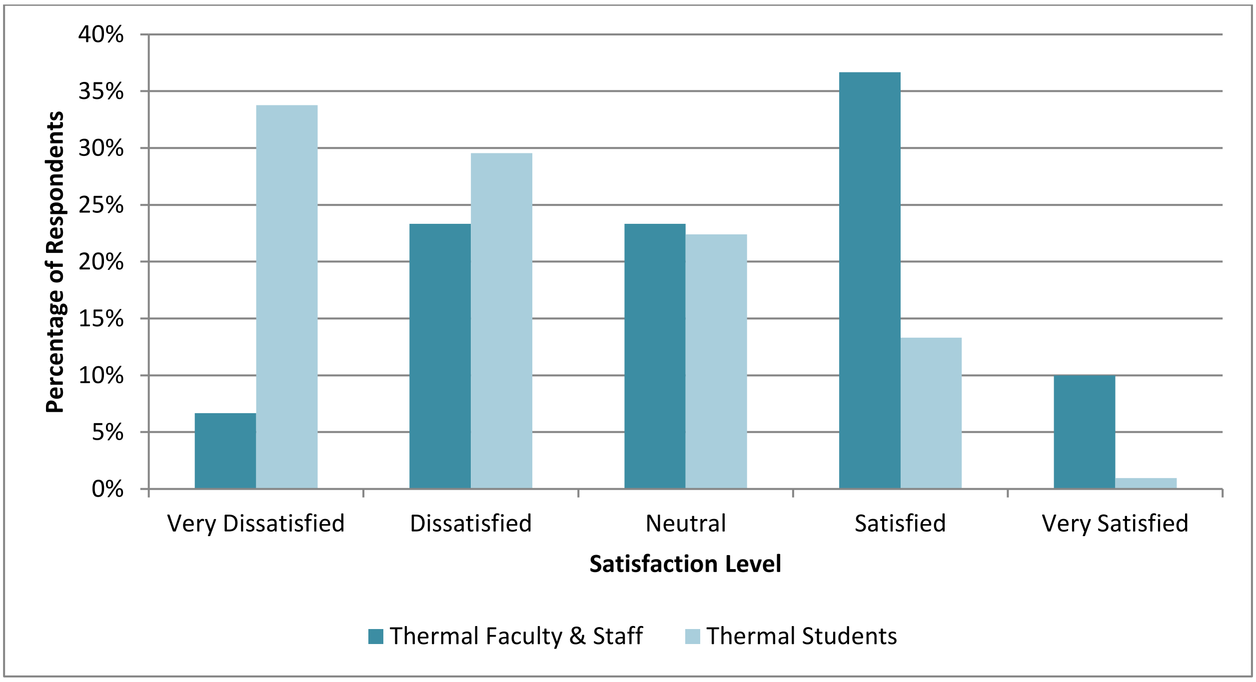

Figure 14 - Satisfaction distribution for thermal comfort by type of respondent (Q13) (sample size = 338)

5.4.2. Indoor Air Quality

Figure 15 presents the distribution of satisfaction with IAQ in each of the three buildings. In the Architecture building, 80% of the respondents are dissatisfied or very dissatisfied with the IAQ. In Bechtel, 57% of the respondents are dissatisfied or very dissatisfied with the IAQ. Only in IOEC, respondents are more satisfied with IAQ as only 29% of them are dissatisfied or very dissatisfied. This result is expected since IOEC building is new and the ventilation system should be properly working. Figure 17 and Figure 18 depict freshness of the air quality and satisfaction with ventilation, respectively, in the Architecture building. These two graphs help in understanding the high level of dissatisfaction felt by the Architecture building respondents. They find the classrooms very stuffy (55% of the responses) and are mostly very dissatisfied with the ventilation (46% of the responses). Hence, the high percentage of dissatisfaction in the Architecture building is probably due to the poor HVAC system. Furthermore, the old wall paintings and furniture add a stuffy feeling to the indoor environment. Moreover, students are more dissatisfied with IAQ than faculty and staff members as shown in Figure 16. These results are expected since faculty and staff members are usually alone in an office whereas in classrooms there is a large number of students, which decreases the indoor air quality. This warrants further discussion in the policy analysis in Chapter 8.

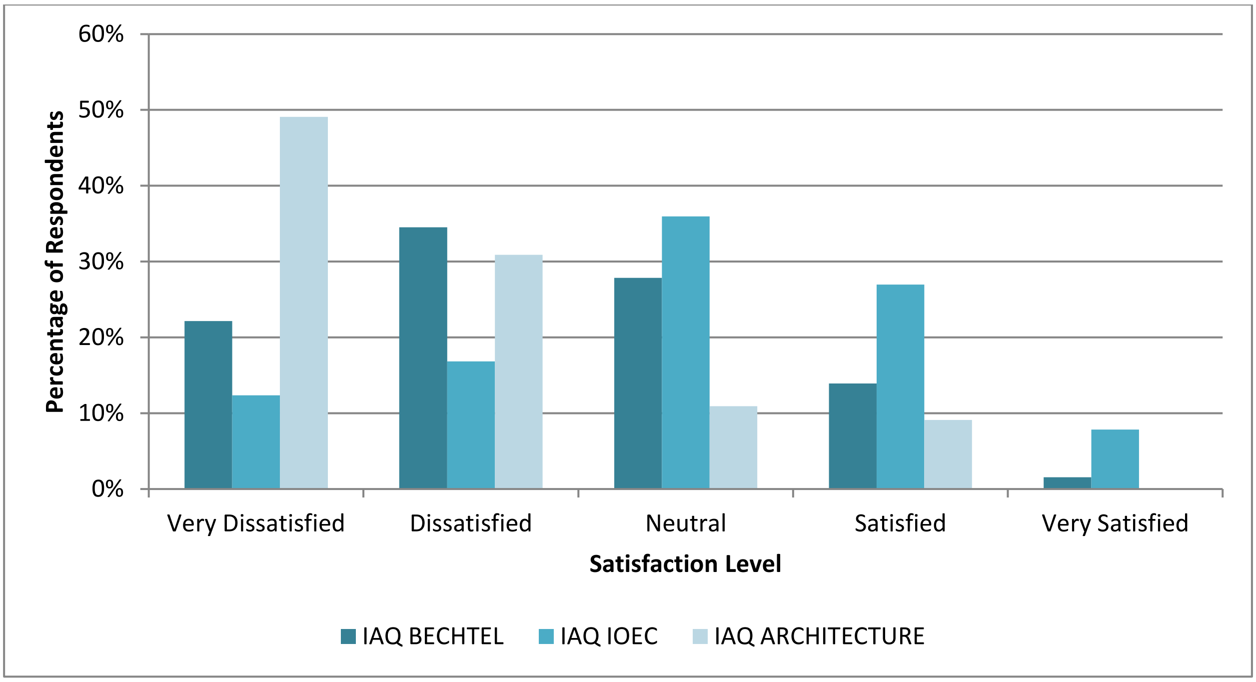

Figure 15 - Satisfaction distribution for IAQ by building (Q19) (sample size = 338)

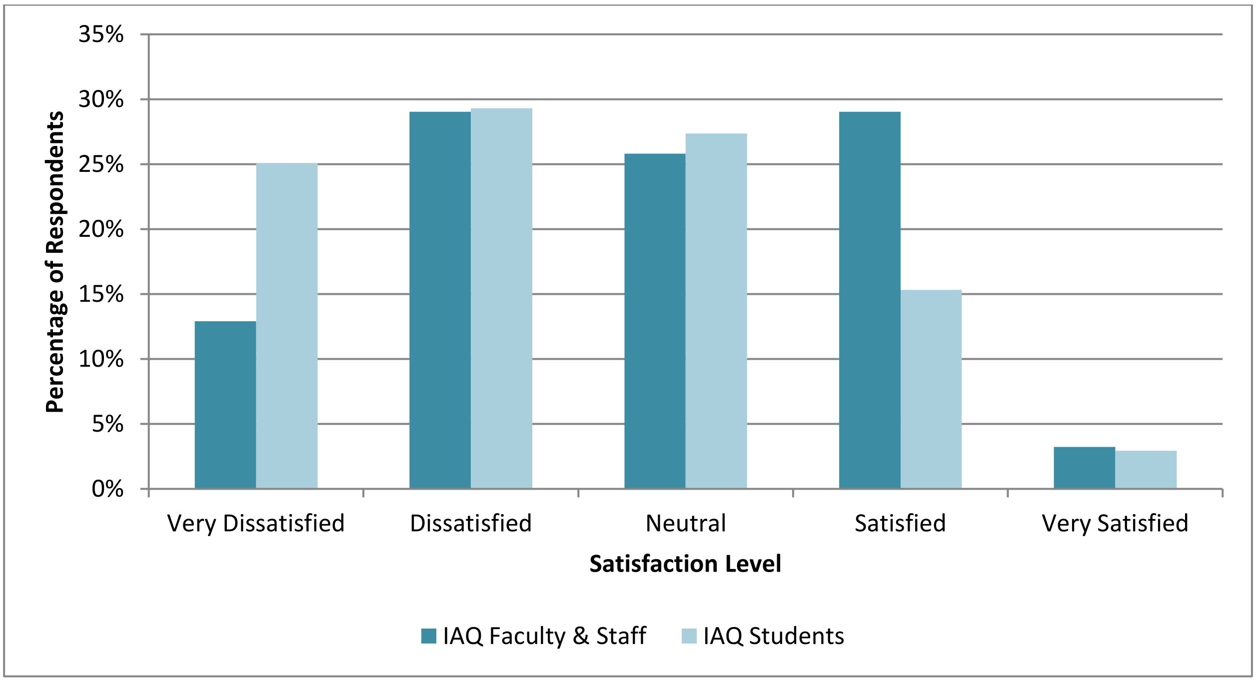

Figure 16 - Satisfaction distribution for IAQ by type of respondent (Q19) (sample size = 338)

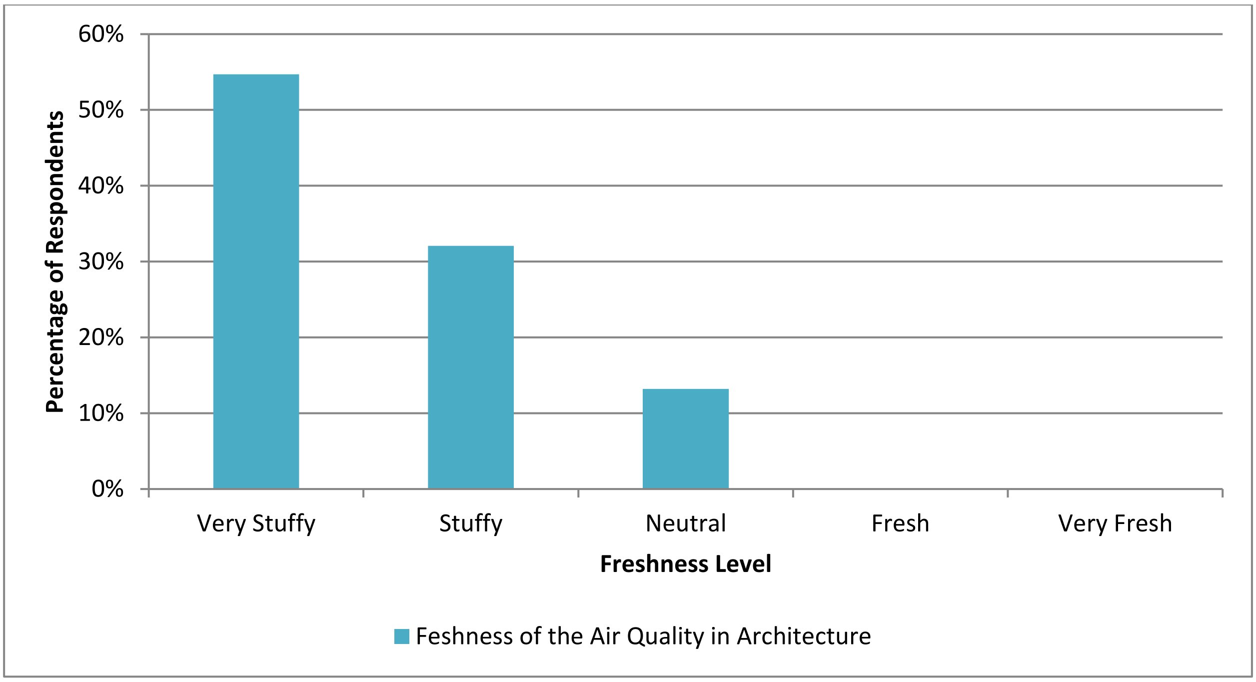

Figure 17 – Freshness of the air quality in the Architecture building (Q20) (sample size = 53)

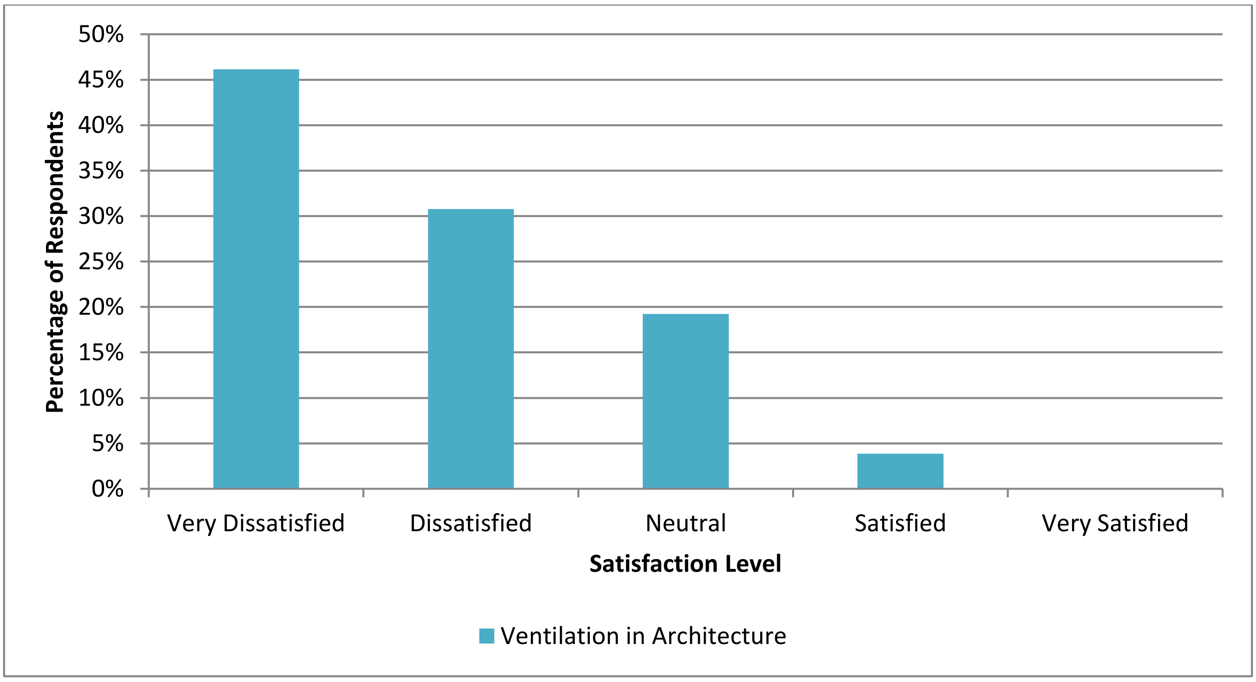

Figure 18 – Satisfaction distribution for ventilation in the Architecture building (Q21)

(sample size = 52)

5.4.3. Acoustic Comfort

The satisfaction distribution in the case of acoustic comfort is presented in Figure 19 for each building. Results reveal that the level of acoustic comfort in the Architecture building is low and this is because the building is located near the generators of the power plant. This is further verified in Figure 20 which plots the answers to the question "Q25: How do you usually find the level of noise coming from outside in the classroom?" in the case of the Architecture building.

Additionally, in IOEC, 51% of the respondents are dissatisfied and very dissatisfied with the acoustic comfort which might be attributed to the lack of false ceilings and as such, the noise coming from exposed mechanical systems in classrooms, in particular ventilation fans. This can be further shown in Figure 21 which illustrates the answers to the question "Q27: How do you usually find the level of noise coming from Mechanical systems in the classroom (such as HVAC, ventilation…)?" in the IOEC building.

Also, the students show more dissatisfaction with the acoustic comfort than the faculty and staff members (44% versus 34%, respectively) as shown in Figure 22. This can be justified by the fact that faculty members and staff have the freedom to open or close their windows and doors in their offices whereas students are more restricted in classrooms.

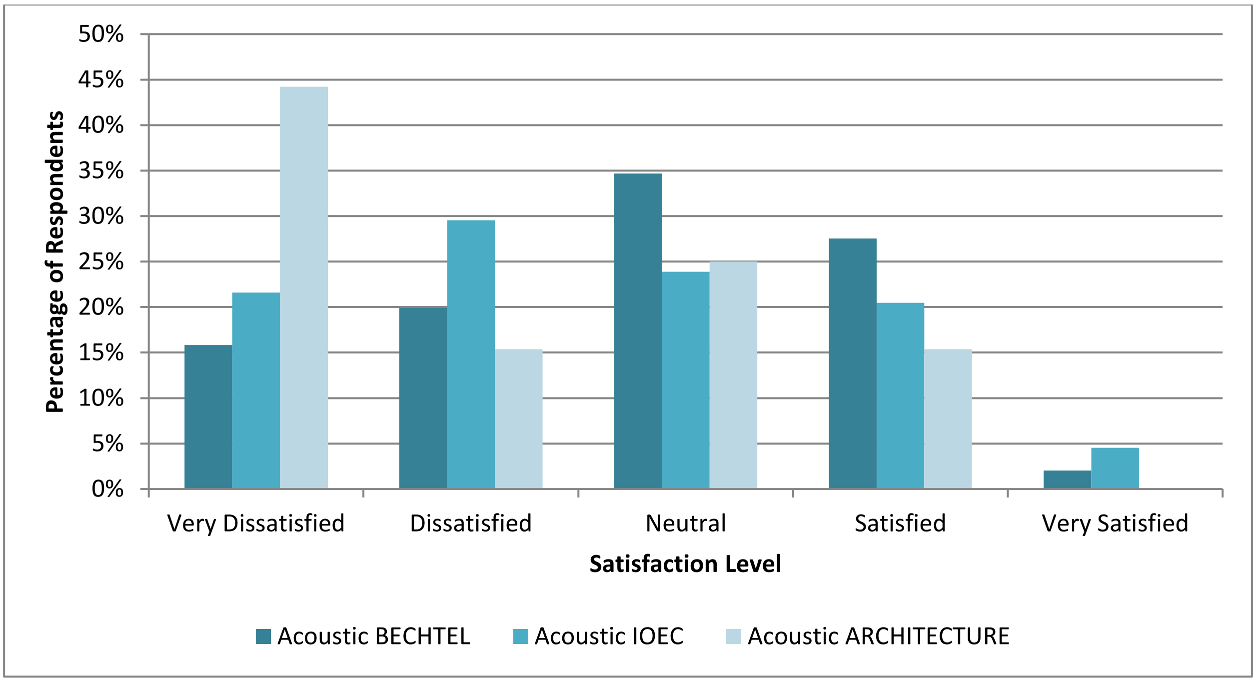

Figure 19 - Satisfaction distribution for acoustic comfort by building (Q24) (sample size = 336)

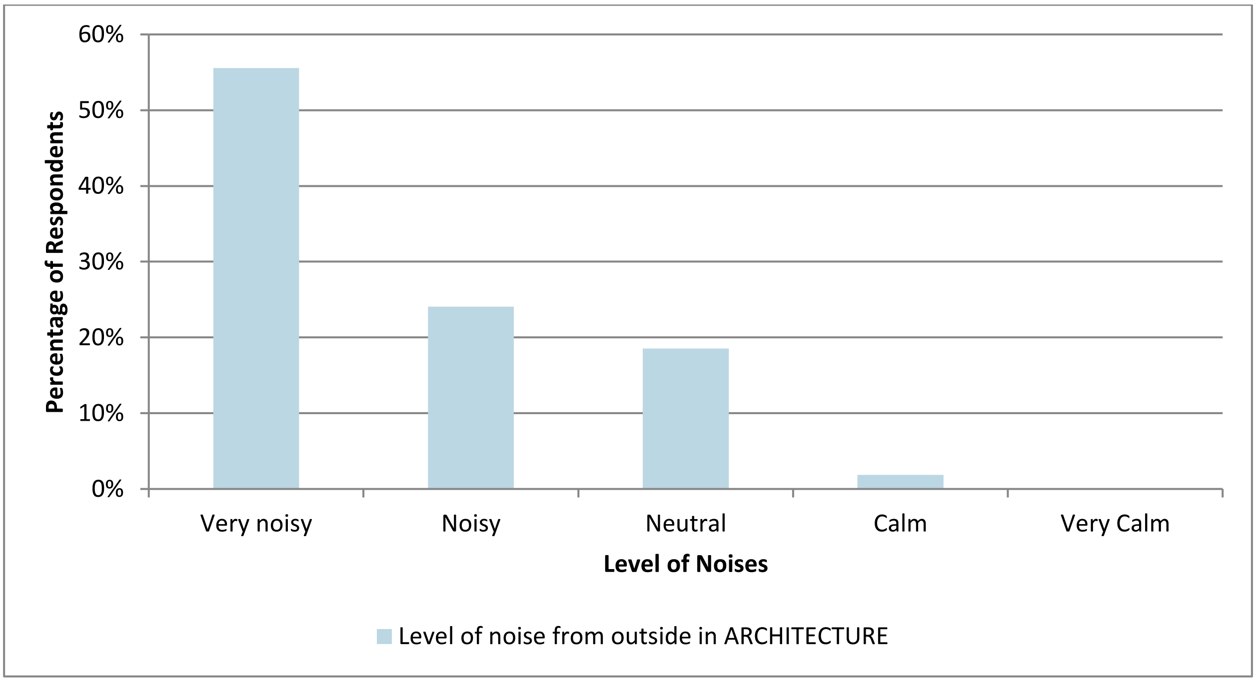

Figure 20 – Perceived level of noise coming from outside in Architecture building (Q25) (sample size = 54)

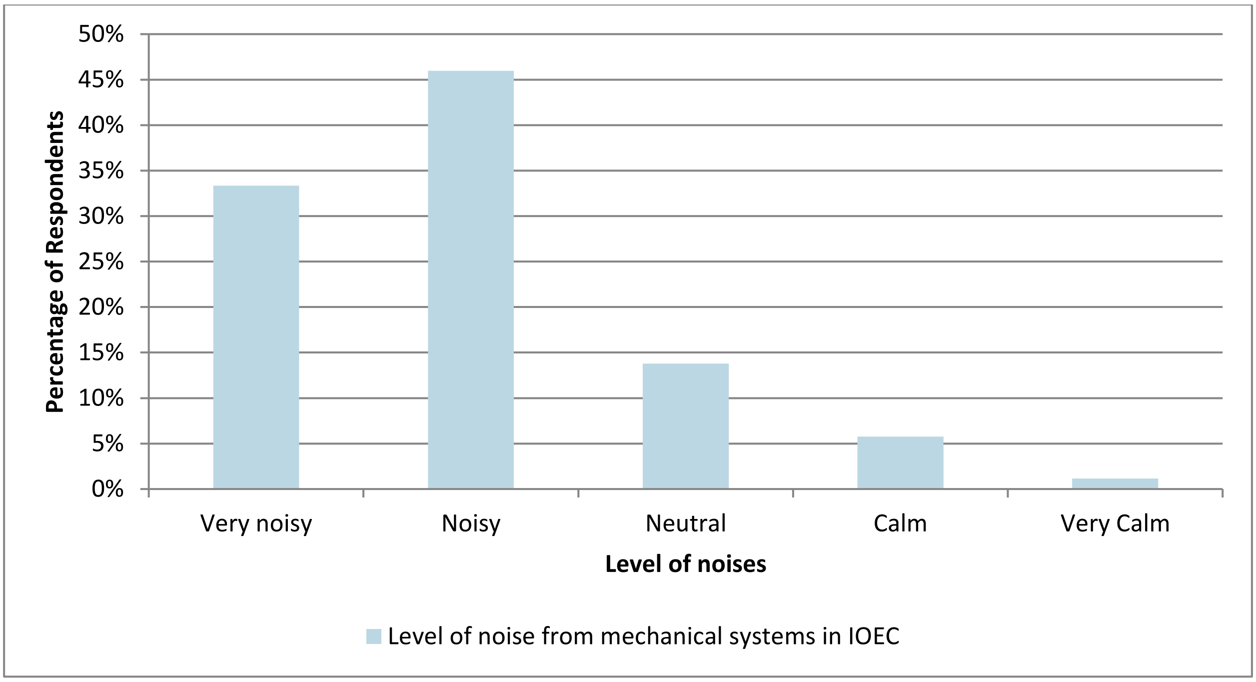

Figure 21 – Perceived level of noise coming from mechanical systems in IOEC (Q27)

(sample size = 87)

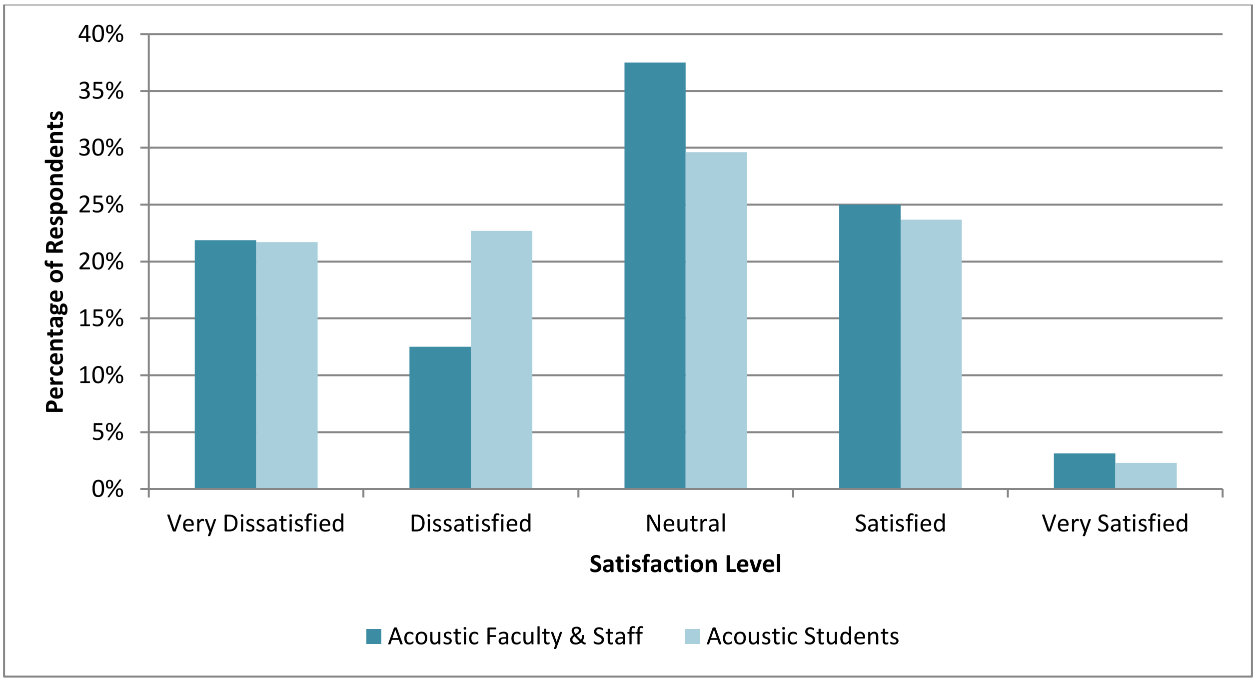

Figure 22 - Satisfaction distribution for acoustic comfort by type of respondent (Q24)

(sample size = 336)

5.4.4. Visual Comfort

By observing the graphs in Figures 23 and 24 which show the satisfaction distribution for visual comfort by building and by type of respondent, respectively, it can be concluded that in general, students and faculty members are satisfied with the visual comfort in all buildings.

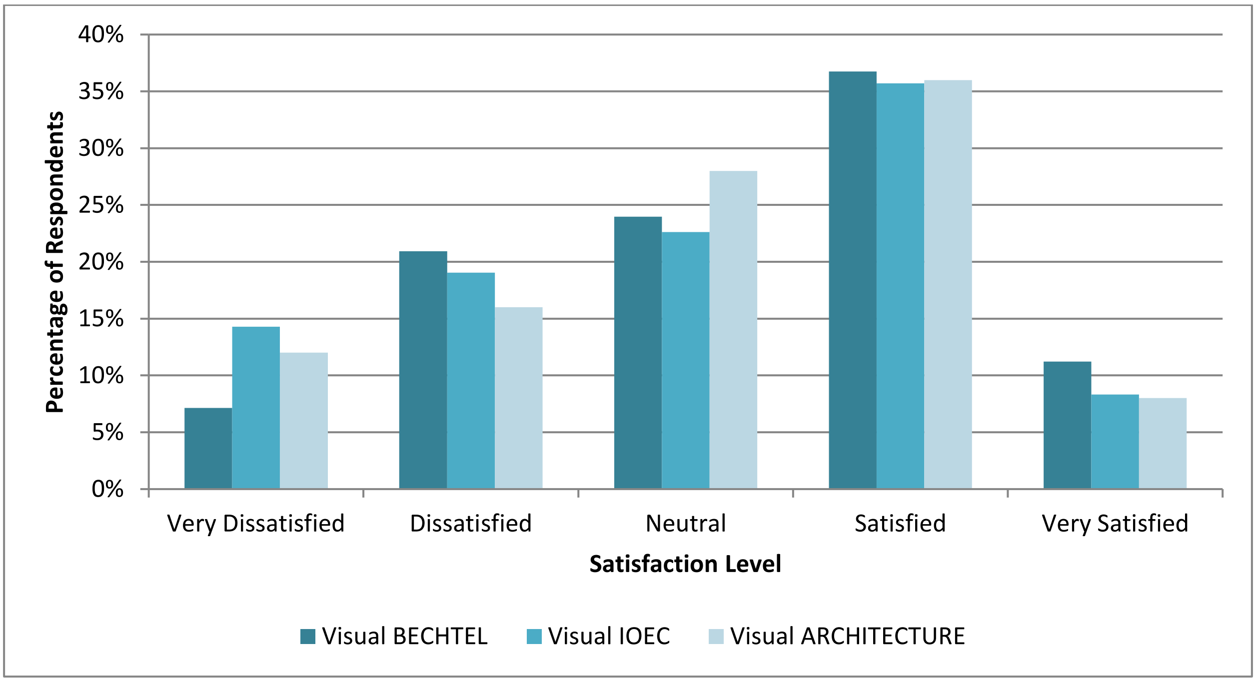

Figure 23 - Satisfaction distribution for visual comfort by building (Q29) (sample size = 330)

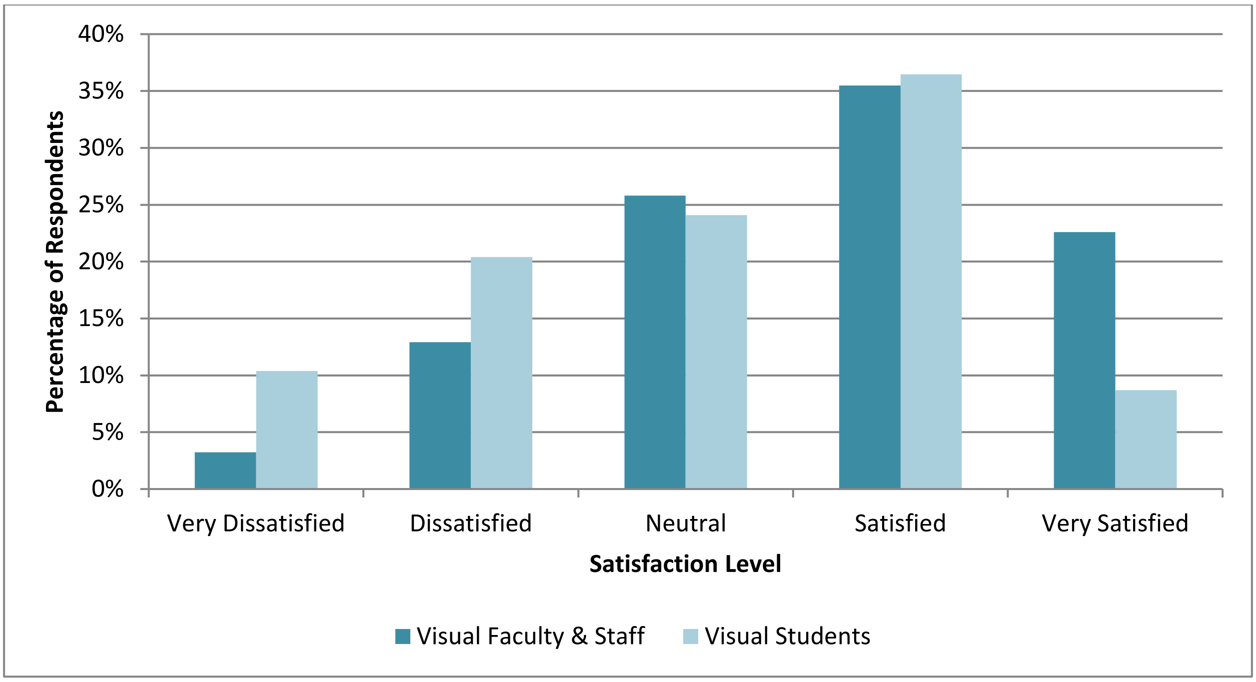

Figure 24 - Satisfaction distribution for Visual comfort by type of respondent (Q29)

(sample size = 330)

5.4.5. Aesthetics

The satisfaction distribution for aesthetics in the three buildings is presented in Figure 25. In the Architecture building, a large percentage of respondents are not satisfied with the aesthetics (64%). As aforementioned, the Architecture building is very old and is being renovated to improve the aesthetics. It is also important to note that occupants of this building are architecture students and faculty members who allocate importance to building design and aesthetics. On the other hand, Bechtel occupants are more dissatisfied and neutral in comparison to occupants of IOEC. The latter building is a modern structure overlooking the Mediterranean Sea on the North facade, whereas the Bechtel building is an old building which looks less aesthetically pleasant despite being recently renovated. More specifically, as depicted in Figure 26, a large number of students seem to be more dissatisfied with the aesthetics than faculty members. This might be due to the fact that offices are more aesthetically pleasant than classrooms, in terms of furniture and design. Also, the classrooms are located on the first and second floors of Bechtel and IOEC buildings, and the view from the windows is limited, in contrast to offices which are located on the upper floors and provide a better view for their occupants.

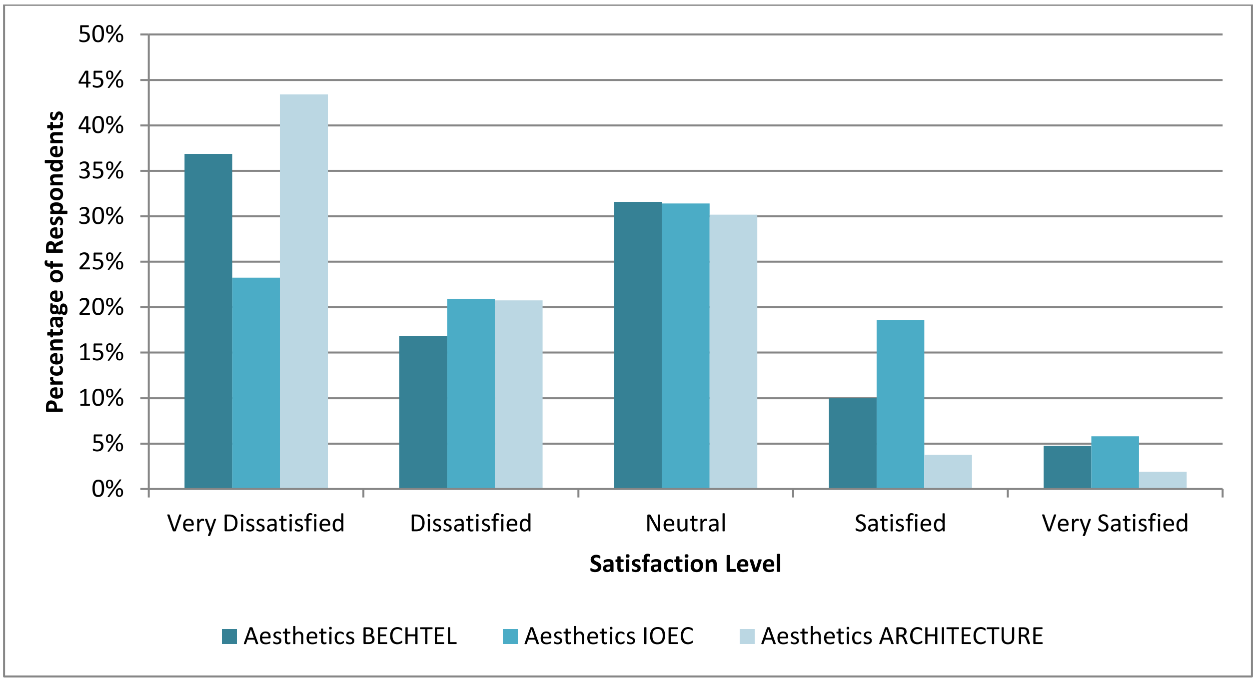

Figure 25 - Satisfaction distribution for aesthetics by building (Q34) (sample size = 329)

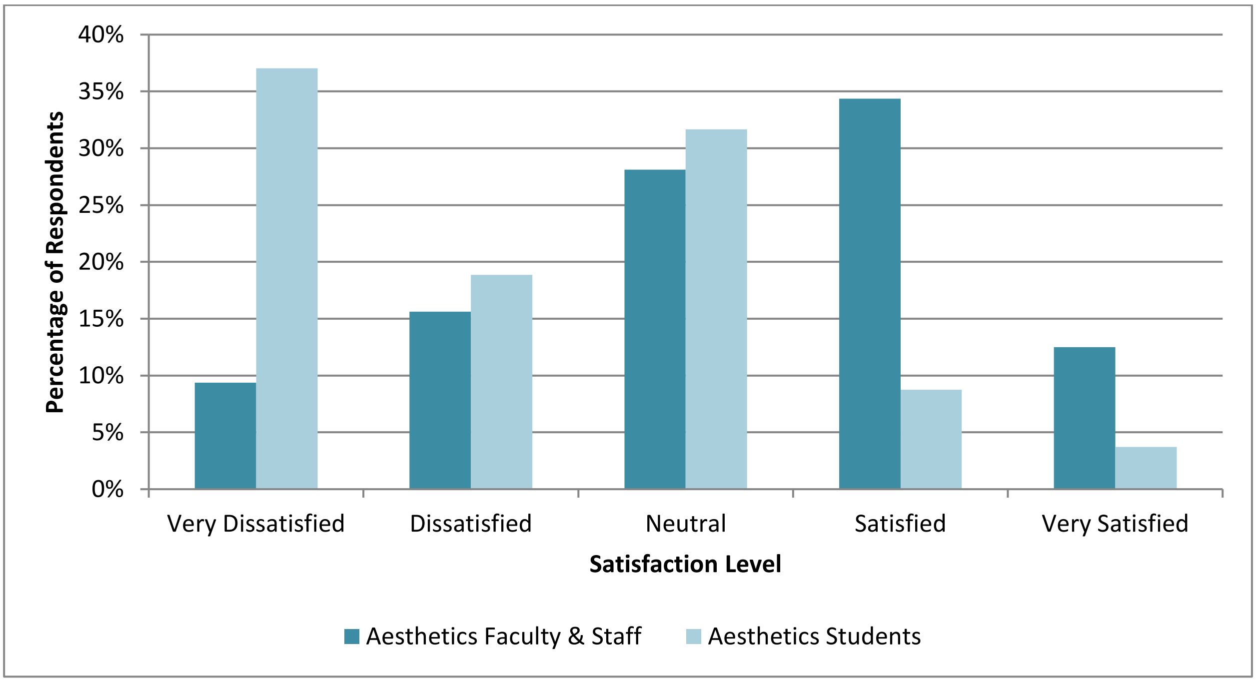

Figure 26 - Satisfaction distribution for aesthetics by type of respondent (Q34) (sample size = 329)

CHAPTER 6

BEHAVIOR ANALYSIS

The behavior analysis is presented in this chapter; it is first presented with respect to satisfaction with each of the Indoor Environmental Quality components, followed by an analysis with respect to occupant's professional status (students vs faculty and staff members).

6.1. Analysis of behavior with respect to IEQ satisfaction

As aforementioned, students and faculty members do not have full control over the classroom environment in order to adjust their IEQ comfort. Therefore, the survey asks respondents about their preference with different systems in the classroom like the HVAC system, windows, shades, and lights with respect to each of the IEQ features separately, while indicating their behavior if they were allowed to control them. Figures 27, 28, 29 & 30 summarize the behavior/preference of students and faculty members in classrooms depending on their satisfaction with the different features of the IEQ: thermal, IAQ, acoustic and visual.

First, the behavior of respondents regarding their thermal comfort satisfaction is presented in Figure 27. The survey asks the following question to the respondents:

"Q16: When you arrive to this class & regarding your thermal comfort, would you prefer if:

A. HVAC is ON / Window is Closed
B. HVAC is ON / Window is Opened
C. HVAC is OFF / Window is Opened
D. HVAC is OFF / Window is Closed"

The graph shows that 34% of those who responded "dissatisfied" or "very dissatisfied" with the thermal comfort prefer to have the HVAC on and the window closed, which is also the preference of 69% of occupants who are satisfied or very satisfied with the thermal comfort. This behavior is acceptable in terms of energy saving, as no dissipation occurs from opened windows. The most desired sustainable situation is “HVAC off and Window Opened”, and this is the preferred option for 40% of the thermally neutral respondents. However, a good proportion of those who are dissatisfied or very dissatisfied (31%) behave in a non-environmentally friendly way as they prefer to have HVAC on and window open. This situation is the worst in terms of energy saving and therefore occupants satisfaction should be increased to limit this type of behavior.

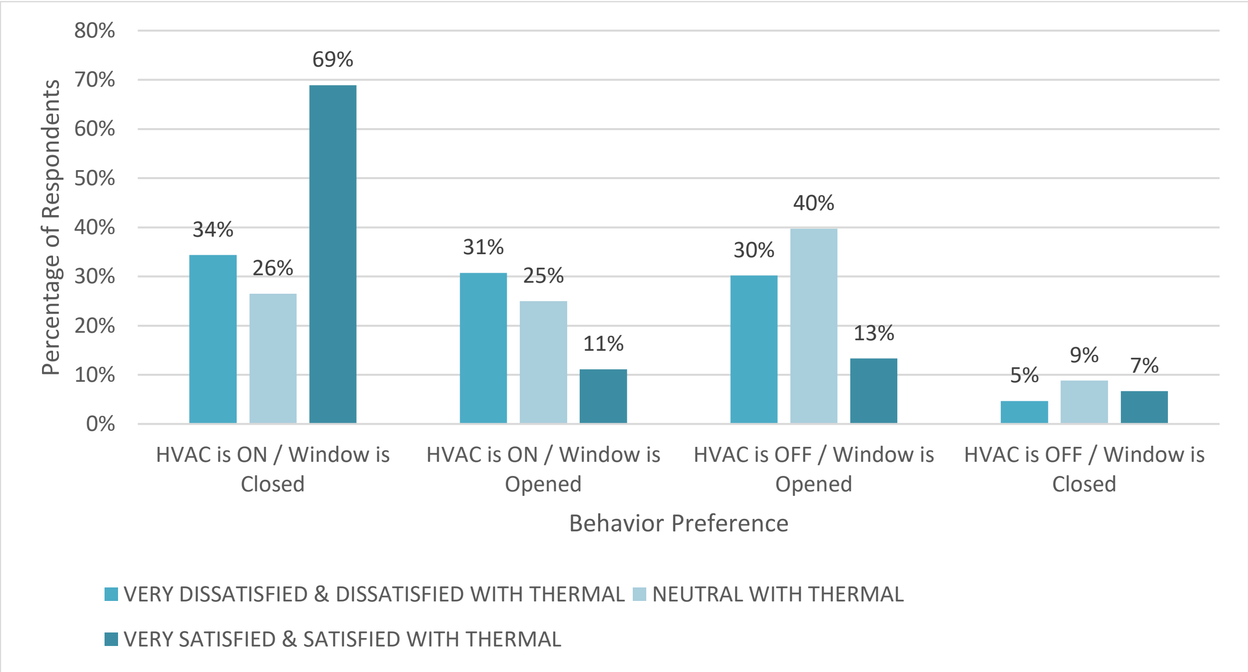

Figure 27 – Behavior regarding thermal comfort satisfaction (Q13 & Q16) (sample size = 305)

Similarly, the survey asks respondents about their behavior preference with regards to Indoor Air Quality “Q23: During class & regarding Indoor Air Quality, would you prefer if […]” with the same four response categories as Q16 above. Figure 28 presents the preferred behavior of respondents regarding the satisfaction with IAQ. A large proportion of occupants who are dissatisfied or very dissatisfied or neutral with the IAQ seem to prefer to have the HVAC on and window opened, which is the least wanted energy-related behavior, as dissipation of the energy occurs and energy consumption increases. In fact, ventilation system is not working properly and windows should be kept open to keep the indoor air fresh. On the contrary, 49% of occupants who are satisfied or very satisfied prefer to have the HVAC on with the window close. Therefore, satisfied occupants are less likely to act in a non-environmentally friendly way.

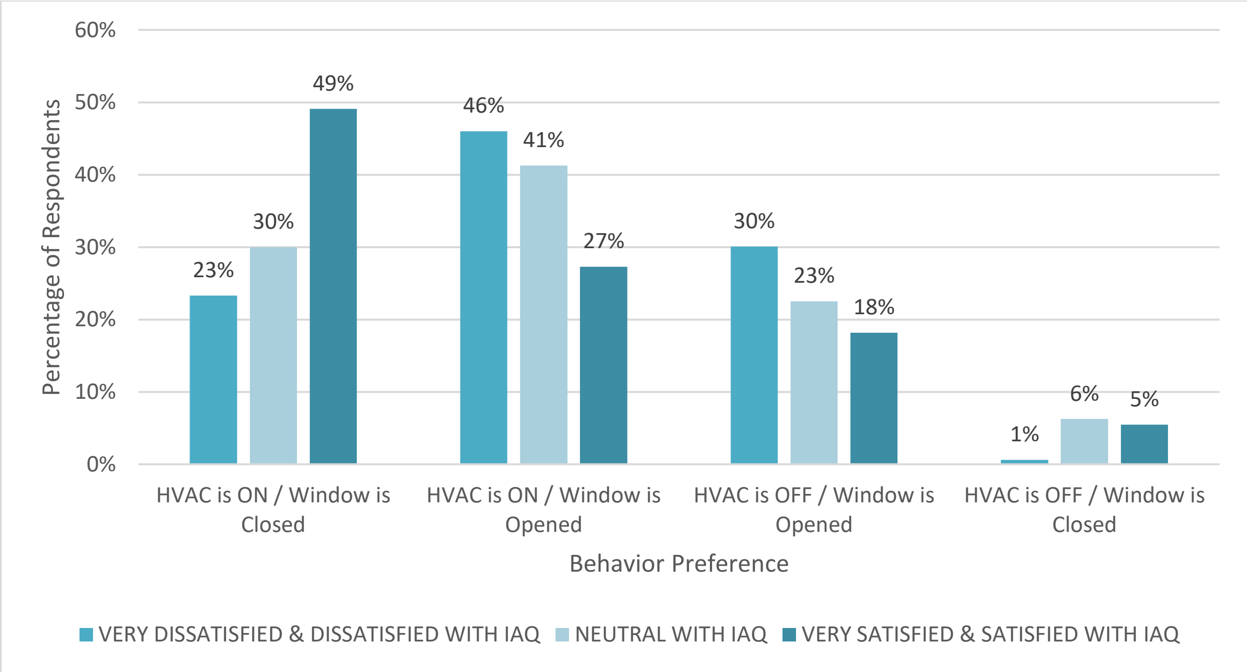

Figure 28 - Behavior regarding Indoor Air Quality satisfaction (Q19 & Q23) (sample size = 298)

The behavior of respondents regarding the satisfaction with acoustic comfort is presented in Figure 29. In the survey, question Q26 asks the respondents the following:

"During class & regarding the acoustic comfort, would you prefer if:

A. Window is Opened / Door is Opened
B. Window is Opened / Door is Closed
C. Window is Closed / Door is Opened
D. Window is Closed / Door is Closed"

Most occupants prefer to have both window and door closed to avoid disturbances from outside noises as shown in the graph of Figure 29.

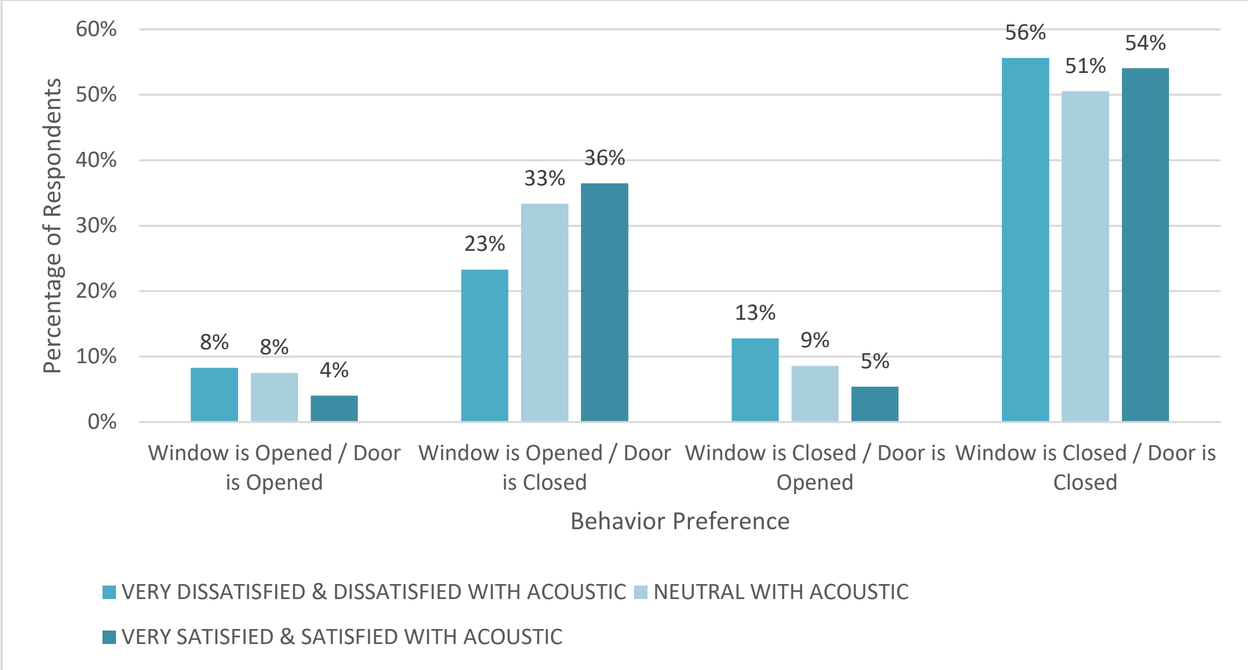

Figure 29 - Behavior regarding acoustic comfort satisfaction (Q24 & Q26) (sample size = 300)

The behavior of respondents regarding visual comfort satisfaction is presented in Figure 30. In the survey, question Q33 is as follows:

"During class & regarding visual comfort, would you prefer if:

A. Shades Open & Lights OFF
B. Shades Open & Lights ON
C. Shades Closed & Lights ON
D. Shades Closed & Lights OFF"

The highest percentage of the respondents stated that they prefer if the shades were closed and the lights on, which is not environmentally friendly as daylight is a major component in green design. In fact, the green building IOEC was designed with a glass façade to encourage reducing the use of lights and therefore decreasing the use of energy. However, occupants do not prefer this option because of the high perceived level of glare reflection. As a matter of fact, the survey question Q32 asks the respondents about their satisfaction with the level of glare/reflection on the white board or the PC screen. The results in IOEC are presented in

Figure 31 which shows that most respondents are dissatisfied or very dissatisfied with the level of glare/reflection (71%).

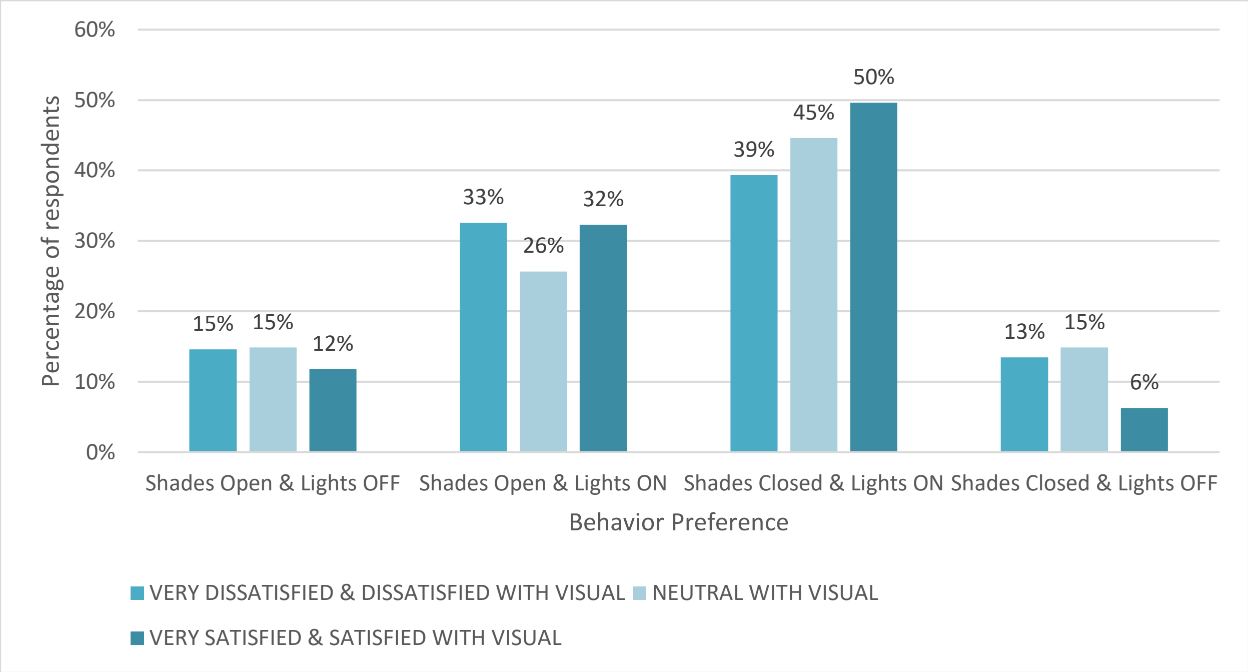

Figure 30 - Behavior regarding visual comfort satisfaction (Q29 & Q33) (sample size = 290)

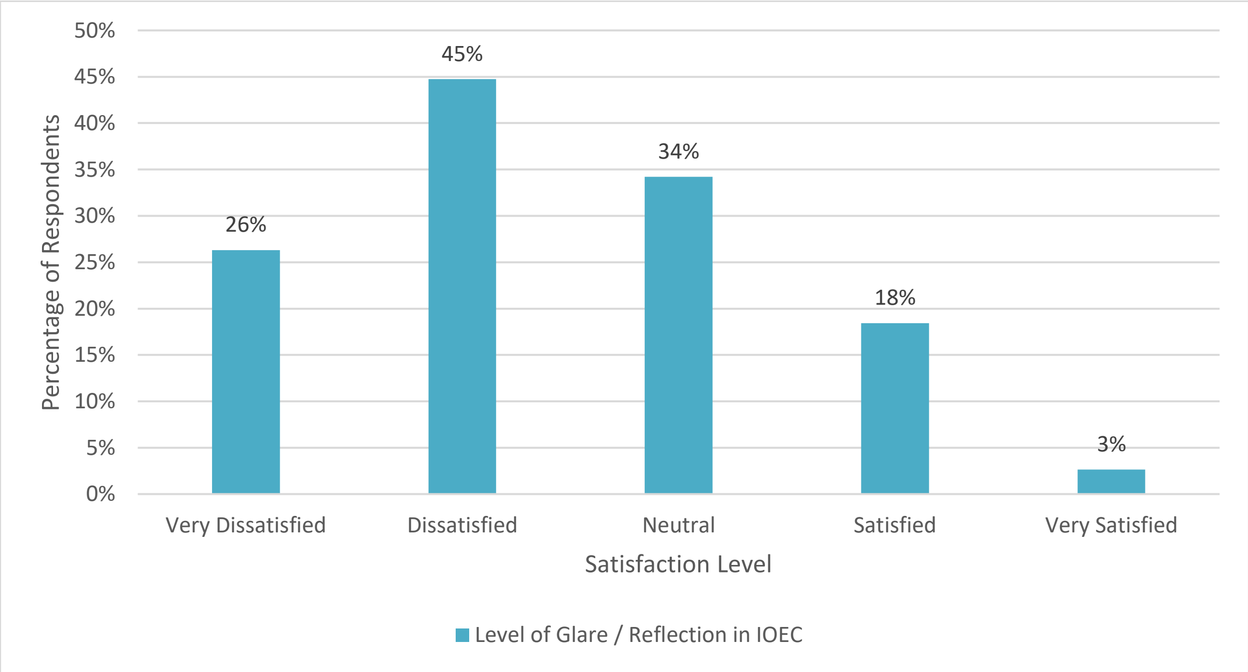

Figure 31 – Satisfaction distribution for level of glare/reflection in IOEC (Q32) (sample size = 76)

Finally, it should be noted that the way the respondents would behave regarding acoustic comfort, is almost similar among them, regardless of their satisfaction level. But for the visual, thermal and IAQ comfort, occupants behave in different ways depending on their satisfaction level with the corresponding IEQ component. Only for the visual comfort, a large proportion of occupants seem to choose the least environmentally friendly way due to an issue in the building design, which affects those who are satisfied and those who aren't. However, regarding thermal and IAQ comfort, occupants tend to behave in more environmentally friendly ways when they are more satisfied with the corresponding IEQ component. This indicates that occupants' satisfaction is important in designing sustainable buildings, to ensure that occupants' behavior doesn't contradict with the objectives of the Green design. Therefore, designers should be aware of occupants' comfort levels, by doing post occupancy evaluation in existing buildings to guarantee a successful design of new environmentally friendly buildings.

6.2. Analysis of behavior with respect to occupant's professional status

The behavior of respondents depending on their professional status is presented in Figures 32, 33, 34 & 35.

With respect to thermal comfort, a large number of faculty and staff members prefer to have the HVAC off with the window open or the window closed (34% and 28%, respectively). Only 9% of them versus 27% of the students want to have HVAC on and window opened which is the least wanted behavior with regards to energy saving as mentioned before. This indicates that faculty and staff members are more aware of the sustainability ethic, especially knowing that in general, they are more satisfied with their thermal comfort in comparison to students as can be seen in Figure 14.

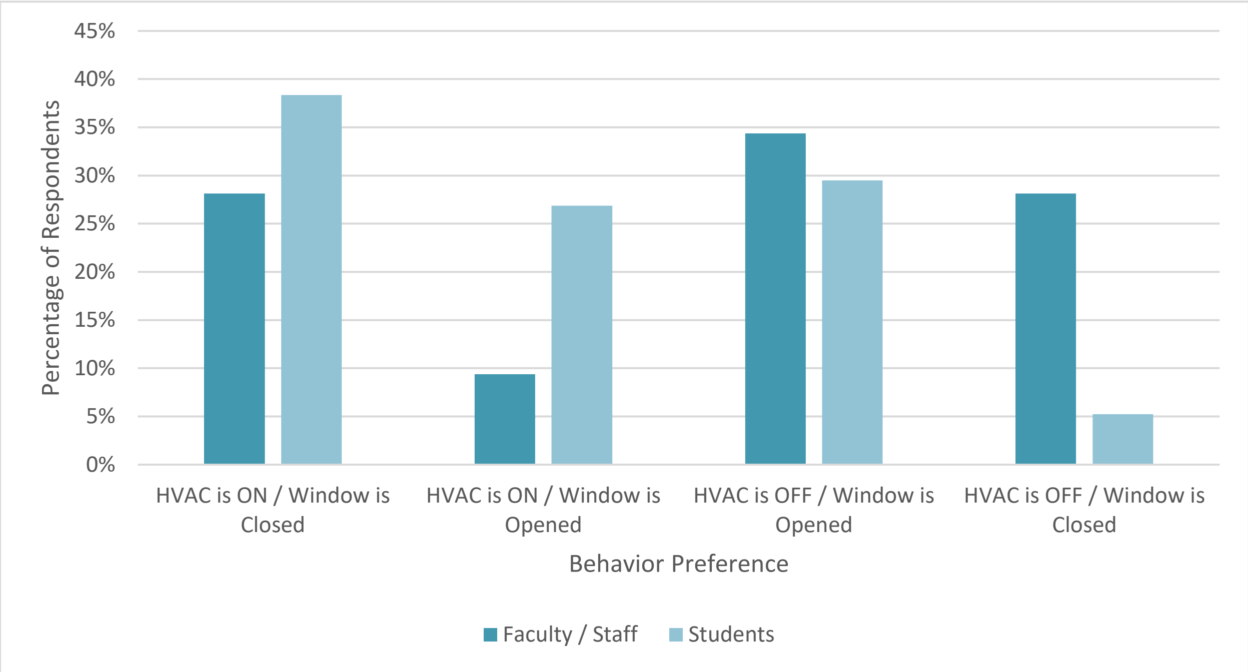

Figure 32 – Thermal behavior with respect to professional status (Q16) (sample size = 337)

For the IAQ component, the situation is similar to that of the thermal comfort as most faculty and staff members prefer to have the HVAC off and only 23% of them versus 57% of the students prefer to have both HVAC on and window opened as shown in Figure 33. A similar conclusion can be made whereby faculty and staff members are more energy aware.

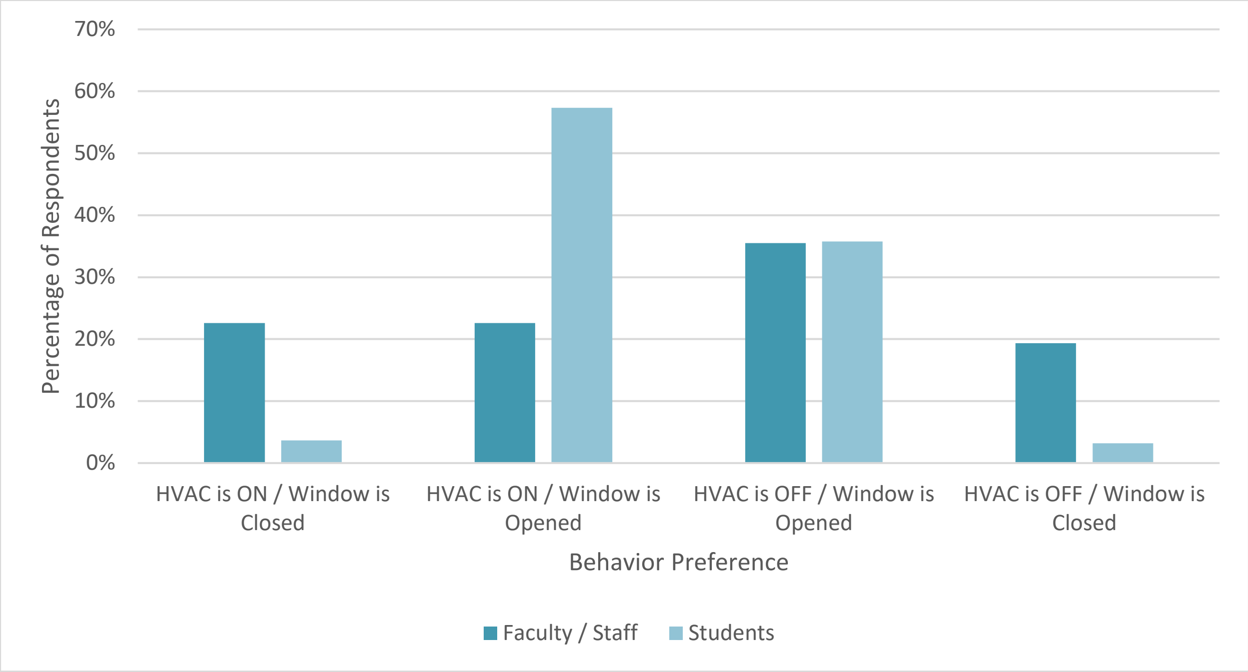

Figure 33 – IAQ behavior with respect to professional status (Q23) (sample size = 249)

Acoustically, as shown in Figure 34, both faculty and staff members and students generally prefer to have the door and the window closed to avoid getting disturbed from outside noises.

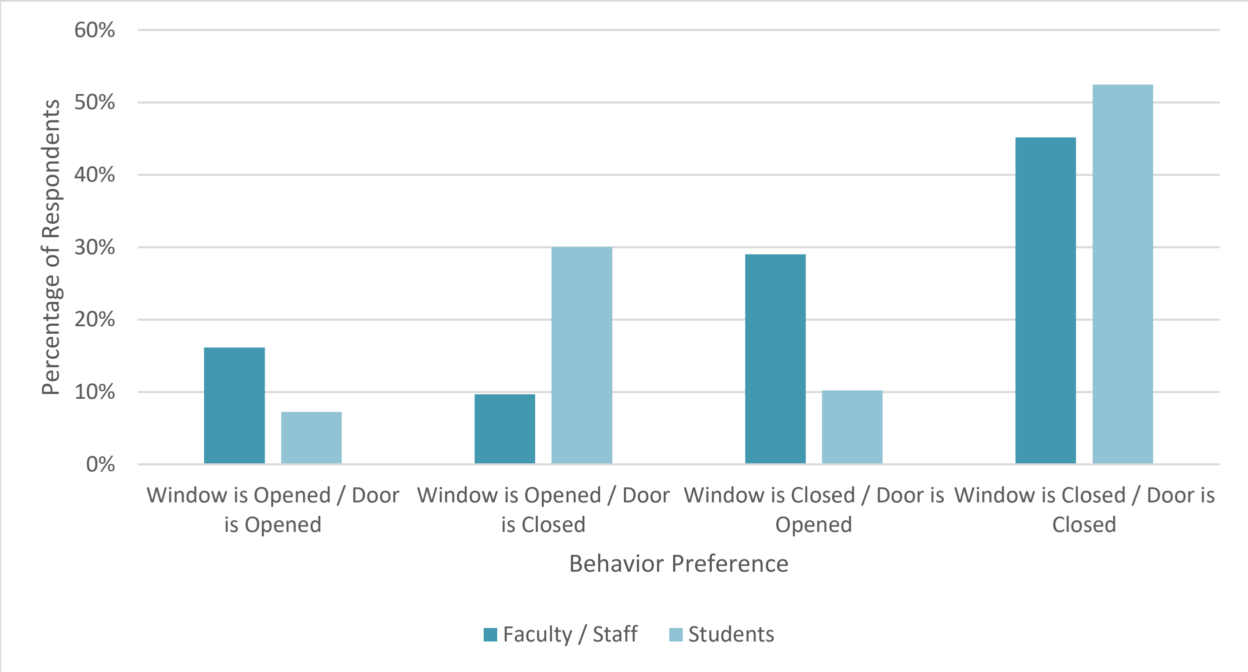

Figure 34 – Acoustic behavior with respect to professional status (Q26) (sample size = 334)

Regarding the visual comfort, most faculty and staff members (81%) prefer to have the shades open and the lights on or off, depending on the orientation of their offices with respect to the sun and time of the day. In contrast, most students (76%) prefer to always have the lights on with the shades open or closed. This can be explained by the fact that most classrooms are longer in shape than offices, and they have windows only on the end side of the classroom. In addition, offices are located on the upper floors of the buildings whereas classrooms are located on the first and second floors. Therefore, less daylight penetrates classrooms in comparison to offices. Also, sunlight glare and reflection on the white board is a major problem in classrooms which causes students to prefer to turn on the lights and close the shades because the board location on the wall is fixed, whereas faculty and staff members can adjust their screen to avoid this problem without closing the shades.

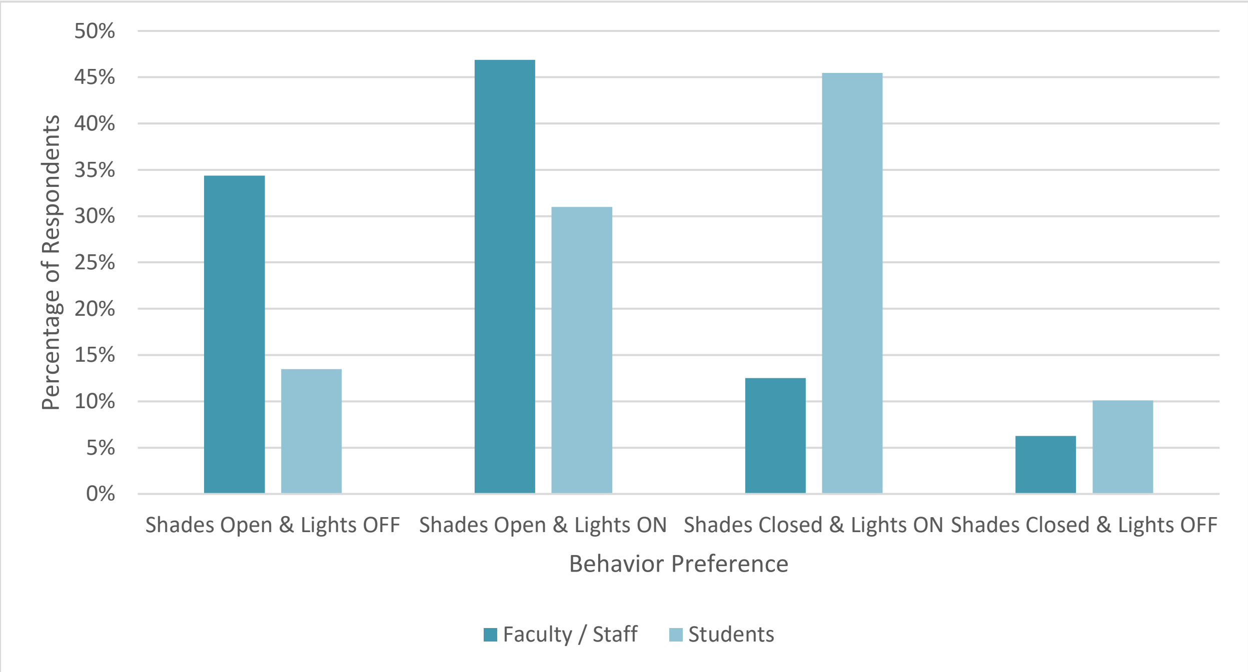

Figure 35 – Visual behavior with respect to professional status (Q33) (sample size = 329)

CHAPTER 7

STRUCTURAL EQUATION MODELING

The following chapter describes an overview of the Structural Equation Modeling (SEM) followed by the framework adapted. Then the results of the conducted SEM analysis and the generated model are presented. Subsequently, the model is discussed and later used for policy analysis in the following chapter.

7.1. Overview of Structural Equation Model

Structural Equation Modeling (SEM) is a tool applied to test if a specified theory fits the data. It combines confirmatory factor analysis (CFA) and multiple regression analysis and takes into consideration measurement errors. It is implemented in this research to estimate the causal relations between the level of satisfaction with the different components of the indoor environmental quality and the overall level of satisfaction.

There are two types of variables in the model: the measured (observed) and the latent variables. The first type of variable, which can also be called “indicator”, is the actual answered item by participants in the survey, like satisfaction level with the room temperature or freshness of the air quality. It is represented in the model diagram by a rectangular shape. The other type of variable – latent, also called “factors” – is an abstract factor measured by indicators (ideally three or more) with error which is known as measurement error. A latent variable is represented in the model diagram by an ellipse.

Different model specifications were studied and assessed according to multiple criteria including the coefficients signs and statistical significance of the variables as well as the following fit indices:

- Chi-square: a value used to assess “the magnitude of discrepancy between the sample and fitted covariances matrices.” (Hu & Bentler, 1999)
- Comparative Fit Index (CFI): “an incremental fit index that measures the relative improvement in the fit of the researcher’s model over that of a baseline model, typically the independence model.” (Kline, 2011)
- Tucker-Lewis Index (TLI): “assesses the model by comparing the Chi-square value of the model to the Chi-square of the null model.” (Hooper et al., 2008)
- Root Mean Square Error of Approximation (RMSEA): “scaled as a badness-of-fit index where a value of zero indicates the best fit” (Kline, 2011).
- Standardized Root Mean Square Residual (SRMR): “a measure of the mean absolute correlation residual, the overall difference between the observed and predicted correlations.” (Kline, 2011)

For a good fitting model, CFI and TLI should be greater than 0.95, SRMR should be less than 0.08 and RMSEA less than 0.06 (Hu & Bentler, 1999). These are just rules of thumb but they are not requirements for a model to be accepted. It was also shown that CFI, TLI and RMSEA perform best when a robust approach is used for categorical data estimated with diagonally weighted least squares (DWLS) which was applied to the model with robust standard errors and mean and variance adjusted test statistic to account for non-normality of the data (Yu & Muthén, 2002). Accordingly, the different models generated were compared based on these fit indices as well as statistical significance of the paths and the best model was chosen.

To set the scale of the latent variables, their variances are normalized. The indicators are treated as ordinal variables in the model and they are used in the model in deviations form (from the mean).

7.2. Framework of the Structural Equation Model

The initial proposed structural equation model for this study is presented in Figure 36. The model has 25 indicators with 25 measurement errors and 6 latent variables. It was hypothesized in previous studies (Kamaruzzamann, 2015, Huizenga, 2003, Zagreus, 2004, Frontczak, 2012, Dili, 2010, El Asmar, 2014, Kim, 2015, Sakellaris, 2016) that the overall level of satisfaction in a building is influenced by the satisfaction with the different components of the IEQ. The primary variable of interest for prediction is the overall level of satisfaction. As such, the latent variables chosen in the model were: “Overall Level of Satisfaction”, “Satisfaction with Indoor Air Quality”, “Satisfaction with Visual Comfort”, “Satisfaction with Acoustic Level of Comfort”, “Satisfaction with Thermal Comfort” and “Satisfaction with Appearance and Layout”. Structural relationships are shown by solid arrows while measurement relationships are shown by dashed arrows.

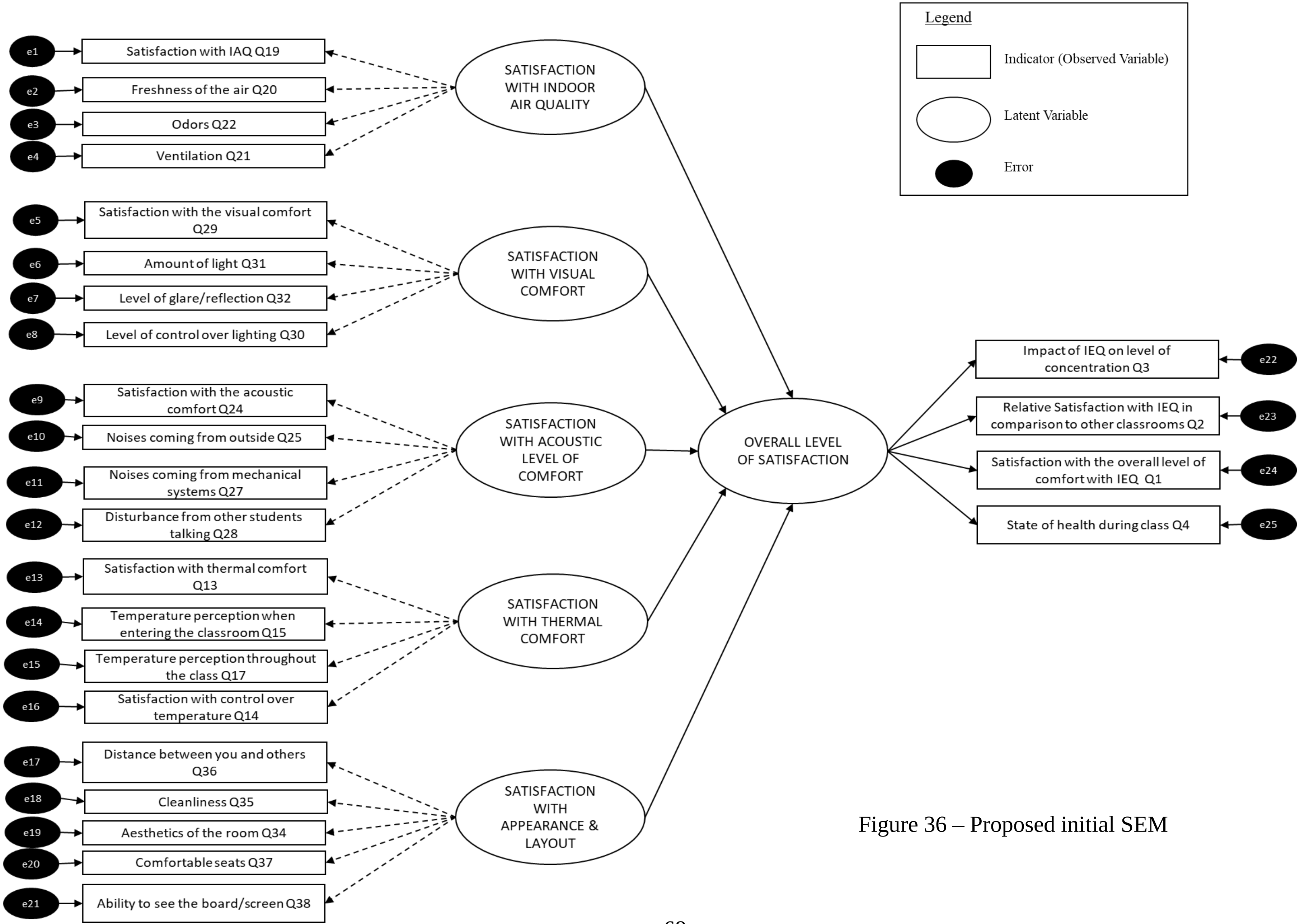

Figure 36 – Proposed initial SEM

There are no exact guidelines for SEM sample size, but some authors suggest some rules of thumb. It was proposed by Kline (2011) that for a model to be acceptable, the sample size should exceed 200. Another reference by Lee and Song (2004) recommends a ratio of sample size to indicators of 4:1 or 5:1 to get a precise and good fit of the model. In this study, 349 classroom survey responses were initially collected in total and the number of initial indicators is 25; therefore, a ratio of 349:25 $\approx$ 14:1 which is accurate for a good model fit.

Since the number of faculty members and staff is much lower than that of students, the SEM analysis is conducted using students' responses only. The data was cleaned manually to remove any survey response with missing data. The total number of respondents used in SEM is 207, after cleaning the data from outliers and missing answers.

Considering the survey questions, some of the responses needed to be adjusted to be acceptable for the model analysis. Question 15 and question 17 asked the respondents how they find the temperature of the classroom when they arrive to class and throughout the class, respectively. They are represented as indicators in the model shown in Figure 36. The response categories were as follows:

A. Hot

B. Warm

C. Neutral

D. Cool

E. Cold

Therefore, the answers were altered like the other indicators to represent a level of satisfaction and accordingly manifest the latent variables as follows:

A. Hot → transformed to → "very dissatisfied"

B. Warm→ transformed to → "very satisfied"

C. Neutral → transformed to → “neutral”

D. Cool → transformed to → “very satisfied”

E. Cold → transformed to → “very dissatisfied”

Question Q3, shown in the initial proposed model in Figure 36, asked the respondents to indicate their level of agreement with the following statement: “The overall level of comfort impacts your level of concentration in this classroom”. 70% of the respondents agree or strongly agree with this statement. Since this question doesn’t represent a satisfaction level like the other questions, it was omitted from the updated SEM analysis later on.

7.3. SEM Results

Few software packages are used to conduct a SEM study like R, LISREL or AMOS (Rosseel, 2012). For this study, the software R (a language and environment for statistical computing -Version 1.0.44) is used to estimate the model (R Development Core Team, 2008).

The package *lavaan* (version 0.5-23) was used in R to estimate the SEM model. The procedure followed consists of gradually checking the model to reach the one with best fit to the data. First, the initial model presented in Figure 36, is estimated after adjusting the answers of questions 15 and 17 and omitting question 3 from the analysis, as explained above. The results are presented in Table 11 in Appendix B. The latent variable “Satisfaction with Appearance and Layout”, referred to as “Appearance” in the SEM model results in Table 11, has a negative coefficient sign and is insignificant at the 90% level of confidence with a z-value = 0.828 < 1.96 (values are highlighted in Table 11). Therefore, this latent variable was removed from the model and the updated model was re-estimated in R and results are presented in Table 12 in Appendix B. In this case, the latent variable “Satisfaction with Visual Comfort”, referred to as “Visual” in the Structural model results in Table 12, has a negative coefficient sign and is insignificant at the 90% level of confidence with a z-value = 0.946 < 1.96. The model was again updated by removing the Visual latent variable and the final model results are presented in Table 13 in Appendix B. In this case, the model fit is acceptable with CFI = 0.938, TLI = 0.922, RMSEA = 0.077 and SRMR = 0.085. The remaining latent variables used to explain overall satisfaction are:

- Satisfaction with Indoor Air Quality (IAQ)
- Satisfaction with acoustic level of comfort (Acoustic)
- Satisfaction with thermal comfort (Thermal)

The three latent variables have coefficients with positive signs and are significant at the 90% level of confidence. The updated model is illustrated in Figure 37 showing estimated standardized parameter estimates and p-values between parentheses. For clarity of presentation, the threshold model was not shown in the model figure (Figure 37). Brown (2014) defines a threshold model as follow:

"In the case of a binary indicator (y = 0 or 1), the threshold is the point on *y** where y = 1 if the threshold is exceeded (and where y = 0 if the threshold is not exceeded)" Polytomous items have more than one threshold parameter. Specifically, the number of thresholds is equal to the number of categories minus one".

In this model, there are four threshold parameters since there are 5-point scale answers for each indicator. This will be further discussed in the Policy Analysis chapter.

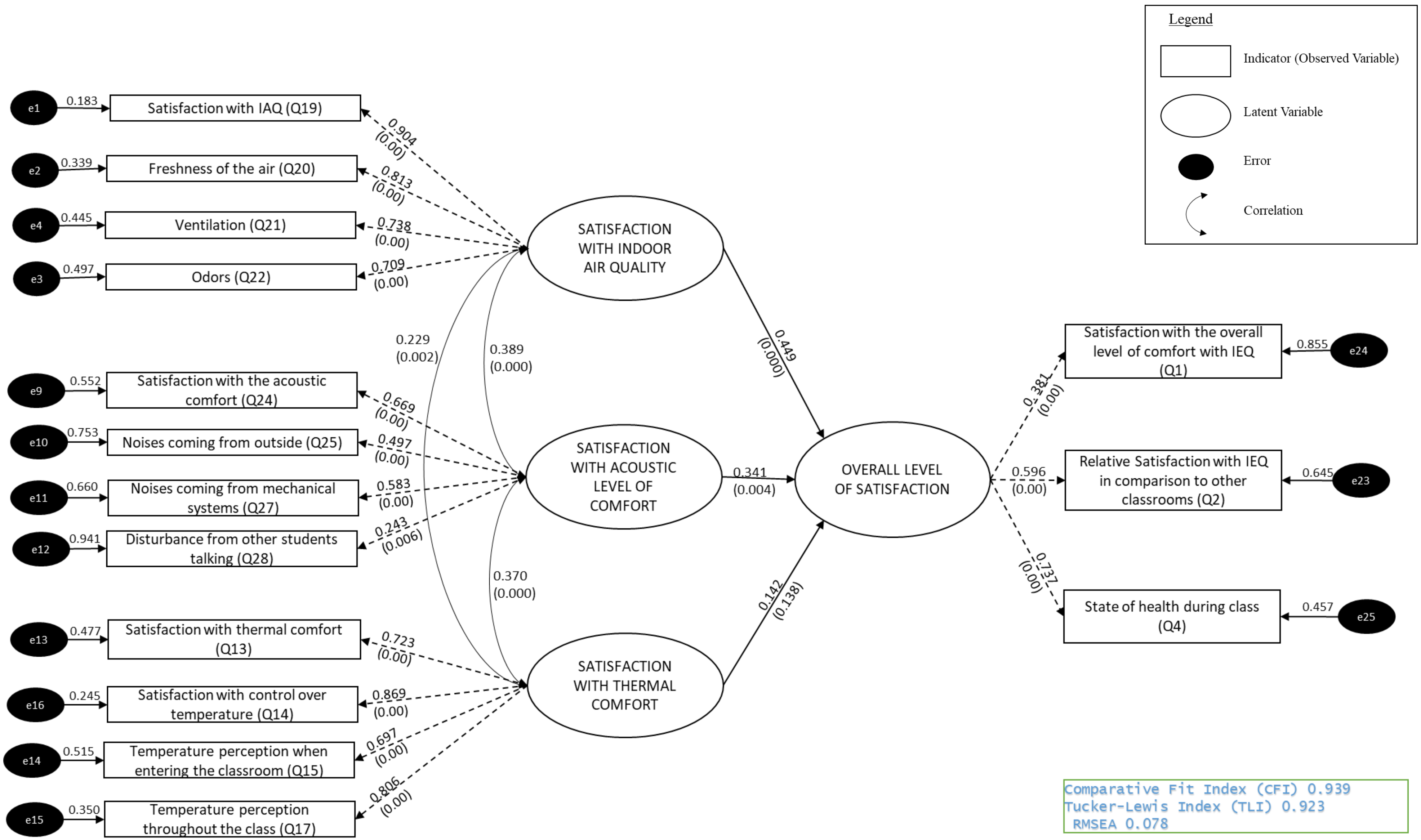

Figure 37 – Final SEM

The building type was introduced to the model as two dummy variables: Bechtel (0/1) and Architecture (0/1), and the effects of these two buildings on satisfaction were interpreted relative to the IOEC building which was kept as a base. The final model shown in Figure 37 was updated by adding the two buildings dummy variables. The results of the model are presented in Table 13 in Appendix B and the model is represented in Figure 38. After estimating this model, the fit indices were not as good as the previous model; CFI = 0.750, TLI = 0.698, RMSEA = 0.122 and SRMR = 0.084. The standardized estimate for the Bechtel building is positive (0.077) which indicates that respondents are more satisfied in Bechtel than in IOEC. The standardized estimate for the Architecture building is negative (-0.426) which shows that respondents are less satisfied in this building than in IOEC. This is in accordance with the statistical analysis initially done which shows the overall satisfaction by building in the following order; Bechtel (3.07), IOEC (2.58) and Architecture building (2.31) (Table 2). The highest satisfaction in Bechtel can be explained by the fact that the building was lately renovated. The lowest satisfaction in the Architecture building may be attributed to the old systems which need to be upgraded to increase the occupants' satisfaction. IOEC is relatively new (built in 2014), but the LEED certificate that the designer was seeking made him only focus on energy reduction systems but apparently led to less careful attention to occupants' comfort and satisfaction.

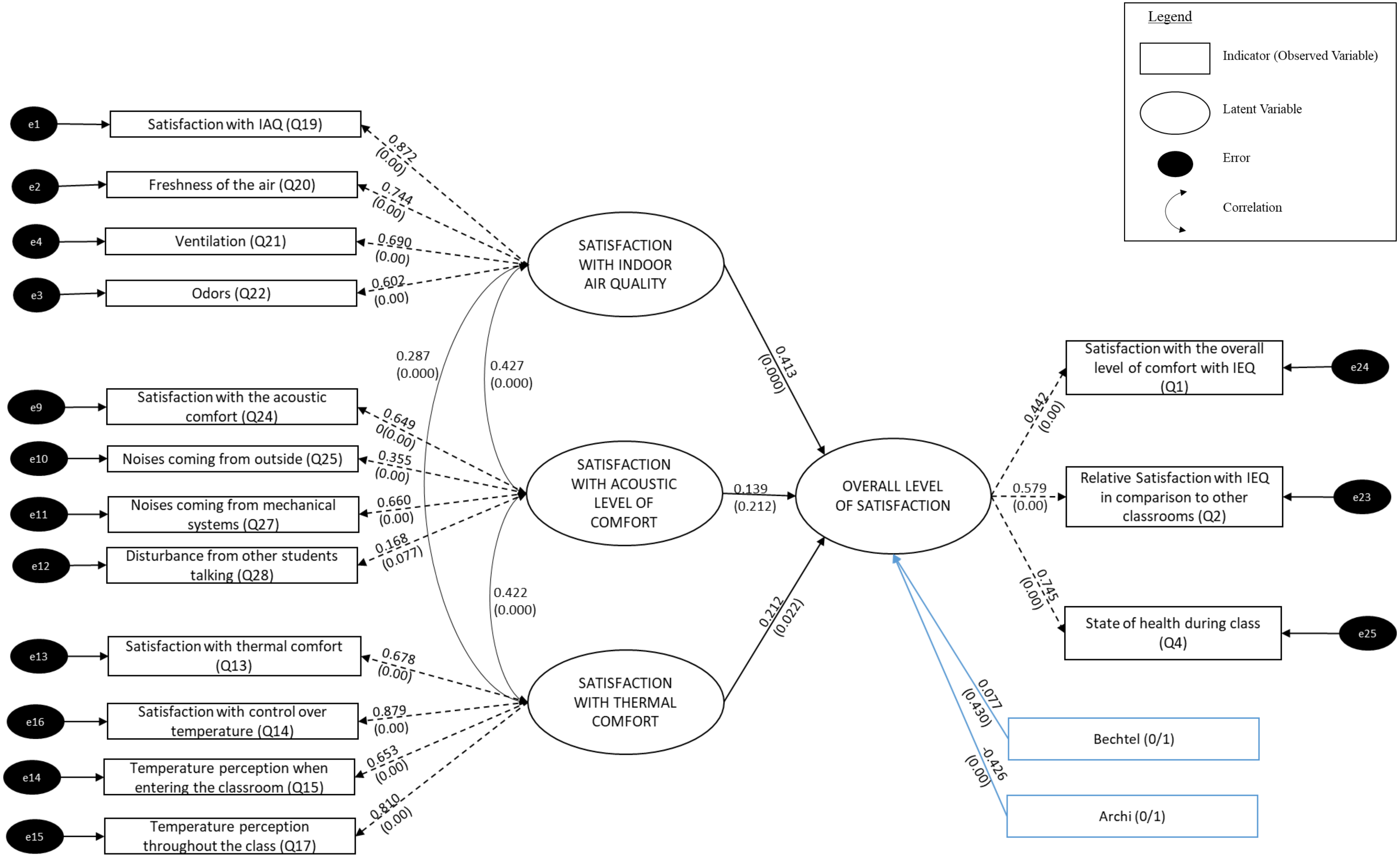

Figure 38 – SEM with building type

7.4. Model Discussion

The final selected model does not include the dummy variables representing building type due to the lower model fit. Below is a discussion of the measurement model and structural model results.

7.4.1. Measurement model

All factor loadings of the measurement model are positive as expected, and significant at the 90% level of confidence. Table 7 summarizes the standardized estimates and R-square results of the SEM measurement model. More details of the SEM results are presented in Table 13 of Appendix B. The standardized estimates of the factor loadings are relatively high for the Indoor Air Quality and Thermal comfort latent variables, and all R-squared values are higher than 0.5, which shows that these latent variables are measured well by their indicators. The other two latent variables, Acoustic Level of Comfort and Overall Level of Satisfaction, have lower loadings on their respective indicators and smaller R-squared values.

More specifically, the latent variable "Satisfaction with Indoor Air Quality" has the highest loading of 0.813 on the indicator "Freshness of the Air (Q20)" with an R-squared value of 0.661. It is then followed by "Ventilation" (Q21) with a loading of 0.738 and R-square of 0.545. "Odors" (Q22) comes last with a loading of 0.709 and R-square of 0.503.

The latent variable "Satisfaction with Thermal Comfort" is measured by its respective indicators in the following order of influence: "Satisfaction with control over temperature (Q14)" with a loading of 0.869 and R-squared of 0.755, followed by "Temperature perception throughout the class" (Q17) and finally "Temperature perception when entering the classroom" (Q15) with loadings of 0.806 and 0.697, and R-squared of 0.650 and 0.485, respectively.

The latent variable “Satisfaction with Acoustic Level of Comfort” has the highest loading of 0.583 on the indicator “Noises coming from mechanical systems (Q27)” with an R-squared value of 0.340. It is followed by the loading on “Noises coming from outside” with a value of 0.497 and an R-squared of 0.247. In third place comes “Disturbance from other students talking” (Q28) with a loading of 0.243 and an R-square of 0.059, which shows that this indicator is the least correlated with the Satisfaction with Acoustic comfort.

The latent variable “Overall Level of Satisfaction” is primarily measured by “State of health during class”(Q4) with a loading of 0.737 and an R-squared of 0.543, followed by the indicator “Relative satisfaction with IEQ in comparison to other classrooms (Q2)” with a loading of 0.596 and an R-squared value of 0.355.

Table 7 – Standardized estimates and R-square results of the Measurement Model

Latent Variable	Indicator	Standardized Estimate	R-Square
Overall Level of Satisfaction	Satisfaction with the overall level of comfort with IEQ (Q1)	0.381	0.145
	Relative Satisfaction with IEQ in comparison to other classrooms (Q2)	0.596	0.355
	State of health during class (Q4)	0.737	0.543
Satisfaction with Thermal Comfort	Satisfaction with thermal comfort (Q13)	0.723	0.523
	Satisfaction with control over temperature (Q14)	0.869	0.755
	Temperature perception when entering the classroom (Q15)	0.697	0.485
	Temperature perception throughout the class (Q17)	0.806	0.650
Satisfaction with Indoor Air Quality	Satisfaction with IAQ (Q19)	0.904	0.817
	Freshness of the air (Q20)	0.813	0.661
	Ventilation (Q21)	0.738	0.545
	Odors (Q22)	0.709	0.503

Latent Variable	Indicator	Standardized Estimate	R-Square
Satisfaction with Acoustic Level of Comfort	Satisfaction with the acoustic comfort (Q24)	0.669	0.448
	Noises coming from outside (Q25)	0.497	0.247
	Noises coming from mechanical systems (Q27)	0.583	0.340
	Disturbance from other students talking (Q28)	0.243	0.059

7.4.2. Structural model

All latent variables are significant at the 90% confidence level. The standardized estimates and R-square results of the SEM structural model are presented in Table 8. The R-Square of the "Overall Level of satisfaction" is 0.522 indicating that the dependent variable is well measured by the independent latent variables - the different components of the IEQ. The "Overall Level of Satisfaction" is mostly influenced by "Satisfaction with Indoor Air Quality" with a coefficient estimate of 0.449, followed by "Satisfaction with Acoustic Level of Comfort" at 0.341 and "Satisfaction with Thermal Comfort" at 0.142. This shows that for the present sample of buildings and respondents, satisfaction is most sensitive to changes with the "Indoor Air Quality" provided in the buildings. As a matter of fact, in a previous study conducted by Sakellaris et al. (2016), it was found that the IEQ components impact the occupants' overall satisfaction in the following decreasing order: acoustic, air quality, visual and thermal satisfaction. Other studies revealed that the most important IEQ component which affect the occupants' satisfaction is Aesthetics, followed by Acoustic. It is worth mentioning that all these studies were conducted in office buildings where noise level is important to keep workers satisfied with minimum disturbance. Furthermore, aesthetics is important for their comfort as they spend more than 8 hours in their office, as opposed to students who visit the educational building to attend a class and leave. Further discussion is presented in the Policy Analysis chapter. Different scenarios are proposed following the order of importance concluded from the SEM.

Table 8 - Standardized estimates and R-square results of the Structural Model

Dependent Latent Variable	**Independent Latent Variable**	**Standardized Estimate**	**R-Square (Dependent Variable)**
Overall Level of Satisfaction	Satisfaction with Indoor Air Quality	0.449	0.522
	Satisfaction with Acoustic Level of Comfort	0.341	
	Satisfaction with Thermal Comfort	0.142	

The latent variables are correlated with a value of 0.389 between IAQ and Acoustic, 0.229 between IAQ and Thermal and 0.370 between Acoustic and Thermal. These positive correlations are expected as some authors state that the environmental components are “experienced as an integrated whole” (Veitch et al., 2002).

CHAPTER 8

POLICY ANALYSIS

In this chapter, policy analysis is conducted to assess the impacts of a shift in the different IEQ components on the overall level of satisfaction, using the results of the SEM presented in the previous chapter. This analysis is useful to gain insights on prioritizing policies to increase students' satisfaction and to assess the extent to which satisfaction may be increased. The focus of this analysis will be on students since faculty members and staff are generally more satisfied. The chapter presents the approach used, the results, and the proposed policies.

8.1. Approach

A two-step approach is used to forecast the overall level of satisfaction, namely finding the factor scores first and then analyzing the change in satisfaction with the overall level of comfort as a function of its three indicators Q1, Q2 and Q4.

8.1.1. Factor scores

Factor scores represents "composite variables which provide information about an individual's placement on the [latent] factor" (Distefano et al., 2009). First, factor scores of the three IEQ latent variables were retrieved from R for each individual in the sample. These are called the base factor scores. Subsequently, the base overall level of satisfaction for each individual is computed using the structural model of the SEM (equation (1)). The error term was ignored in the following equation.

$$(\text{Overall \_Sat})_n = 0.449\ (\text{IAQ})_n + 0.341\ (\text{ACS})_n + 0.142\ (\text{THR})_n \qquad (1)$$

Where $(\text{Overall \_Sat})_n$ is the value of the latent variable Overall Level of Satisfaction for individual *n*, $(\text{IAQ})_n$ represents the factor score of the Indoor Air

Quality latent variable, $(ACS)_n$ is the factor score of the Acoustic latent variable and $(THR)_n$ is the factor score of the Thermal latent variable for each individual *n*.

For each IEQ component, two scenarios were tested to study the impact of the shift in satisfaction in the IEQ component on the overall level of satisfaction. The first scenario, called median minimum, consists of setting all values of the factor scores that are less than the median in the sample to be equal to the median value. Therefore, all new values of the latent variable are greater than or equal to the median value. The new overall level of satisfaction is computed using equation (1) and the new factor scores. For example, to examine the impact of an increase in the Indoor Air Quality satisfaction on the overall level of satisfaction, the factor scores of the IAQ that are less than the median were set to be equal to the median value which is -0.0049 in that case (note that values are in deviation form as mentioned in previous sections). The new values IAQ_med are used to compute the new Overall Level of Satisfaction:

$$(Overall\_Sat\_med)_n = 0.449\ (IAQ\_med)_n + 0.341\ (ACS)_n + 0.142\ (THR)_n \qquad (2)$$

The second scenario simulates the case where the latent variable (such as IAQ) is at its maximum for everyone in the sample. That is, how would the overall level of satisfaction change if every individual was very highly satisfied with IAQ for example? One way to do this is to set the value of the factor score (of IAQ in this case) to be equal to the maximum value any of the indicators of the latent variable can have, which corresponds to the very satisfied level of satisfaction. This is because the scale of a latent variable is related to the scale of its indicators. As before, this scenario is tested for each latent variable separately. As an example, for the Indoor Air Quality, the following equation is used:

$$(Overall\ \_Sat\_max)_n = 0.449\ (IAQ\_max)_n + 0.341\ (ACS)_n + 0.142\ (THR)_n \qquad (3)$$

8.1.2. Indicators of overall level of satisfaction

Once the latent variable "overall level of satisfaction" changes (due to changes in one of the IEQ components), one can predict the change in its indicators. This is useful to understand how the distribution of satisfaction levels for the different indicators would change if certain policies were implemented.

The indicators Q1, Q2 and Q4 of the overall level of satisfaction are computed using the thresholds table retrieved from the SEM results (see table 9). Figure 39, 40 and 41 depict the relationship between the latent variable "Overall Level of Satisfaction" and its indicators Q1, Q2 and Q4, respectively. As an example, values of the latent variable "Overall Level of Satisfaction" that are less than -1.124 result in a "Satisfaction with the overall level of comfort with IEQ (Q1)" equal to 1 which represents the very dissatisfied level. Values ranging between -0.238 and 0.671 result in a level of satisfaction for the "Satisfaction with the overall level of comfort with IEQ (Q1)" equal to 3 which represents the neutral level. Values that are above 1.767 correspond to a level of satisfaction of Q1 equal to 5 which is the very satisfied level. Accordingly, knowing the values of the latent variable "Overall Level of Satisfaction" for the base case and for each of the tested scenarios, the satisfaction indicators Q1, Q2 and Q4 are computed for all individuals in the sample for the base, median minimum, and maximum scenarios. Results are discussed in the following section.

Table 9 – Thresholds for the indicators of the overall level of satisfaction

	Estimate	Std.Err	z-value	P(>|z|)	Std.lv	Std.all
Q1|t1	-1.124	0.111	-10.160	0.000	-1.124	-1.124
Q1|t2	-0.238	0.088	-2.702	0.007	-0.238	-0.238
Q1|t3	0.671	0.095	7.071	0.000	0.671	0.671
Q1|t4	1.767	0.160	11.023	0.000	1.767	1.767
Q2|t1	-1.102	0.110	-10.053	0.000	-1.102	-1.102
Q2|t2	0.030	0.087	0.347	0.729	0.030	0.030
Q2|t3	0.781	0.098	7.992	0.000	0.781	0.781
Q2|t4	1.827	0.168	10.900	0.000	1.827	1.827

Q4|t1	-0.781	0.098	-7.992	0.000	-0.781	-0.781
Q4|t2	-0.103	0.087	-1.179	0.239	-0.103	-0.103
Q4|t3	0.831	0.099	8.378	0.000	0.831	0.831
Q4|t4	1.827	0.168	10.900	0.000	1.827	1.827

Figure 39 - Change in satisfaction with the Overall Level of Comfort with IEQ (Q1) as a function of the Latent Variable Overall Level of Satisfaction

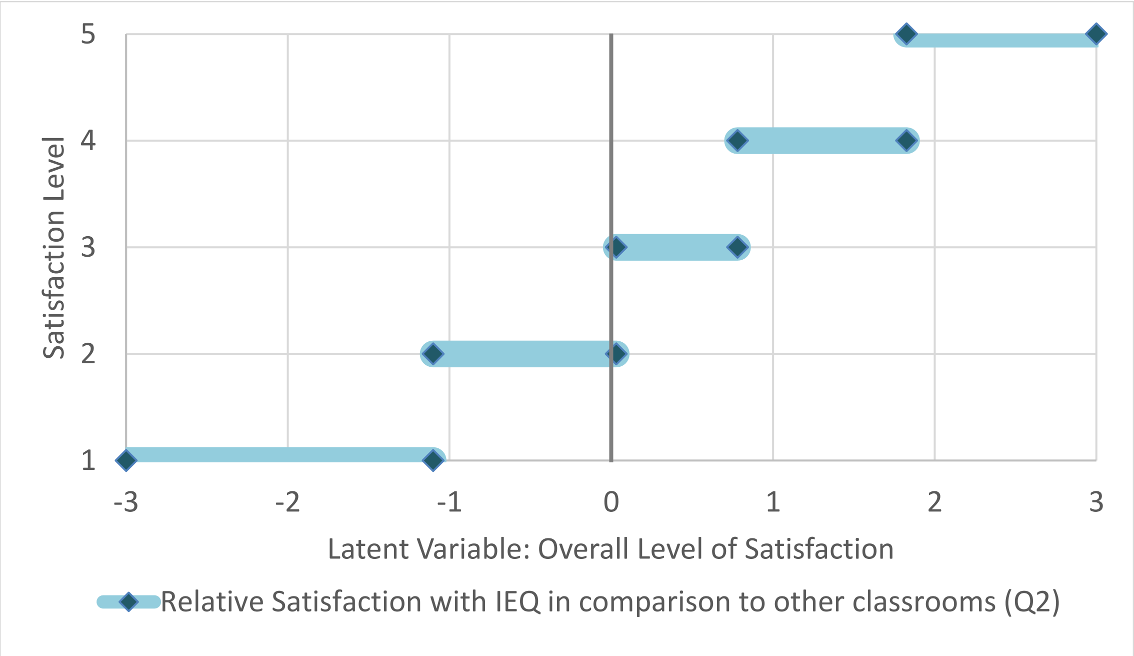

Figure 40 - Change in Relative Satisfaction with IEQ in comparison to other classrooms (Q2) as a function of the Latent Variable Overall Level of Satisfaction

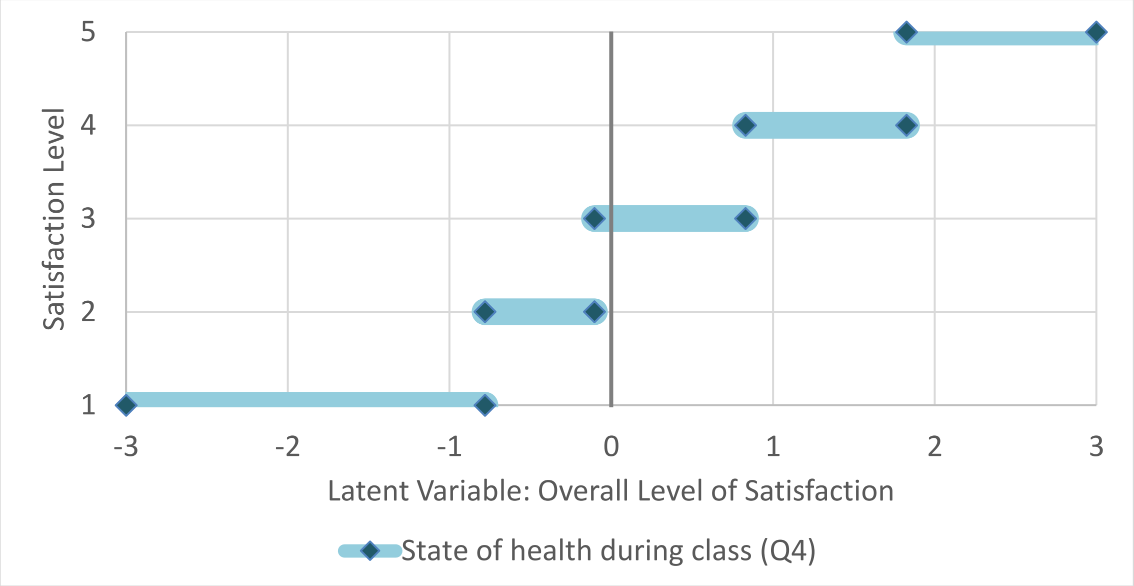

Figure 41 - Change in State of Health during class (Q4) as a function of the Latent Variable Overall Level of Satisfaction

8.2. Results

The change in satisfaction with the three indicators of the overall level of satisfaction Q1, Q2 and Q4 as a function of the Indoor Air Quality are presented in Figures 42, 43 and 44 respectively. The base, median minimum and maximum scenarios are compared. Increasing the level of satisfaction with the IAQ leads to a shift of the overall satisfaction levels trendline to the right, i.e. to higher satisfaction, as expected.

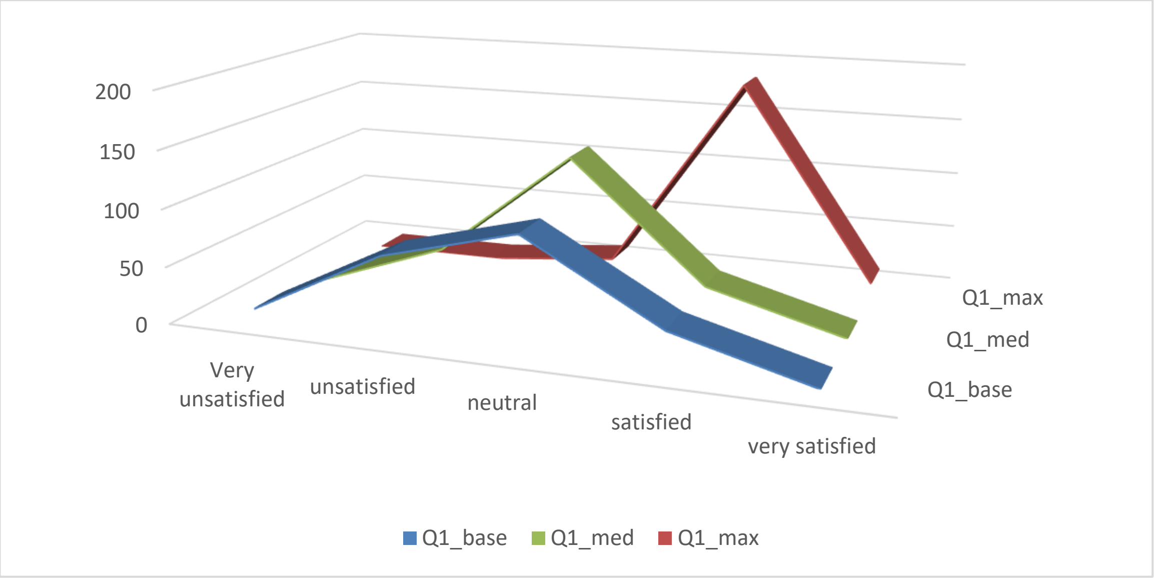

Figure 42 - Change in satisfaction with the overall level of comfort with IEQ (Q1) as a function of IAQ

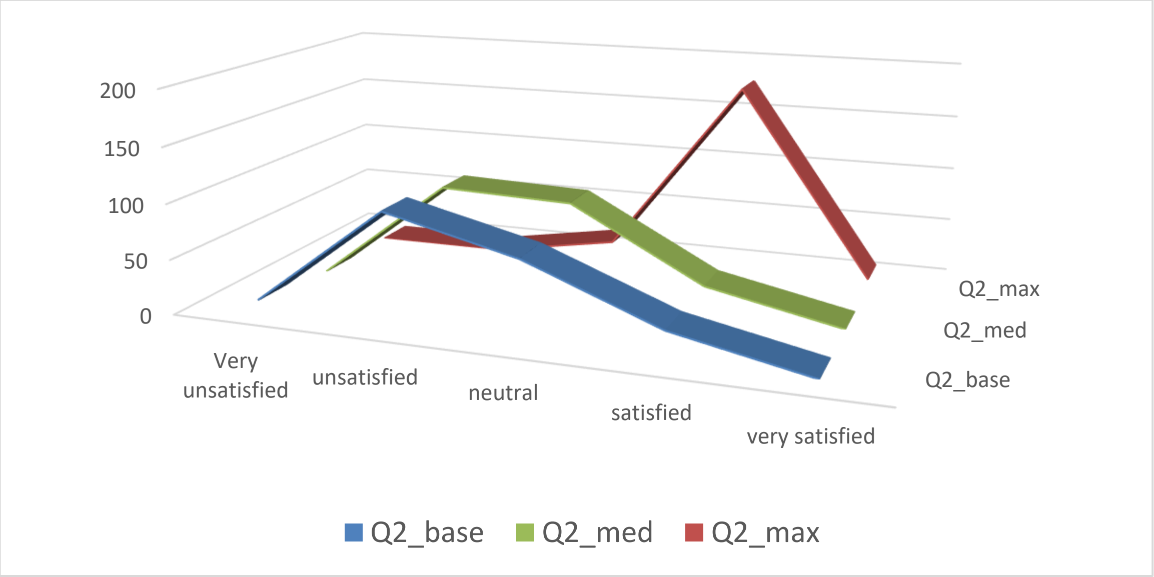

Figure 43 - Change in relative satisfaction with IEQ in comparison to other classrooms (Q2) as a function of IAQ

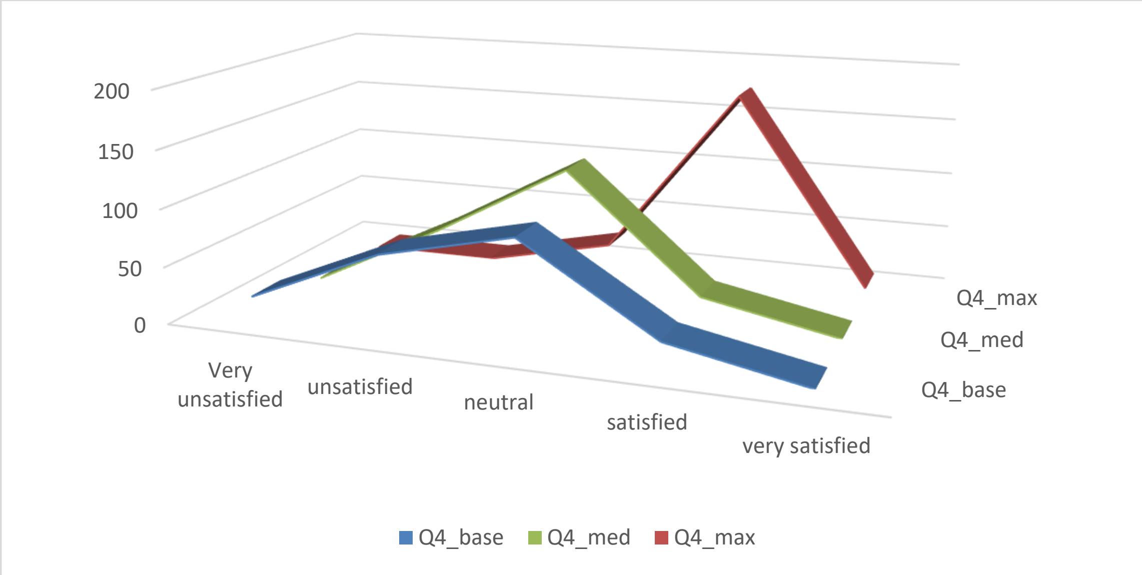

Figure 44 - Change in state of health during class (Q4) as a function of IAQ

Likewise, the change in satisfaction with the three indicators of the overall level of satisfaction Q1, Q2 and Q4 as a function of the Acoustic level of comfort are presented in Figures 45, 46 and 47. Again, the median and maximum scenarios trendlines are skewed to the right indicating higher overall satisfaction with the increase in acoustic satisfaction.

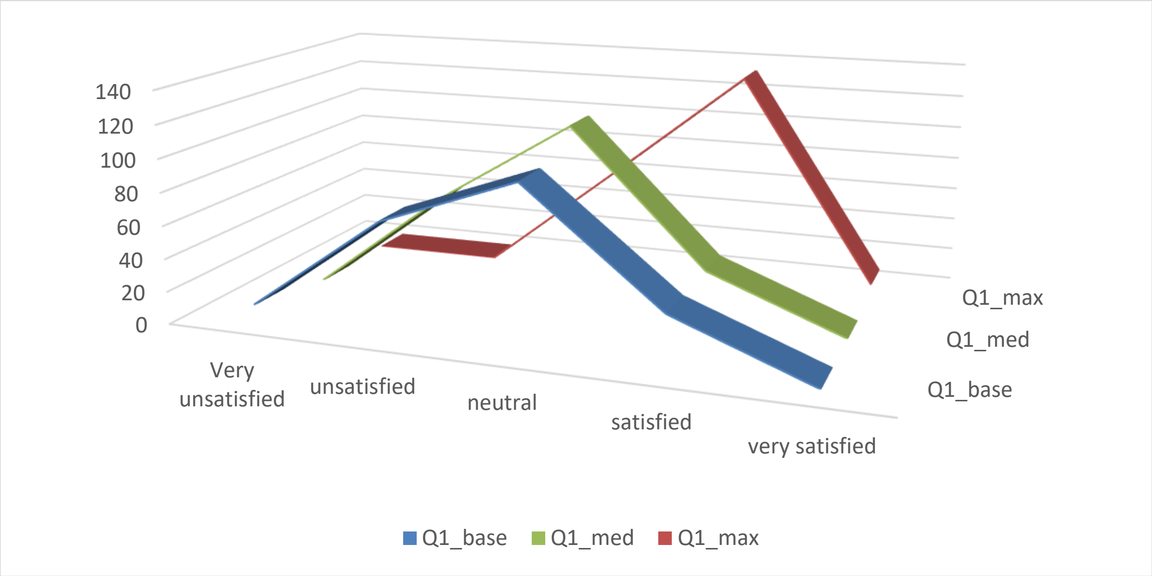

Figure 45 - Change in satisfaction with the overall level of comfort with IEQ (Q1) as a function of Acoustic level of comfort

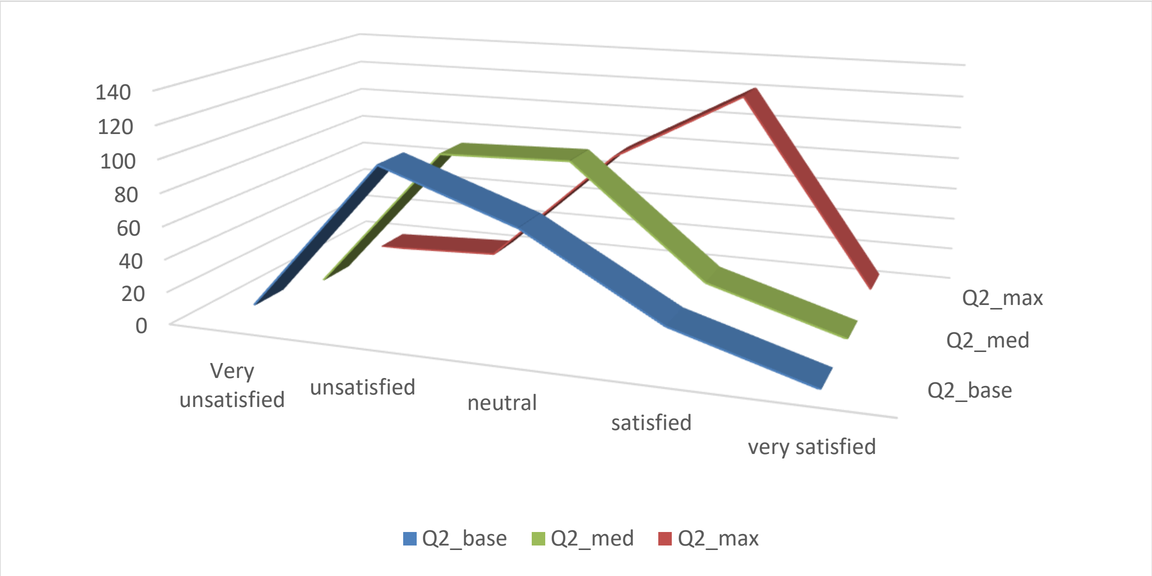

Figure 46 - Change in relative satisfaction with IEQ in comparison to other classrooms (Q2) as a function of Acoustic level of comfort

Figure 47 - Change in state of health during class (Q4) as a function of Acoustic level of comfort

Finally, the change in satisfaction with the three indicators of the overall level of satisfaction Q1, Q2 and Q4 as a function of the Thermal level of comfort are presented in Figures 48, 49 and 50 respectively. It can be noted that increasing the thermal level of satisfaction has the least impact on the overall level of satisfaction as the trendline doesn't shift as much as it does with the two other latent variables. This is further verified in Table 10 below which presents the percentage of respondents who are satisfied or very satisfied for the different indicators of the Overall level of satisfaction (Q1, Q2 and Q4) for the three scenarios. The median minimum scenarios for the different IEQ components increase the number of neutral respondents but do not increase the number of satisfied or very satisfied respondents. However, the maximum scenarios highly affect the numbers. Almost all respondents become satisfied or very satisfied with the overall level of satisfaction if satisfaction with IAQ is increased. Similarly, for the acoustic component, a large number of respondents become satisfied or very satisfied. For the thermal component, the numbers of satisfied and very satisfied respondents increase too but to a lesser extent.

Figure 48 - Change in satisfaction with the overall level of comfort with IEQ (Q1) as a function of Thermal level of comfort

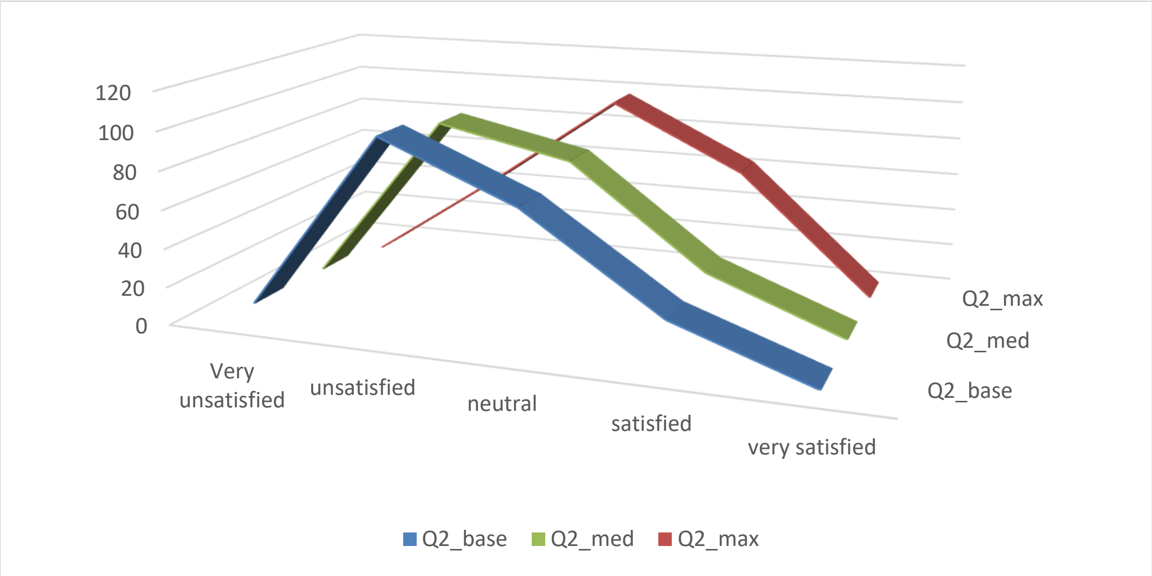

Figure 49 - Change in relative satisfaction with IEQ in comparison to other classrooms (Q2) as a function of Thermal level of comfort

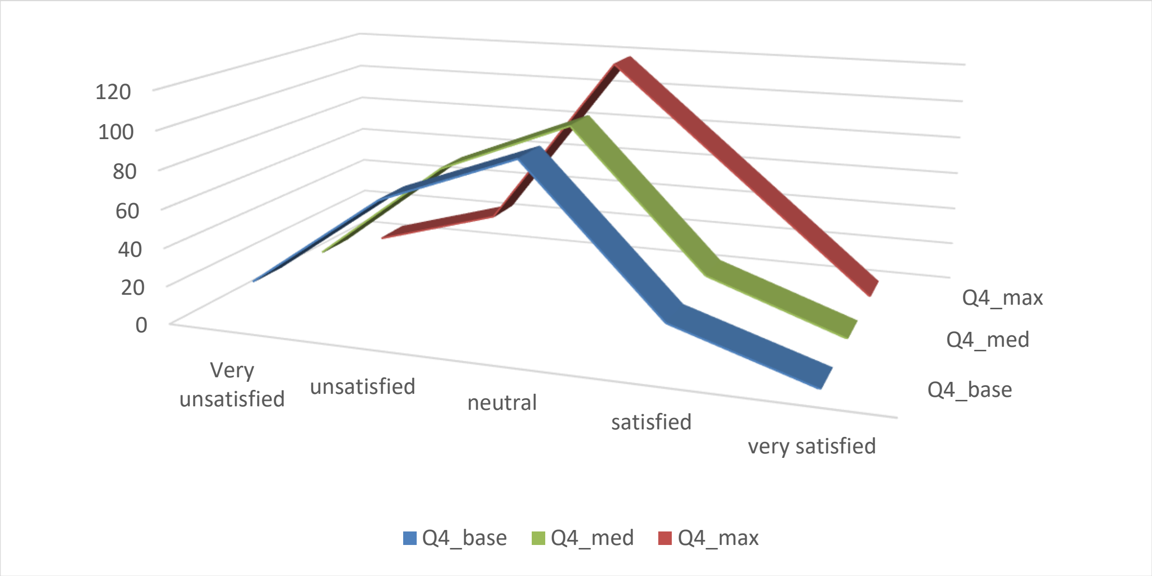

Figure 50 - Change in state of health during class (Q4) as a function of Thermal level of comfort

Table 10 – Policy analysis scenarios summary

Scenario	Percentage of respondents who are satisfied or very satisfied with the overall level of comfort with IEQ (Q1)	Percentage of respondents who are satisfied or very satisfied with IEQ in comparison to other classrooms (Q2)	Percentage of respondents who are satisfied or very satisfied with the state of health during class (Q4)
IAQ (Fig. 36, 37 & 38)			
Base Scenario	15%	12%	11%
Median Minimum	15%	12%	11%
Maximum	95%	90%	88%
Acoustic (Fig. 39, 40 & 41)			
Base Scenario	15%	12%	11%
Median Minimum	15%	12%	11%
Maximum	68%	61%	57%
Thermal (Fig. 42, 43 & 44)			
Base Scenario	15%	12%	11%
Median Minimum	15%	13%	12%
Maximum	35%	30%	29%

8.3. Proposed Policies

Different scenarios can be proposed to increase the level of satisfaction of students. From the SEM results, it was shown that the Satisfaction with Indoor Air Quality has the highest influence on the Overall Level of Satisfaction, followed by the Satisfaction with Acoustic Level of Comfort and lastly by the Satisfaction with Thermal Comfort. As expected, the policy analysis also confirmed that increasing the level of satisfaction with the IAQ component would highly increase the overall level of satisfaction, followed by the Acoustic component and finally the Thermal component.

Accordingly, to increase the level of overall satisfaction, priority should be given to improve the Indoor Air Quality first. The SEM model results show that the highest factor loading for the Indoor Air Quality latent variable is on Q20: Freshness of the air (0.813). Therefore, improving the freshness is expected to highly improve the IAQ (given the high correlation between the two even though the causality goes from IAQ to Q20) and consecutively the overall level of satisfaction. Freshness can be improved by regularly cleaning and maintaining the air ducts. In addition, in the Architecture building, the furniture is old which gives a sense of stuffiness. Therefore, to allow better satisfaction of the occupants, the furniture should be changed. A specific type of natural furniture should be chosen which doesn’t emit toxic chemicals (like formaldehyde phthalates, PBDEs, etc.). Attention should be also given to the fabric of couches and chairs, as some materials absorb dust and release it when someone sits on them. Wall paints and furniture varnishes should be accurately chosen to limit the emission of volatile organic compounds. Ventilation (Q21) follows in terms of factor loading hierarchy (0.738). The orientation of classrooms and the location of windows on one side of the classroom or office make the ventilation low. The Architecture building is undergoing renovation and the interior should be designed in a way to ensure that all classrooms are well ventilated by adding windows on two or more sides of the room, making sure that they are aligned with the prevailing winds (South/West or from the sea). In IOEC, windows cannot be opened. This is a major issue faced by the occupants of this building and causes very low ventilation. Thus, the windows should be replaced by operable ones in all classrooms and offices. More specifically, windows should be placed in strategic locations, in the direction of the prevailing winds, to allow natural ventilation in the building. IOEC has a narrow width (as can be seen in the plan in Appendix C), and therefore it's very easy to take advantage of the wind and create a natural ventilation. Since the building is facing the sea on its North facade, it would be beneficial to place windows on the North and South facades to allow the prevailing wind from the sea to enter the building. Finally, to improve Odors (Q22) which has the lowest loading of 0.709, automatic air fresheners can be installed in classrooms and offices. Therefore, the importance of maintaining the ventilation systems, providing fresh air continuously into the building and controlling odors are necessary steps for the satisfaction of occupants.

Following the IAQ, the Acoustic level of comfort comes second in terms of improvement priority. The highest loading is on Q27 "Level of noises coming from mechanical systems in the classrooms" (0.583). In IOEC, the HVAC system is not embedded in a false ceiling which produces a very disturbing noise that decreases the level of satisfaction of occupants. In the Architecture building, the whole mechanical system is old and needs to be replaced when renovating the building. By applying noise reduction machines on the mechanical systems or improving the false ceiling to be acoustically insulated, higher level of satisfaction could be achieved in all three buildings. The following indicator which influences the Satisfaction with Acoustic Level of Comfort is "Noises coming from outside" (Q25). It is recommended to install signs in hallways and outside the buildings (see Figure 51) to remind students and people passing outside to keep calm while classes are in progress and therefore decrease noises coming from outside. It is also important to limit construction activities to a timeframe when there are no classes, for example between 4:00 AM and 8:00 AM, and between 6:00 PM and 10:00 PM, and add weekend shifts. The last indicator, "Disturbance coming from other students talking" (Q28), has a low influence on the latent variable with a factor loading of 0.243; however, it can also be improved by installing acoustic tiles on the ceiling to reduce echoes.

Figure 51 – "Quiet" sign

Finally, the thermal level of comfort should also be improved although it has the least influence on the overall level of satisfaction, but still is an important factor. The highest loading is on Q14: Level of control over temperature (0.860). The level of control is minimal in classrooms: the temperature is set for the whole season and students and faculty and staff members cannot change it. Since the campus is located in Beirut, the weather can vary from day to day enormously or even during the same day between morning and afternoon, so it is not convenient to keep the temperature fixed all the time. Higher levels of satisfaction could be achieved by allowing more control (by faculty members especially) through providing a certain code or key to the control panel in each classroom. Another solution is to install temperature sensors to adjust the temperature and not keep it constant for the whole building, the whole day and the whole season.

CHAPTER 9

CONCLUSION

The topic of occupants' comfort and satisfaction has been of interest to many researchers since human beings spend most of their time indoors and therefore their comfort with the Indoor Environmental Quality is of utmost importance. Maintaining a high level of IEQ in buildings not only results in health benefits but also environmental ones. Occupants' behavior in response to their satisfaction with the IEQ could result in energy savings as well.

Hence, this study focuses on occupants' comfort and behavior in three academic buildings at the American University of Beirut in Lebanon. The three buildings were particularly chosen because of their different status: an old building (Architecture building), a renovated building (Bechtel building) and a new LEED certified building (IOEC building). Based on data collected through surveys and interviews, statistical analysis was conducted to quantify the level of satisfaction with each component of the IEQ in the different buildings and depending on the occupants' professional status. They are mostly dissatisfied with the thermal level of comfort and aesthetics, followed by the Indoor Air Quality and acoustic level of comfort. Since the number of occupants who are satisfied with the thermal level of comfort does not reach 80%, the thermal environment is not acceptable as stated by ASHRAE Standard 55 (ASHRAE, 2004). The visual level of comfort is the only component which students are mostly satisfied with. Behavior was also analyzed, and it was shown that when students are not satisfied (particularly with thermal comfort or indoor air quality) they tend to behave in ways to increase their level of satisfaction which causes dissipation of energy. Therefore, it was deemed necessary to study well the occupants' needs in terms of satisfaction levels and accommodate accordingly energy saving designs in buildings to ensure that the behavior does not contradict the purpose of the environmentally friendly design. A structural equation model was developed based on the collected data. The results show that the Indoor Air Quality, the Acoustic level of comfort and the Thermal level of comfort predict the Overall Level of Satisfaction in a decreasing order of importance.

Therefore, there is a need to identify solutions and policies to increase the level of satisfaction with the different IEQ components. Different policies are recommended for building managers and owners. Regular maintenance of the different building systems (HVAC) is necessary to ensure a higher level of satisfaction. Thorough design of the interiors and exteriors of a building should be implemented before the construction. In fact, studies of the wind direction in the area location and proper location of windows and doors are necessary to ensure good ventilation into the building. Furthermore, providing control to occupants to be able to operate windows, shades and HVAC systems is necessary to allow them to accommodate their needs and comfort. Finally, as an educational building, the acoustic component is important to allow occupants to focus on their work/studies in a quiet environment. Therefore, more regulations are needed to restrict any noisy activity.

While the proposed study has achieved promising results under different scenarios, it exhibits some limitations. The scope of the study is limited to classrooms and offices of three academic buildings. Labs, public spaces, hallways and toilets are not included in the study. The study can be extended by applying it to the whole campus, and even to other types of buildings like offices, healthcare or residential. Also, classroom attributes like orientation, size and floor are not accounted for in the study. Furthermore, survey data is only collected in some classrooms and offices as not all faculty and staff members accepted to participate in the survey. In addition, the start of construction works near Bechtel building caused the temporary relocation of many classes to another building, which also affected the comfort of occupants. The current study is limited to studying the effect of the following features on the well-being of occupants and their behavior: thermal comfort, indoor air quality, acoustic, visual comfort and appearance. The study does not include non-physical features that can also affect the occupant's satisfaction like psychological behavior or human interactions, nor occupants' characteristics like age, gender, health problems, etc. The model can be expanded to include time of day or season and observe what effects it has on the results. The research can be further developed to study the effect of IEQ on the productivity of students, faculty members and staff. Moreover, behavior and satisfaction were studied under a statistical descriptive analysis only but further research could develop an integrated model of behavior and satisfaction. Additionally, the SEM was performed on students' data only but future studies can collect a larger data sample including more categories (faculty members and staff) and run a new model. Finally, after the renovation of the Architecture building is completed, a study could be conducted on the satisfaction of occupants in the new building and results will be compared to the pre-renovation results found in this study.

The study contributes to the literature regarding occupants' comfort by adding the occupants' behavioral aspect with respect to their satisfaction and occupation, and putting it in an environmentally friendly frame. Furthermore, a comparison of a new building, an old building and a renovated one in terms of IEQ satisfaction has been studied. The structural equation model results provide insights on satisfaction of students in such types of buildings, especially important for owners and managers to take into consideration when constructing or renovating a building. In fact, the Architecture building started a renovation just at the end of the study, and the recommendations proposed in this thesis can benefit the new design. Moreover, the study results and proposed scenarios can help improve academic buildings in different areas as well as other types of commercial buildings and residential ones.

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APPENDIX A

SURVEY QUESTIONNAIRE

BUILDING OCCUPANTS COMFORT SURVEY

(Faculty and Staff Members Version)

Purpose of the Survey

Thank you for taking the time to answer the following questions. The survey is made for research purposes as part of a master thesis about quantifying occupants' comfort and behavior in a typical academic building. The survey should take [10 min] to complete. All answers will be confidential.

For any further information please contact Nour Fayed on 03841949 or Dr. Hiam Khoury on 70270798.

General

{PLEASE TRY NOT TO TAKE INTO CONSIDERATION THE ONGOING CONSTRUCTION WHILE ANSWERING THE FOLLOWING QUESTIONS}

Please think of the last two weeks when you were coming at this time of the day to this OFFICE

1. How would you rate your satisfaction with the OVERALL LEVEL OF COMFORT with the Indoor Environmental Quality (**IEQ**) in this OFFICE most of the time:

   A. **Very Dissatisfied**
   B. **Dissatisfied**
   C. **Neutral**
   D. **Satisfied**
   E. **Very Satisfied**

2. Compared to other OFFICES in other buildings, how do you find the level of comfort with the IEQ in this OFFICE most of the time?

   A. **Much Worse**
   B. **Worse**
   C. **Same**
   D. **Better**
   E. **Much Better**

3. Please rate your level of agreement with the following statement: "the overall level of comfort impacts your level of concentration in this OFFICE":

A. **Strongly Disagree**

B. **Disagree**

C. **Neutral**

D. **Agree**

E. **Strongly Agree**

4. How satisfied are you with your state of health in this OFFICE (headache, fatigue, cough, sore eyes…)?

A. **Very Dissatisfied**

B. **Dissatisfied**

C. **Neutral**

D. **Satisfied**

E. **Very Satisfied**

Participant information

Please tell us a bit about yourself.

These questions are to ensure that we have a representative sample.

5. Gender

A. **Female**

B. **Male**

6. Age bracket

A. **[18-24]**

B. **[25-36]**

C. **[37-45]**

D. **[46-55]**

E. **[56-64]**

F. **[>64]**

Thermal comfort

13. How satisfied are you with your THERMAL COMFORT IN THE OFFICE:

A. **Very Dissatisfied**

B. **Dissatisfied**

C. **Neutral**

D. **Satisfied**

E. **Very Satisfied**

14. How satisfied are you with the level of control over temperature in THE OFFICE:

A. **Very Dissatisfied**

B. **Dissatisfied**

C. **Neutral**

D. **Satisfied**

E. **Very Satisfied**

<u>THERMAL COMFORT</u>

Now let's consider the moment you arrive to THE OFFICE.

15. When you arrive to this OFFICE most of the time, how do you find the temperature?

A. **Hot**

B. **Warm**

C. **Neutral**

D. **Cool**

E. **Cold**

16. When you arrive to this OFFICE & regarding your thermal comfort, would you prefer if:

A. **HVAC is ON / Window is Closed**

B. **HVAC is ON / Window is Opened**

C. **HVAC is OFF / Window is Opened**

D. **HVAC is OFF / Window is Closed**

Now let's consider SOME time spent IN THE OFFICE.

17. How do you find the temperature of the OFFICE AFTER SOME TIME?

A. **Hot**

B. **Warm**

C. **Neutral**

D. **Cool**

E. **Cold**

18. Given what you said before, how would you prefer to feel?

A. **Warmer**

B. **No Change**

C. **Cooler**

Indoor air quality

Now we would like to know about the indoor air quality of the OFFICE.

19. How satisfied are you with the INDOOR AIR QUALITY of the OFFICE:

A. **Very Dissatisfied**

B. **Dissatisfied**

C. **Neutral**

D. **Satisfied**

E. **Very Satisfied**

20. How do you find the FRESHNESS of the AIR QUALITY in the OFFICE?

A. **Very Stuffy**

B. **Stuffy**

C. **Neutral**

D. **Fresh**

E. **Very Fresh**

21. How satisfied are you with the ventilation in the OFFICE?

A. **Very Dissatisfied**

B. **Dissatisfied**

C. **Neutral**

D. **Satisfied**

E. **Very Satisfied**

22. How satisfied are you with the odors in this OFFICE?

A. **Very Dissatisfied**

B. **Dissatisfied**

C. **Neutral**

D. **Satisfied**

E. **Very Satisfied**

23. DURING THE TIME SPENT IN THE OFFICE & regarding Indoor Air Quality, would you prefer if:

A. **HVAC is ON / Window is Closed**

B. **HVAC is ON / Window is Opened**

C. **HVAC is OFF / Window is Opened**

D. **HVAC is OFF / Window is Closed**

ACOUSTIC COMFORT

How loud?

24. How satisfied are you with the ACOUSTIC COMFORT in the OFFICE:

A. **Very Dissatisfied**

B. **Dissatisfied**

C. **Neutral**

D. **Satisfied**

E. **Very Satisfied**

25. WHEN YOU ARE IN YOUR OFFICE, how do you usually find the level of noises coming from outside:

A. **Very noisy**

B. **Noisy**

C. **Neutral**

D. **Calm**

E. **Very Calm**

26. During THE TIME SPENT AT THE OFFICE & regarding the acoustic comfort, would you prefer if:

A. **Window is Opened / Door is Opened**

B. **Window is Opened / Door is Closed**

C. **Window is Closed / Door is Opened**

D. **Window is Closed / Door is Closed**

27. How do you usually find the level of noises coming from Mechanical systems in the OFFICE (such as HVAC, ventilation…):

A. **Very noisy**

B. **Noisy**

C. **Neutral**

D. **Calm**

E. **Very Calm**

28. How do you find the level of noises coming from other PEOPLE talking in YOUR OFFICE (EX: FYP meeting, office hours, etc.):

A. **Very noisy**

B. **Noisy**
C. **Neutral**
D. **Calm**
E. **Very Calm**

<u>VISUAL COMFORT</u>

Now let's focus on the brightness and visual comfort in the room

29. How satisfied are you with the VISUAL COMFORT (brightness) in the OFFICE:
    A. **Very Dissatisfied**
    B. **Dissatisfied**
    C. **Neutral**
    D. **Satisfied**
    E. **Very Satisfied**
30. How satisfied are you with the level of control over lighting in the OFFICE:
    A. **Very Dissatisfied**
    B. **Dissatisfied**
    C. **Neutral**
    D. **Satisfied**
    E. **Very Satisfied**
31. How satisfied are you with the amount of light in the room (Daylight + Electric)?
    A. **Very Dissatisfied**
    B. **Dissatisfied**
    C. **Neutral**
    D. **Satisfied**
    E. **Very Satisfied**
32. How satisfied are you with the level of glare/reflection on the PC screen?
    A. **Very Dissatisfied**
    B. **Dissatisfied**
    C. **Neutral**
    D. **Satisfied**
    E. **Very Satisfied**

33. During THE TIME SPENT AT THE OFFICE & regarding visual comfort, would you prefer if:

A. **Shades Open & Lights OFF**

B. **Shades Open & Lights ON**

C. **Shades Closed & Lights ON**

D. **Shades Closed & Lights OFF**

<u>APPEARANCE & LAYOUT</u>

Now let's focus on the physical appearance & layout of the room

34. How satisfied are you with the Aesthetics of the OFFICE:

A. **Very Dissatisfied**

B. **Dissatisfied**

C. **Neutral**

D. **Satisfied**

E. **Very Satisfied**

35. How satisfied are you with the cleanliness of the OFFICE:

A. **Very Dissatisfied**

B. **Dissatisfied**

C. **Neutral**

D. **Satisfied**

E. **Very Satisfied**

36. WHEN THERE ARE SEVERAL PEOPLE IN YOUR OFFICE, how satisfied are you with the distance between you AND THEM:

A. **Very Dissatisfied**

B. **Dissatisfied**

C. **Neutral**

D. **Satisfied**

E. **Very Satisfied**

37. Do you find your seats in the OFFICE:

A. **Very Uncomfortable**

B. **Uncomfortable**

C. **Neutral**

D. **Comfortable**

E. **Very Comfortable**

38. How satisfied are you with the LOCATION AND ORIENTATION of the SCREEN in the OFFICE:

A. **Very Dissatisfied**

B. **Dissatisfied**

C. **Neutral**

D. **Satisfied**

E. **Very Satisfied**

APPENDIX B

SEM RESULTS DETAILS

Table 11 – Initial Structural Equation Model results

Number of observations	207					
Fit indices (robust):						
Minimum Function Test Statistic	469.840					
Degrees of freedom	237					
P-value (Chi-square)	0.000					
Comparative Fit Index (CFI)	0.887					
Tucker-Lewis Index (TLI)	0.868					
RMSEA	0.069					
SRMR	0.090					
Measurement Model:						
	Estimate	Std.Err	z-value	P(>|z|)	Std.lv	Std.all
OVERALL =~						
Q1	0.332	0.118	2.825	0.005	0.413	0.413
Q2	0.464	0.142	3.278	0.001	0.578	0.578
Q4	0.587	0.180	3.263	0.001	0.731	0.731
IAQ =~						
Q19	0.902	0.026	35.038	0.000	0.902	0.902
Q20	0.809	0.035	23.015	0.000	0.809	0.809
Q21	0.719	0.042	17.292	0.000	0.719	0.719
Q22	0.735	0.039	18.885	0.000	0.735	0.735
VISUAL =~						
Q29	0.592	0.057	10.348	0.000	0.592	0.592
Q30	0.685	0.049	13.971	0.000	0.685	0.685
Q31	0.818	0.052	15.669	0.000	0.818	0.818
Q32	0.510	0.065	7.857	0.000	0.510	0.510
ACOUSTIC =~						
Q24	0.654	0.058	11.224	0.000	0.654	0.654
Q25	0.489	0.070	7.025	0.000	0.489	0.489
Q27	0.597	0.063	9.479	0.000	0.597	0.597
Q28	0.259	0.080	3.232	0.001	0.259	0.259
THERMAL =~						
Q13	0.717	0.055	13.041	0.000	0.717	0.717
Q14	0.864	0.048	18.000	0.000	0.864	0.864
Q15	0.711	0.060	11.910	0.000	0.711	0.711
Q17	0.809	0.036	22.543	0.000	0.809	0.809
APPEARANCE =~						
Q34	0.514	0.061	8.427	0.000	0.514	0.514
Q35	0.539	0.058	9.331	0.000	0.539	0.539

Q36	0.374	0.065	5.717	0.000	0.374	0.374
Q37	0.292	0.061	4.775	0.000	0.292	0.292
Q38	0.399	0.059	6.742	0.000	0.399	0.399

Structural Model :

	Estimate	Std.Err	z-value	P(>|z|)	Std.lv	Std.all
OVERALL ~						
IAQ	1.286	0.791	1.627	0.104	1.033	1.033
VISUAL	0.522	0.845	0.618	0.537	0.419	0.419
ACOUSTIC	1.358	0.838	1.621	0.105	1.090	1.090
THERMAL	0.149	0.235	0.635	0.526	0.120	0.120
APPEARANCE	-1.612	1.948	-0.828	0.408	-1.295	-1.295

Covariances:

	Estimate	Std.Err	z-value	P(>|z|)	Std.lv	Std.all
IAQ ~~						
VISUAL	0.164	0.075	2.191	0.028	0.164	0.164
ACOUSTIC	0.393	0.077	5.114	0.000	0.393	0.393
THERMAL	0.227	0.073	3.103	0.002	0.227	0.227
APPEARANCE	0.732	0.066	11.022	0.000	0.732	0.732
VISUAL ~~						
ACOUSTIC	0.469	0.080	5.867	0.000	0.469	0.469
THERMAL	0.108	0.088	1.227	0.220	0.108	0.108
APPEARANCE	0.732	0.077	9.453	0.000	0.732	0.732
ACOUSTIC ~~						
THERMAL	0.370	0.090	4.099	0.000	0.370	0.370
APPEARANCE	0.897	0.086	10.406	0.000	0.897	0.897
THERMAL ~~						
APPEARANCE	0.331	0.097	3.401	0.001	0.331	0.331

Thresholds:

	Estimate	Std.Err	z-value	P(>|z|)	Std.lv	Std.all
Q1|t1	-1.124	0.111	-10.160	0.000	-1.124	-1.124
Q1|t2	-0.238	0.088	-2.702	0.007	-0.238	-0.238
Q1|t3	0.671	0.095	7.071	0.000	0.671	0.671
Q1|t4	1.767	0.160	11.023	0.000	1.767	1.767
Q2|t1	-1.102	0.110	-10.053	0.000	-1.102	-1.102
Q2|t2	0.030	0.087	0.347	0.729	0.030	0.030
Q2|t3	0.781	0.098	7.992	0.000	0.781	0.781
Q2|t4	1.827	0.168	10.900	0.000	1.827	1.827
Q4|t1	-0.781	0.098	-7.992	0.000	-0.781	-0.781
Q4|t2	-0.103	0.087	-1.179	0.239	-0.103	-0.103
Q4|t3	0.831	0.099	8.378	0.000	0.831	0.831
Q4|t4	1.827	0.168	10.900	0.000	1.827	1.827
Q19|t1	-0.798	0.098	-8.121	0.000	-0.798	-0.798
Q19|t2	-0.006	0.087	-0.069	0.945	-0.006	-0.006
Q19|t3	0.884	0.101	8.757	0.000	0.884	0.884

Q19|t4	1.896	0.177	10.726	0.000	1.896	1.896
Q20|t1	-0.656	0.094	-6.938	0.000	-0.656	-0.656
Q20|t2	0.417	0.090	4.631	0.000	0.417	0.417
Q20|t3	1.391	0.126	11.026	0.000	1.391	1.391
Q20|t4	2.588	0.344	7.512	0.000	2.588	2.588
Q21|t1	-0.611	0.094	-6.536	0.000	-0.611	-0.611
Q21|t2	0.251	0.088	2.840	0.005	0.251	0.251
Q21|t3	1.080	0.109	9.944	0.000	1.080	1.080
Q22|t1	-0.939	0.103	-9.128	0.000	-0.939	-0.939
Q22|t2	-0.251	0.088	-2.840	0.005	-0.251	-0.251
Q22|t3	0.733	0.096	7.600	0.000	0.733	0.733
Q22|t4	1.975	0.188	10.482	0.000	1.975	1.975
Q29|t1	-1.360	0.124	-10.963	0.000	-1.360	-1.360
Q29|t2	-0.597	0.093	-6.401	0.000	-0.597	-0.597
Q29|t3	0.042	0.087	0.485	0.627	0.042	0.042
Q29|t4	1.360	0.124	10.963	0.000	1.360	1.360
Q30|t1	-1.171	0.113	-10.365	0.000	-1.171	-1.171
Q30|t2	-0.485	0.091	-5.316	0.000	-0.485	-0.485
Q30|t3	0.431	0.090	4.768	0.000	0.431	0.431
Q30|t4	1.458	0.131	11.127	0.000	1.458	1.458
Q31|t1	-1.572	0.140	-11.195	0.000	-1.572	-1.572
Q31|t2	-0.866	0.100	-8.632	0.000	-0.866	-0.866
Q31|t3	-0.030	0.087	-0.347	0.729	-0.030	-0.030
Q31|t4	1.458	0.131	11.127	0.000	1.458	1.458
Q32|t1	-0.902	0.102	-8.882	0.000	-0.902	-0.902
Q32|t2	-0.006	0.087	-0.069	0.945	-0.006	-0.006
Q32|t3	0.671	0.095	7.071	0.000	0.671	0.671
Q32|t4	1.712	0.154	11.106	0.000	1.712	1.712
Q24|t1	-0.765	0.097	-7.862	0.000	-0.765	-0.765
Q24|t2	-0.176	0.088	-2.010	0.044	-0.176	-0.176
Q24|t3	0.597	0.093	6.401	0.000	0.597	0.597
Q24|t4	2.068	0.204	10.139	0.000	2.068	2.068
Q25|t1	-0.958	0.104	-9.249	0.000	-0.958	-0.958
Q25|t2	-0.127	0.088	-1.456	0.145	-0.127	-0.127
Q25|t3	0.656	0.094	6.938	0.000	0.656	0.656
Q25|t4	1.827	0.168	10.900	0.000	1.827	1.827
Q27|t1	-0.526	0.092	-5.724	0.000	-0.526	-0.526
Q27|t2	0.352	0.089	3.944	0.000	0.352	0.352
Q27|t3	0.920	0.102	9.005	0.000	0.920	0.920
Q27|t4	1.712	0.154	11.106	0.000	1.712	1.712
Q28|t1	-0.814	0.099	-8.250	0.000	-0.814	-0.814
Q28|t2	-0.067	0.087	-0.763	0.446	-0.067	-0.067
Q28|t3	0.671	0.095	7.071	0.000	0.671	0.671
Q28|t4	1.247	0.117	10.649	0.000	1.247	1.247
Q13|t1	-0.431	0.090	-4.768	0.000	-0.431	-0.431
Q13|t2	0.391	0.090	4.357	0.000	0.391	0.391
Q13|t3	1.171	0.113	10.365	0.000	1.171	1.171
Q14|t1	0.391	0.090	4.357	0.000	0.391	0.391
Q14|t2	0.977	0.104	9.369	0.000	0.977	0.977
Q14|t3	1.827	0.168	10.900	0.000	1.827	1.827
Q14|t4	2.339	0.264	8.877	0.000	2.339	2.339

Q15|t1	-0.431	0.090	-4.768	0.000	-0.431	-0.431
Q15|t2	0.152	0.088	1.733	0.083	0.152	0.152
Q17|t1	0.417	0.090	4.631	0.000	0.417	0.417
Q17|t2	0.814	0.099	8.250	0.000	0.814	0.814
Q34|t1	-0.365	0.089	-4.082	0.000	-0.365	-0.365
Q34|t2	0.115	0.088	1.317	0.188	0.115	0.115
Q34|t3	1.196	0.114	10.464	0.000	1.196	1.196
Q34|t4	1.767	0.160	11.023	0.000	1.767	1.767
Q35|t1	-1.247	0.117	-10.649	0.000	-1.247	-1.247
Q35|t2	-0.814	0.099	-8.250	0.000	-0.814	-0.814
Q35|t3	-0.042	0.087	-0.485	0.627	-0.042	-0.042
Q35|t4	1.058	0.108	9.833	0.000	1.058	1.058
Q36|t1	-1.017	0.106	-9.604	0.000	-1.017	-1.017
Q36|t2	-0.226	0.088	-2.563	0.010	-0.226	-0.226
Q36|t3	0.339	0.089	3.806	0.000	0.339	0.339
Q36|t4	1.124	0.111	10.160	0.000	1.124	1.124
Q37|t1	-0.457	0.091	-5.042	0.000	-0.457	-0.457
Q37|t2	0.365	0.089	4.082	0.000	0.365	0.365
Q37|t3	0.902	0.102	8.882	0.000	0.902	0.902
Q37|t4	2.068	0.204	10.139	0.000	2.068	2.068
Q38|t1	-1.247	0.117	-10.649	0.000	-1.247	-1.247
Q38|t2	-0.471	0.091	-5.179	0.000	-0.471	-0.471
Q38|t3	0.226	0.088	2.563	0.010	0.226	0.226
Q38|t4	1.360	0.124	10.963	0.000	1.360	1.360

Variances:

	Estimate	Std.Err	z-value	P(>|z|)	Std.lv	Std.all
.Q1	0.829				0.829	0.829
.Q2	0.666				0.666	0.666
.Q4	0.466				0.466	0.466
.Q19	0.187				0.187	0.187
.Q20	0.345				0.345	0.345
.Q21	0.483				0.483	0.483
.Q22	0.460				0.460	0.460
.Q29	0.649				0.649	0.649
.Q30	0.530				0.530	0.530
.Q31	0.330				0.330	0.330
.Q32	0.740				0.740	0.740
.Q24	0.572				0.572	0.572
.Q25	0.761				0.761	0.761
.Q27	0.643				0.643	0.643
.Q28	0.933				0.933	0.933
.Q13	0.486				0.486	0.486
.Q14	0.254				0.254	0.254
.Q15	0.495				0.495	0.495
.Q17	0.346				0.346	0.346
.Q34	0.736				0.736	0.736
.Q35	0.710				0.710	0.710
.Q36	0.860				0.860	0.860
.Q37	0.915				0.915	0.915

.Q38	0.841	0.841	0.841
.OVERALL	1.000	0.645	0.645
IAQ	1.000	1.000	1.000
VISUAL	1.000	1.000	1.000
ACOUSTIC	1.000	1.000	1.000
THERMAL	1.000	1.000	1.000
APPEARANCE	1.000	1.000	1.000

R-Square:

	Estimate
Q1	0.171
Q2	0.334
Q4	0.534
Q19	0.813
Q20	0.655
Q21	0.517
Q22	0.540
Q29	0.351
Q30	0.470
Q31	0.670
Q32	0.260
Q24	0.428
Q25	0.239
Q27	0.357
Q28	0.067
Q13	0.514
Q14	0.746
Q15	0.505
Q17	0.654
Q34	0.264
Q35	0.290
Q36	0.140
Q37	0.085
Q38	0.159
OVERALL	0.355

Table 12 - Structural Equation Model without Appearance results

Number of observations	207
Fit indices (robust):	
Minimum Function Test Statistic	256.912
Degrees of freedom	142
P-value (Chi-square)	0.000
Comparative Fit Index (CFI)	0.936
Tucker-Lewis Index (TLI)	0.923

RMSEA	0.063
SRMR	0.081

Measurement Model:

	Estimate	Std.Err	z-value	P(>|z|)	Std.lv	Std.all
OVERALL =~						
Q1	0.263	0.052	5.030	0.000	0.384	0.384
Q2	0.401	0.059	6.781	0.000	0.585	0.585
Q4	0.512	0.077	6.601	0.000	0.745	0.745
IAQ =~						
Q19	0.902	0.027	33.609	0.000	0.902	0.902
Q20	0.816	0.036	22.604	0.000	0.816	0.816
Q21	0.735	0.041	18.112	0.000	0.735	0.735
Q22	0.711	0.040	17.798	0.000	0.711	0.711
VISUAL =~						
Q29	0.614	0.055	11.192	0.000	0.614	0.614
Q30	0.677	0.048	14.141	0.000	0.677	0.677
Q31	0.820	0.055	14.917	0.000	0.820	0.820
Q32	0.492	0.063	7.833	0.000	0.492	0.492
ACOUSTIC =~						
Q24	0.659	0.066	10.034	0.000	0.659	0.659
Q25	0.469	0.073	6.405	0.000	0.469	0.469
Q27	0.614	0.068	9.083	0.000	0.614	0.614
Q28	0.253	0.086	2.938	0.003	0.253	0.253
THERMAL =~						
Q13	0.715	0.053	13.472	0.000	0.715	0.715
Q14	0.867	0.046	18.702	0.000	0.867	0.867
Q15	0.703	0.058	12.185	0.000	0.703	0.703
Q17	0.810	0.033	24.535	0.000	0.810	0.810

Structural Model :

	Estimate	Std.Err	z-value	P(>|z|)	Std.lv	Std.all
OVERALL ~						
IAQ	0.650	0.158	4.128	0.000	0.446	0.446
VISUAL	-0.159	0.168	-0.946	0.344	-0.109	-0.109
ACOUSTIC	0.573	0.213	2.690	0.007	0.393	0.393
THERMAL	0.198	0.140	1.409	0.159	0.136	0.136

Covariances:

	Estimate	Std.Err	z-value	P(>|z|)	Std.lv	Std.all
IAQ ~~						
VISUAL	0.165	0.075	2.199	0.028	0.165	0.165
ACOUSTIC	0.391	0.077	5.073	0.000	0.391	0.391
THERMAL	0.229	0.073	3.127	0.002	0.229	0.229
VISUAL ~~						
ACOUSTIC	0.467	0.080	5.842	0.000	0.467	0.467
THERMAL	0.108	0.089	1.218	0.223	0.108	0.108
ACOUSTIC ~~						
THERMAL	0.369	0.090	4.084	0.000	0.369	0.369

Thresholds:

	Estimate	Std.Err	z-value	P(>|z|)	Std.lv	Std.all
Q1|t1	-1.124	0.111	-10.160	0.000	-1.124	-1.124
Q1|t2	-0.238	0.088	-2.702	0.007	-0.238	-0.238
Q1|t3	0.671	0.095	7.071	0.000	0.671	0.671
Q1|t4	1.767	0.160	11.023	0.000	1.767	1.767
Q2|t1	-1.102	0.110	-10.053	0.000	-1.102	-1.102
Q2|t2	0.030	0.087	0.347	0.729	0.030	0.030
Q2|t3	0.781	0.098	7.992	0.000	0.781	0.781
Q2|t4	1.827	0.168	10.900	0.000	1.827	1.827
Q4|t1	-0.781	0.098	-7.992	0.000	-0.781	-0.781
Q4|t2	-0.103	0.087	-1.179	0.239	-0.103	-0.103
Q4|t3	0.831	0.099	8.378	0.000	0.831	0.831
Q4|t4	1.827	0.168	10.900	0.000	1.827	1.827
Q19|t1	-0.798	0.098	-8.121	0.000	-0.798	-0.798
Q19|t2	-0.006	0.087	-0.069	0.945	-0.006	-0.006
Q19|t3	0.884	0.101	8.757	0.000	0.884	0.884
Q19|t4	1.896	0.177	10.726	0.000	1.896	1.896
Q20|t1	-0.656	0.094	-6.938	0.000	-0.656	-0.656
Q20|t2	0.417	0.090	4.631	0.000	0.417	0.417
Q20|t3	1.391	0.126	11.026	0.000	1.391	1.391
Q20|t4	2.588	0.344	7.512	0.000	2.588	2.588
Q21|t1	-0.611	0.094	-6.536	0.000	-0.611	-0.611
Q21|t2	0.251	0.088	2.840	0.005	0.251	0.251
Q21|t3	1.080	0.109	9.944	0.000	1.080	1.080
Q22|t1	-0.939	0.103	-9.128	0.000	-0.939	-0.939
Q22|t2	-0.251	0.088	-2.840	0.005	-0.251	-0.251
Q22|t3	0.733	0.096	7.600	0.000	0.733	0.733
Q22|t4	1.975	0.188	10.482	0.000	1.975	1.975
Q29|t1	-1.360	0.124	-10.963	0.000	-1.360	-1.360
Q29|t2	-0.597	0.093	-6.401	0.000	-0.597	-0.597
Q29|t3	0.042	0.087	0.485	0.627	0.042	0.042
Q29|t4	1.360	0.124	10.963	0.000	1.360	1.360
Q30|t1	-1.171	0.113	-10.365	0.000	-1.171	-1.171
Q30|t2	-0.485	0.091	-5.316	0.000	-0.485	-0.485
Q30|t3	0.431	0.090	4.768	0.000	0.431	0.431
Q30|t4	1.458	0.131	11.127	0.000	1.458	1.458
Q31|t1	-1.572	0.140	-11.195	0.000	-1.572	-1.572
Q31|t2	-0.866	0.100	-8.632	0.000	-0.866	-0.866
Q31|t3	-0.030	0.087	-0.347	0.729	-0.030	-0.030
Q31|t4	1.458	0.131	11.127	0.000	1.458	1.458
Q32|t1	-0.902	0.102	-8.882	0.000	-0.902	-0.902
Q32|t2	-0.006	0.087	-0.069	0.945	-0.006	-0.006
Q32|t3	0.671	0.095	7.071	0.000	0.671	0.671
Q32|t4	1.712	0.154	11.106	0.000	1.712	1.712
Q24|t1	-0.765	0.097	-7.862	0.000	-0.765	-0.765
Q24|t2	-0.176	0.088	-2.010	0.044	-0.176	-0.176
Q24|t3	0.597	0.093	6.401	0.000	0.597	0.597
Q24|t4	2.068	0.204	10.139	0.000	2.068	2.068
Q25|t1	-0.958	0.104	-9.249	0.000	-0.958	-0.958

Q25|t2	-0.127	0.088	-1.456	0.145	-0.127	-0.127
Q25|t3	0.656	0.094	6.938	0.000	0.656	0.656
Q25|t4	1.827	0.168	10.900	0.000	1.827	1.827
Q27|t1	-0.526	0.092	-5.724	0.000	-0.526	-0.526
Q27|t2	0.352	0.089	3.944	0.000	0.352	0.352
Q27|t3	0.920	0.102	9.005	0.000	0.920	0.920
Q27|t4	1.712	0.154	11.106	0.000	1.712	1.712
Q28|t1	-0.814	0.099	-8.250	0.000	-0.814	-0.814
Q28|t2	-0.067	0.087	-0.763	0.446	-0.067	-0.067
Q28|t3	0.671	0.095	7.071	0.000	0.671	0.671
Q28|t4	1.247	0.117	10.649	0.000	1.247	1.247
Q13|t1	-0.431	0.090	-4.768	0.000	-0.431	-0.431
Q13|t2	0.391	0.090	4.357	0.000	0.391	0.391
Q13|t3	1.171	0.113	10.365	0.000	1.171	1.171
Q14|t1	0.391	0.090	4.357	0.000	0.391	0.391
Q14|t2	0.977	0.104	9.369	0.000	0.977	0.977
Q14|t3	1.827	0.168	10.900	0.000	1.827	1.827
Q14|t4	2.339	0.264	8.877	0.000	2.339	2.339
Q15|t1	-0.431	0.090	-4.768	0.000	-0.431	-0.431
Q15|t2	0.152	0.088	1.733	0.083	0.152	0.152
Q17|t1	0.417	0.090	4.631	0.000	0.417	0.417
Q17|t2	0.814	0.099	8.250	0.000	0.814	0.814

Variances:

	Estimate	Std.Err	z-value	P(>|z|)	Std.lv	Std.all
.Q1	0.853				0.853	0.853
.Q2	0.658				0.658	0.658
.Q4	0.444				0.444	0.444
.Q19	0.186				0.186	0.186
.Q20	0.335				0.335	0.335
.Q21	0.459				0.459	0.459
.Q22	0.495				0.495	0.495
.Q29	0.623				0.623	0.623
.Q30	0.542				0.542	0.542
.Q31	0.328				0.328	0.328
.Q32	0.758				0.758	0.758
.Q24	0.566				0.566	0.566
.Q25	0.780				0.780	0.780
.Q27	0.623				0.623	0.623
.Q28	0.936				0.936	0.936
.Q13	0.489				0.489	0.489
.Q14	0.249				0.249	0.249
.Q15	0.506				0.506	0.506
.Q17	0.343				0.343	0.343
.OVERALL	1.000				0.471	0.471
IAQ	1.000				1.000	1.000
VISUAL	1.000				1.000	1.000
ACOUSTIC	1.000				1.000	1.000
THERMAL	1.000				1.000	1.000

R-Square:

	Estimate
Q1	0.147
Q2	0.342
Q4	0.556
Q19	0.814
Q20	0.665
Q21	0.541
Q22	0.505
Q29	0.377
Q30	0.458
Q31	0.672
Q32	0.242
Q24	0.434
Q25	0.220
Q27	0.377
Q28	0.064
Q13	0.511
Q14	0.751
Q15	0.494
Q17	0.657
OVERALL	0.529

Table 13 – Final Structural Equation Model results

Number of observations	207					
Fit indices (robust):						
Minimum Function Test Statistic	185.961					
Degrees of freedom	84					
P-value (Chi-square)	0.000					
Comparative Fit Index (CFI)	0.938					
Tucker-Lewis Index (TLI)	0.922					
RMSEA	0.077					
SRMR	0.085					
Measurement Model:						
	Estimate	Std.Err	z-value	P(>|z|)	Std.lv	Std.all
OVERALL =~						
Q1	0.263	0.053	4.941	0.000	0.381	0.381
Q2	0.412	0.060	6.867	0.000	0.596	0.596
Q4	0.509	0.078	6.545	0.000	0.737	0.737
IAQ =~						
Q19	0.904	0.027	33.976	0.000	0.904	0.904
Q20	0.813	0.036	22.440	0.000	0.813	0.813
Q21	0.738	0.040	18.238	0.000	0.738	0.738
Q22	0.709	0.040	17.760	0.000	0.709	0.709

	Estimate	Std.Err	z-value	P(>|z|)	Std.lv	Std.all
ACOUSTIC =~						
Q24	0.669	0.076	8.814	0.000	0.669	0.669
Q25	0.497	0.080	6.239	0.000	0.497	0.497
Q27	0.583	0.076	7.684	0.000	0.583	0.583
Q28	0.243	0.089	2.722	0.006	0.243	0.243
THERMAL =~						
Q13	0.723	0.053	13.732	0.000	0.723	0.723
Q14	0.869	0.045	19.152	0.000	0.869	0.869
Q15	0.697	0.057	12.122	0.000	0.697	0.697
Q17	0.806	0.032	25.532	0.000	0.806	0.806

Structural Model :

	Estimate	Std.Err	z-value	P(>|z|)	Std.lv	Std.all
OVERALL ~						
IAQ	0.650	0.161	4.031	0.000	0.449	0.449
ACOUSTIC	0.493	0.171	2.881	0.004	0.341	0.341
THERMAL	0.206	0.139	1.483	0.138	0.142	0.142

Covariances:

	Estimate	Std.Err	z-value	P(>|z|)	Std.lv	Std.all
IAQ ~~						
ACOUSTIC	0.389	0.077	5.059	0.000	0.389	0.389
THERMAL	0.229	0.073	3.137	0.002	0.229	0.229
ACOUSTIC ~~						
THERMAL	0.370	0.090	4.104	0.000	0.370	0.370

Thresholds:

	Estimate	Std.Err	z-value	P(>|z|)	Std.lv	Std.all
Q1|t1	-1.124	0.111	-10.160	0.000	-1.124	-1.124
Q1|t2	-0.238	0.088	-2.702	0.007	-0.238	-0.238
Q1|t3	0.671	0.095	7.071	0.000	0.671	0.671
Q1|t4	1.767	0.160	11.023	0.000	1.767	1.767
Q2|t1	-1.102	0.110	-10.053	0.000	-1.102	-1.102
Q2|t2	0.030	0.087	0.347	0.729	0.030	0.030
Q2|t3	0.781	0.098	7.992	0.000	0.781	0.781
Q2|t4	1.827	0.168	10.900	0.000	1.827	1.827
Q4|t1	-0.781	0.098	-7.992	0.000	-0.781	-0.781
Q4|t2	-0.103	0.087	-1.179	0.239	-0.103	-0.103
Q4|t3	0.831	0.099	8.378	0.000	0.831	0.831
Q4|t4	1.827	0.168	10.900	0.000	1.827	1.827
Q19|t1	-0.798	0.098	-8.121	0.000	-0.798	-0.798
Q19|t2	-0.006	0.087	-0.069	0.945	-0.006	-0.006
Q19|t3	0.884	0.101	8.757	0.000	0.884	0.884
Q19|t4	1.896	0.177	10.726	0.000	1.896	1.896
Q20|t1	-0.656	0.094	-6.938	0.000	-0.656	-0.656
Q20|t2	0.417	0.090	4.631	0.000	0.417	0.417

Q20|t3	1.391	0.126	11.026	0.000	1.391	1.391
Q20|t4	2.588	0.344	7.512	0.000	2.588	2.588
Q21|t1	-0.611	0.094	-6.536	0.000	-0.611	-0.611
Q21|t2	0.251	0.088	2.840	0.005	0.251	0.251
Q21|t3	1.080	0.109	9.944	0.000	1.080	1.080
Q22|t1	-0.939	0.103	-9.128	0.000	-0.939	-0.939
Q22|t2	-0.251	0.088	-2.840	0.005	-0.251	-0.251
Q22|t3	0.733	0.096	7.600	0.000	0.733	0.733
Q22|t4	1.975	0.188	10.482	0.000	1.975	1.975
Q24|t1	-0.765	0.097	-7.862	0.000	-0.765	-0.765
Q24|t2	-0.176	0.088	-2.010	0.044	-0.176	-0.176
Q24|t3	0.597	0.093	6.401	0.000	0.597	0.597
Q24|t4	2.068	0.204	10.139	0.000	2.068	2.068
Q25|t1	-0.958	0.104	-9.249	0.000	-0.958	-0.958
Q25|t2	-0.127	0.088	-1.456	0.145	-0.127	-0.127
Q25|t3	0.656	0.094	6.938	0.000	0.656	0.656
Q25|t4	1.827	0.168	10.900	0.000	1.827	1.827
Q27|t1	-0.526	0.092	-5.724	0.000	-0.526	-0.526
Q27|t2	0.352	0.089	3.944	0.000	0.352	0.352
Q27|t3	0.920	0.102	9.005	0.000	0.920	0.920
Q27|t4	1.712	0.154	11.106	0.000	1.712	1.712
Q28|t1	-0.814	0.099	-8.250	0.000	-0.814	-0.814
Q28|t2	-0.067	0.087	-0.763	0.446	-0.067	-0.067
Q28|t3	0.671	0.095	7.071	0.000	0.671	0.671
Q28|t4	1.247	0.117	10.649	0.000	1.247	1.247
Q13|t1	-0.431	0.090	-4.768	0.000	-0.431	-0.431
Q13|t2	0.391	0.090	4.357	0.000	0.391	0.391
Q13|t3	1.171	0.113	10.365	0.000	1.171	1.171
Q14|t1	0.391	0.090	4.357	0.000	0.391	0.391
Q14|t2	0.977	0.104	9.369	0.000	0.977	0.977
Q14|t3	1.827	0.168	10.900	0.000	1.827	1.827
Q14|t4	2.339	0.264	8.877	0.000	2.339	2.339
Q15|t1	-0.431	0.090	-4.768	0.000	-0.431	-0.431
Q15|t2	0.152	0.088	1.733	0.083	0.152	0.152
Q17|t1	0.417	0.090	4.631	0.000	0.417	0.417
Q17|t2	0.814	0.099	8.250	0.000	0.814	0.814

Variances:

	Estimate	Std.Err	z-value	P(>|z|)	Std.lv	Std.all
.Q1	0.855				0.855	0.855
.Q2	0.645				0.645	0.645
.Q4	0.457				0.457	0.457
.Q19	0.183				0.183	0.183
.Q20	0.339				0.339	0.339
.Q21	0.455				0.455	0.455
.Q22	0.497				0.497	0.497
.Q24	0.552				0.552	0.552
.Q25	0.753				0.753	0.753
.Q27	0.660				0.660	0.660
.Q28	0.941				0.941	0.941

.Q13	0.477	0.477	0.477
.Q14	0.245	0.245	0.245
.Q15	0.515	0.515	0.515
.Q17	0.350	0.350	0.350
.OVERALL	1.000	0.478	0.478
IAQ	1.000	1.000	1.000
ACOUSTIC	1.000	1.000	1.000
THERMAL	1.000	1.000	1.000

R-Square:

	Estimate
Q1	0.145
Q2	0.355
Q4	0.543
Q19	0.817
Q20	0.661
Q21	0.545
Q22	0.503
Q24	0.448
Q25	0.247
Q27	0.340
Q28	0.059
Q13	0.523
Q14	0.755
Q15	0.485
Q17	0.650
OVERALL	0.522

Table 14 - Final Structural Equation Model with Building type results

Number of observations	207
Fit indices (robust):	
Minimum Function Test Statistic	456.588
Degrees of freedom	112
P-value (Chi-square)	0.000
Comparative Fit Index (CFI)	0.750
Tucker-Lewis Index (TLI)	0.698
RMSEA	0.122
SRMR	0.084

Measurement Model:

	Estimate	Std.Err	z-value	P(>|z|)	Std.lv	Std.all
OVERALL =~						
Q1	0.293	0.060	4.920	0.000	0.452	0.442

	Estimate	Std.Err	z-value	P(>|z|)	Std.lv	Std.all
Q2	0.390	0.064	6.132	0.000	0.601	0.579
Q4	0.516	0.077	6.741	0.000	0.796	0.745
IAQ =~						
Q19	0.872	0.038	23.095	0.000	0.872	0.872
Q20	0.744	0.048	15.430	0.000	0.744	0.744
Q21	0.690	0.049	14.035	0.000	0.690	0.690
Q22	0.602	0.051	11.790	0.000	0.602	0.602
ACOUSTIC =~						
Q24	0.640	0.078	8.156	0.000	0.640	0.640
Q25	0.355	0.086	4.136	0.000	0.355	0.355
Q27	0.660	0.083	7.957	0.000	0.660	0.660
Q28	0.168	0.095	1.767	0.077	0.168	0.168
THERMAL =~						
Q13	0.678	0.058	11.795	0.000	0.678	0.678
Q14	0.879	0.048	18.314	0.000	0.879	0.879
Q15	0.653	0.062	10.464	0.000	0.653	0.653
Q17	0.810	0.035	23.373	0.000	0.810	0.810

Structural Model :

	Estimate	Std.Err	z-value	P(>|z|)	Std.lv	Std.all
OVERALL ~						
IAQ	0.636	0.179	3.543	0.000	0.413	0.413
ACOUSTIC	0.214	0.171	1.248	0.212	0.139	0.139
THERMAL	0.326	0.142	2.293	0.022	0.212	0.212
ARCHI	-1.768	0.427	-4.142	0.000	-1.148	-0.426
BECHTEL	0.238	0.301	0.790	0.430	0.154	0.077

Covariances:

	Estimate	Std.Err	z-value	P(>|z|)	Std.lv	Std.all
IAQ ~~						
ACOUSTIC	0.427	0.075	5.664	0.000	0.427	0.427
THERMAL	0.287	0.077	3.750	0.000	0.287	0.287
ACOUSTIC ~~						
THERMAL	0.422	0.089	4.724	0.000	0.422	0.422

Thresholds:

	Estimate	Std.Err	z-value	P(>|z|)	Std.lv	Std.all
Q1|t1	-0.885	0.149	-5.942	0.000	-0.885	-0.865
Q1|t2	0.054	0.141	0.385	0.700	0.054	0.053
Q1|t3	1.012	0.149	6.806	0.000	1.012	0.990
Q1|t4	2.151	0.191	11.281	0.000	2.151	2.104
Q2|t1	-1.418	0.144	-9.815	0.000	-1.418	-1.365
Q2|t2	-0.163	0.141	-1.152	0.249	-0.163	-0.157
Q2|t3	0.627	0.144	4.358	0.000	0.627	0.603
Q2|t4	1.705	0.199	8.546	0.000	1.705	1.641
Q4|t1	-0.970	0.147	-6.576	0.000	-0.970	-0.908
Q4|t2	-0.263	0.147	-1.790	0.073	-0.263	-0.246

Q4|t3	0.695	0.153	4.552	0.000	0.695	0.651
Q4|t4	1.698	0.195	8.690	0.000	1.698	1.591
Q19|t1	-1.615	0.160	-10.091	0.000	-1.615	-1.615
Q19|t2	-0.722	0.154	-4.685	0.000	-0.722	-0.722
Q19|t3	0.279	0.149	1.876	0.061	0.279	0.279
Q19|t4	1.421	0.207	6.866	0.000	1.421	1.421
Q20|t1	-1.784	0.176	-10.128	0.000	-1.784	-1.784
Q20|t2	-0.504	0.156	-3.226	0.001	-0.504	-0.504
Q20|t3	0.712	0.164	4.329	0.000	0.712	0.712
Q20|t4	2.145	0.397	5.406	0.000	2.145	2.145
Q21|t1	-1.351	0.169	-7.990	0.000	-1.351	-1.351
Q21|t2	-0.415	0.153	-2.719	0.007	-0.415	-0.415
Q21|t3	0.506	0.155	3.261	0.001	0.506	0.506
Q22|t1	-1.741	0.163	-10.670	0.000	-1.741	-1.741
Q22|t2	-0.943	0.161	-5.854	0.000	-0.943	-0.943
Q22|t3	0.164	0.151	1.086	0.277	0.164	0.164
Q22|t4	1.563	0.220	7.117	0.000	1.563	1.563
Q24|t1	-0.738	0.158	-4.660	0.000	-0.738	-0.738
Q24|t2	-0.130	0.149	-0.873	0.383	-0.130	-0.130
Q24|t3	0.656	0.152	4.318	0.000	0.656	0.656
Q24|t4	2.142	0.219	9.764	0.000	2.142	2.142
Q25|t1	-1.091	0.177	-6.175	0.000	-1.091	-1.091
Q25|t2	-0.132	0.153	-0.864	0.388	-0.132	-0.132
Q25|t3	0.724	0.160	4.529	0.000	0.724	0.724
Q25|t4	1.956	0.190	10.282	0.000	1.956	1.956
Q27|t1	-0.344	0.162	-2.124	0.034	-0.344	-0.344
Q27|t2	0.543	0.165	3.289	0.001	0.543	0.543
Q27|t3	1.127	0.179	6.295	0.000	1.127	1.127
Q27|t4	1.936	0.200	9.683	0.000	1.936	1.936
Q28|t1	-0.692	0.161	-4.291	0.000	-0.692	-0.692
Q28|t2	0.101	0.154	0.657	0.511	0.101	0.101
Q28|t3	0.879	0.160	5.476	0.000	0.879	0.879
Q28|t4	1.472	0.175	8.422	0.000	1.472	1.472
Q13|t1	-0.431	0.156	-2.762	0.006	-0.431	-0.431
Q13|t2	0.391	0.154	2.537	0.011	0.391	0.391
Q13|t3	1.171	0.170	6.908	0.000	1.171	1.171
Q14|t1	0.280	0.158	1.771	0.076	0.280	0.280
Q14|t2	0.868	0.160	5.432	0.000	0.868	0.868
Q14|t3	1.724	0.192	8.957	0.000	1.724	1.724
Q14|t4	2.239	0.284	7.873	0.000	2.239	2.239
Q15|t1	-0.504	0.161	-3.118	0.002	-0.504	-0.504
Q15|t2	0.081	0.159	0.511	0.609	0.081	0.081
Q17|t1	0.428	0.170	2.520	0.012	0.428	0.428
Q17|t2	0.827	0.176	4.695	0.000	0.827	0.827

Variances:

	Estimate	Std.Err	z-value	P(>|z|)	Std.lv	Std.all
.Q1	0.841				0.841	0.804
.Q2	0.718				0.718	0.665
.Q4	0.507				0.507	0.445

.Q19	0.239	0.239	0.239
.Q20	0.446	0.446	0.446
.Q21	0.523	0.523	0.523
.Q22	0.637	0.637	0.637
.Q24	0.590	0.590	0.590
.Q25	0.874	0.874	0.874
.Q27	0.564	0.564	0.564
.Q28	0.972	0.972	0.972
.Q13	0.540	0.540	0.540
.Q14	0.227	0.227	0.227
.Q15	0.574	0.574	0.574
.Q17	0.343	0.343	0.343
.OVERALL	1.000	0.421	0.421
IAQ	1.000	1.000	1.000
ACOUSTIC	1.000	1.000	1.000
THERMAL	1.000	1.000	1.000

R-Square:

	Estimate
Q1	0.196
Q2	0.335
Q4	0.555
Q19	0.761
Q20	0.554
Q21	0.477
Q22	0.363
Q24	0.410
Q25	0.126
Q27	0.436
Q28	0.028
Q13	0.460
Q14	0.773
Q15	0.426
Q17	0.657
OVERALL	0.579

APPENDIX C

LAYOUT PLANS OF THE THREE BUILDINGS