Long-Term Indoor Environmental Quality Assessment of a University Sports Facility

By

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DECLARATION

I, Mahboubeh Zamani, declare this document to be my own unaided work, and where published sources are used, they are acknowledged.

ABSTRACT

Providing a healthy and comfortable indoor environment is essential as people spend the majority of their time indoors. While indoor environmental quality includes different aspects, thermal comfort and indoor air quality are two of the most important. Researchers have studied the indoor environmental quality of different types of buildings such as offices or residential buildings, but there has been less focus on sports facilities. The literature also shows that the objective measurements of thermal comfort and indoor air quality usually require costly devices and workforce, and do not provide a long-term picture as they are based on snapshot measurements.

This research aimed to address these gaps through a post-occupancy evaluation of thermal comfort and indoor air quality of a sports facility: The Active Living Centre, certified as a Leadership in Energy and Environmental Design Silver building and located at the Fort Garry campus of the University of Manitoba. The facility's automation systems were used as the data source for objective measurements. Temperature, relative humidity, and carbon dioxide data were extracted from enteliWEB, the studied facility's automation systems application, for the Summer (June and July) and Fall (September and October) 2019. In addition, users of the facility's main fitness area (gym users) and staff were surveyed in July and October to compare their perceptions with actual conditions. A total of 104 and 49 gym users participated in the survey in the Summer and Fall, respectively. Also, eight and seven staff members took part in the survey in the Summer and Fall, respectively.

Although indoor air temperatures were higher in the Fall, gym users were more dissatisfied with the temperature in the Summer. As the mean relative humidity level in the Summer was nearly

14% higher than its Fall value, the higher dissatisfaction rate with temperature in the Summer may have been due to higher relative humidity levels in that season. The majority of users were satisfied with indoor air quality in both seasons. Mean CO_2 levels were 510 ppm and 521 ppm in the Summer and Fall, respectively. The facility, as a green building, was more thermally comfortable in the Fall.

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List of Abbreviations

Air_Smell	The Perception of Indoor Air Smell
Air_Stuffy	The Perception of Indoor Air Stuffiness
Air_Dusty	The Perception of Indoor Air Dustiness
AHU	Air Handling Units
ALC	Active Living Centre
BASs	Building Automation Systems
CBE	Center for the Built Environment
FKC	Frank Kennedy Centre
IAQ	Indoor Air Quality
IAQ_Perform	The Effect of Indoor Air Quality on Participants abilities to Exercise
IEQ	Indoor Environmental Quality
LEED	Leadership in Energy and Environmental Design
PCS	Personal Comfort Systems
PM	Particulate Matter
PMV	Predicted Mean Vote
PPD	Predicted Percentage of Dissatisfied
RH	Relative Humidity
SAT_AirFlow	Satisfaction with Airflow
SAT_IAQ	Satisfaction with Indoor Air Quality
SAT_RH	Satisfaction with Relative Humidity
SAT_T	Satisfaction with Temperature
SAT_TSurf	Satisfaction with the Surface Temperature
T	Temperature
T_Perform	The Effect of Thermal Conditions on Participants abilities to Exercise
T_Pref	Preferred Temperature
T_Sense	Thermal Sensation
AV	Air velocity
MRT	Mean Radiant Temperature

CHAPTER 1: INTRODUCTION

This chapter provides background information about the indoor environmental quality (IEQ) of sports facilities. The chapter also describes the problem that this research aims to address as well as its goal, objectives, scope, and significance.

1.1 Background

Indoor environmental quality (IEQ) has an important impact on occupants' wellbeing (Wolkoff, 2018) and productivity (Kang et al., 2017) as occupants spend a large part of their time indoors. Many factors such as air temperature, relative humidity, air movement, ventilation rate, lighting, noise level, and the concentration of indoor air pollutants influence IEQ. These factors are categorized as thermal comfort, visual comfort, acoustics comfort, and indoor air quality (IAQ), which together determine the level of IEQ in the built environment (Newsham et al., 2013). Thermal comfort and IAQ are the two main IEQ aspects usually investigated in the literature. According to ASHRAE (2013), air temperature (T), relative humidity (RH), mean radiant temperature (MRT), air velocity (AV), clothing insulation, and metabolic rate are the variables that influence thermal comfort, whereas IAQ is usually assessed by measuring ventilation rates and different indoor air pollutants such as particulate matters (PM) (e.g., Alves et al., 2014; Slezakova et al., 2018), bacteria, and fungi (Jung et al., 2019; Varjo et al., 2015).

Ensuring acceptable IEQ is an important sustainable building design principle addressed by relevant organizations such as the U.S. Green Building Council (2019). The American Society of

Heating, Refrigerating, and Air-Conditioning (ASHRAE) emphasizes the importance of meeting IAQ and thermal comfort requirements, as two important aspects of IEQ in the design, construction, and commissioning of buildings (ASHRAE, 2009). These requirements include controlling moisture in building assemblies and mechanical systems, limiting the entry of outdoor contaminants, limiting the emission of contaminants from indoor sources by capturing and exhausting them, and reducing contaminants concentration through ventilation, filtration and air cleaning. The U.S. Green Building Council (2019b) specifies IEQ requirements (including thermal comfort and IAQ design and performance as well as occupants' comfort survey) in Leadership in Energy and Environmental Design (LEED) green buildings. The Leadership in Energy and Environmental Design (LEED) is a green building rating system and certification program developed by the U.S. Green Building Council. Green buildings, also known as sustainable buildings aim to create healthier and more efficient construction, renovation, operation, maintenance, and demolition. In the LEED green building rating system, green buildings are certified as "Certified", "Silver", "Gold" or "Platinum" (the lowest to highest possible rate, respectively) based on the credits achieved in different categories such as Sustainable Site, Transportation and Location, and Indoor Environmental Quality.

Buildings have different IEQ design considerations depending on their types. For example, daylighting in schools and offices can be very beneficial, because it helps raise the visual satisfaction and productivity of occupants (Godish, 2016). Sports facilities require a different indoor environment than that of other buildings such as offices (Andrade & Dominski, 2018; Revel & Arnesano, 2014b). This is because these facilities' users usually have higher metabolic and inhalation rates because of physical exercise. Therefore, they might inhale higher concentrations of carbon dioxide (CO_2) and other indoor air pollutants (Alves et al., 2014; Andrade & Dominski, 2018; Ramos et al., 2015). Ensuring acceptable IAQ levels in ice skating rinks for example requires taking into account the carbon monoxide (CO) and nitrogen dioxide (NO_2) emitted from ice resurfacing machines (Government of Alberta, 2012).

The post-occupancy evaluation of existing buildings involves assessing their actual IEQ (Geng et al., 2017). This is usually done using objective and subjective assessments (Cianfanelli et al., 2016; Revel & Arnesano, 2014b). Objective assessments involve measuring IEQ parameters physically, while subjective assessments are carried out by surveying or interviewing building occupants and asking for their perceptions and preferences. Most researchers like Cianfanelli et al., (2016) and Revel & Arnesano (2014) mainly used snapshot rather than long-term measurements to objectively assess IEQ in sports facilities.

There are two significant drawbacks to the objective assessment of thermal comfort and IAQ: 1) the need for costly equipment and workforce, and 2) the short-term, snapshot nature of measurements usually conducted using this equipment. A viable alternative that addresses these drawbacks is to use the data provided by building automation systems (BASs). BASs are centralized networks of hardware (e.g., data loggers) and software that monitor, record, and control buildings' performance including their mechanical systems' operation (Aparicio-Ruiz et al., 2018).

1.2 Problem Statement, Research Goal, and Objectives

Many studies evaluated IEQ in office (e.g., Geng et al., 2019; Lou & Ou, 2019), school (e.g., Toyinbo et al., 2019; Vilcekova et al., 2017), and residential buildings (e.g., Laskari et al., 2017; Xue et al., 2016), whereas fewer studies (e.g., Cianfanelli et al. (2016) and Revel & Arnesano, (2014a)) investigated them in sports facilities. Moreover, those that evaluated the IEQ of sports facilities focused on sports facilities outside North America. Therefore, there's a lack of empirical evidence on the long-term IEQ of sports facilities in Canada.

The goal of the current research was to evaluate the long-term IEQ of sports facilities in Canada. Specific objectives involved:

1. Developing a method to evaluate the long-term IEQ of these facilities
2. Applying the method to evaluate the long-term objective physical IEQ of these facilities
3. Applying the method to evaluate the subjective perceptions of long-term IEQ of these facilities' users
4. Comparing the results of the objective and subjective evaluations

1.3 Scope

The research focused on evaluating the thermal comfort and IAQ aspects of IEQ in one green sports and recreation facility in the University of Manitoba, Canada: The Active Living Centre (ALC), in the Summer and Fall of 2019. The evaluation took place in the facility's main fitness area, also called "gym", and in its offices. Because of how different those two areas were, two surveys were developed to enable the subjective assessment. One evaluated gym users' satisfaction, perceptions, and preferences with respect to thermal comfort and IAQ in the gym; the other evaluated staff's satisfaction, perceptions, and preferences with respect to thermal comfort and IAQ in the offices. The gym was located on the third floor, while the offices were mostly found on the second floor. The objective assessment involved measuring T and RH as indicators of the facility's thermal comfort, and CO_2 as an indicator of its IAQ. Data were extracted for T, RH, and CO_2 based on the ALC's building automation systems (BASs) records in June, July, September, and October of 2019. Surveys were conducted in July and October of 2019.

1.4 Significance

While many studies investigated the IEQ of offices, schools, and residential buildings, very few (e.g., Alves et al., 2013; Cianfanelli et al., 2016) investigated the IEQ of sports facilities, thus the significance of this research. Moreover, most of the studies that investigated the IEQ of sports facilities, evaluated sports facilities in Europe (e.g., Italy, Portugal, and Spain) as opposed to Canada. This research is the first to address the lack of empirical evidence on the IEQ of sports facilities and gyms in particular, in Canada. Moreover, this is the first research ever conducted to investigate a green sports facility's IEQ.

The research is also the first to show that gym users' IEQ satisfaction changes by season. It is also one of the few studies to look at the long-term seasonal performance of IEQ parameters such as T, RH, and CO_2. The research shows that dissatisfaction with gym temperatures can be due to seasonal changes in RH levels. This is an important finding because of occupants' higher metabolic rates in sports facilities as opposed to other buildings such as offices, and thus the need to provide satisfactory levels of T and RH to them. The research is also one of the few research projects to rely on the raw data provided by BASs to conduct its long-term objective physical IEQ assessment. It does not therefore use moveable physical equipment to conduct snapshot or permanent measurements of IEQ in a specific location. Using data recorded by BASs can be a cost-effective way to evaluate the IEQ of buildings like the ALC. In green buildings, they can help determine whether the actual IEQ conditions meet expected design conditions, based on captured long-term data.

CHAPTER 2: LITERATURE REVIEW

This chapter provides a review of the literature on the IEQ of sports facilities focusing specifically on thermal comfort and IAQ. The first section defines IEQ, its different aspects, and assessment methods. The second section describes sports facilities and what makes them unique. The third section is devoted to a review of the literature on IEQ assessment in sports facilities, including applied methods and investigated parameters. In the fourth section, existing IEQ guidance in sports facilities are reviewed. Lastly, the implementation of BASs, as a data collection method for investigating IEQ is presented.

2.1 Indoor Environmental Quality

Buildings aim to provide a healthy and comfortable environment to their occupants (Sakhare & Ralegaonkar, 2014). Given that people spend 90% of their time indoors, it’s only natural that buildings, and their IEQ in particular, would have an effect on occupants’ well-being (Wolkoff, 2018) and productivity (Kang et al., 2017). IEQ refers to the whole indoor environment of a building and encompasses all physical, chemical, biological, and particle factors existing within it (Toyinbo, 2019). Toyinbo (2019) categorizes temperature, relative humidity, airspeed, lighting, noise, and cleanliness as physical factors, and indoor air pollutants such as CO_2 and NOx (Nitrogen Oxides) as chemical factors. Biological factors include items such as mold, bacteria, and dust mites, while particle factors contain elements like dust, and tobacco smoke (Toyinbo, 2019).

Researchers believe IEQ encompasses four main aspects: thermal comfort, IAQ, lighting comfort, and acoustics (Sakhare & Ralegaonkar. 2014). There are also other aspects to IEQ such as indoor space layout (Kang et al., 2017) that have been studied less in the literature. According to ASHRAE (2013), thermal comfort refers to an individual's subjective level of satisfaction with thermal conditions and is influenced by six main parameters: temperature (T), relative humidity (RH), mean radiant temperature (MRT), air velocity (AV), clothing insulation, and metabolic rate. Predicted Mean Vote (PMV) is a thermal comfort index and is calculated for a large group of people as their mean thermal sensation vote, based on these six parameters (ASHRAE, 2013). An indoor environment is thermally comfortable to its occupants when PMV values are between -0.5 and +0.5 (ASHRAE, 2013). With respect to IAQ, different indoor air pollutants such as PM, Volatile Organic Compounds (VOCs), and CO_2 are measured to determine IAQ (EPA, 2003). Ventilation rates and emissions from indoor resources such as building materials, furniture, and equipment also affect IAQ (Varjo et al., 2015). Although IAQ is only one aspect of IEQ, the terms are sometimes used interchangeably in the literature (Tam & Le, 2019). Lighting comfort is greatly affected by available daylight or natural lighting and is thus usually assessed by measuring the illuminance parameter (Cao et al., 2012; Catalina & Iordache, 2012) or daylight factor (Sadick, 2018). Acoustics comfort is evaluated using parameters such as background noise level, reverberation time, and speech privacy (ASTM, 2019).

Three main methods have been used in the literature to evaluate different aspects of IEQ: 1) the objective measurement of physical IEQ variables (e.g., Andrade & Dominski, 2018; Castro et al., 2015; Majd et al., 2019); 2) the subjective assessment of occupants' satisfaction with IEQ (e.g., Ricciardi & Buratti, 2018); and 3) a mixed approach of both methods (e.g., Revel & Arnesano, 2014b; Zuhaib et al., 2018). Sakhare & Ralegaonkar (2014) identified three main reasons behind the increased number of occupants' IEQ complaints: 1) increased building tightness, 2) the growing use of materials that consume natural resources, and 3) the increase in energy use to achieve indoor comfort. This increased number of IEQ complaints emphasizes the significance of assessing occupants' feedback. Therefore, applying the mixed-method approach that involves both surveying occupants and measuring physical parameters simultaneously will provide a more realistic characterization of IEQ conditions.

2.2 Sports Facilities

Sports and physical exercise are usually performed indoors (Andrade & Dominski, 2018) in sports facilities. Sports facilities are complex buildings that are different than buildings such as offices or homes, due to their specific energy consumption, materials, and comfort requirements (Revel & Arnesano, 2014b). These facilities have different IEQ requirements than office or residential buildings because of the unique activities that take place within them (Andrade & Dominski, 2018; Revel & Arnesano, 2014b). They can be composed of different spaces like stadiums, swimming pools, fitness venues (also called gyms), racquetball and squash courts, and running tracks. Various types of sports and recreational or leisure activities can be carried out in these multi-purpose buildings (Cianfanelli et al., 2016) such as running, swimming, fitness training, and ball games. For instance, the Frank Kennedy Centre (FKC), a three-story sports facility located at the Fort Garry campus of the University of Manitoba, encompasses three gymnasiums, as well as racquetball and squash courts.

2.3 IEQ Assessment of Sports Facilities

Many studies evaluated the IEQ of offices (e.g., Geng et al., 2019; Lou & Ou, 2019), schools (e.g., Toyinbo et al., 2019; Vilcekova et al., 2017), and residential buildings (e.g., Laskari et al., 2017; Xue et al., 2016), whereas fewer studies (e.g., Cianfanelli et al. (2016) and Revel & Arnesano, (2014a) investigated the IEQ of sports facilities. Those that did primarily focused on assessing these facilities' IAQ, with thermal comfort being the second most assessed aspect. Air temperature and relative humidity have been the most frequently investigated thermal comfort parameters in sports facilities (e.g., Revel & Arnesano, 2014b; Ramos et al., 2014), whereas particulate matter has been the most frequently studied indoor air pollutant (e.g., Braniš & Šafránek, 2011; Slezakova et al., 2018). Some studies (Jedovnický & Peter, 2014; Jurak et al., 2015; Lia et al., 2015) assessed acoustics in sports facilities, while no study appears to have investigated lighting comfort. Most (e.g., Alves et al., 2013; Ramos et al., 2014; Slezakova et al., 2018) analyzed IEQ using objective measurements of select parameters. A minority (e.g., Cianfanelli et al., 2016; Revel & Arnesano, 2014a) combined subjective and objective tools together. Surveying users' IEQ perception in a sports facility helps evaluate its livability and usability and helps develop IEQ improvement strategies (Cianfanelli et al., 2016). As a result, subjective and objective IEQ assessment tools in sports facilities should be used concurrently to supplement each other.

The current research aims to investigate the IEQ of a sports facility, focusing on its IAQ and thermal comfort in particular. The following subsection provides a review of relevant studies assessing the IEQ of sports facilities focusing specifically on gyms and fitness areas. The literature review excluded studies investigating specific spaces such as ice rinks, or pools, as they have different indoor conditions than general fitness areas and gyms.

2.3.1 Subjective Assessment

No study appears to have investigated the IEQ of sports facilities by only surveying occupants' IEQ perceptions.

2.3.2 Objective Assessment

IAQ has been the most common IEQ aspect investigated in studies, with PM being the most common IAQ parameter investigated in them (e.g., Braniš & Šafránek, 2011, Alves et al., 2014; Braniš et al., 2009; Buonanno et al., 2012). The majority of studies were published after 2010, none were conducted in Canada, but mostly in Europe.

2.3.2.1 Indoor Air Quality

Stathopoulou et al. (2008) investigated IAQ in relation to outdoor air quality in two large athletic halls in Greece, in 2002. The first hall was mechanically ventilated daily, whilst the HVAC systems in the second hall were operated only on the event days with a mixing ratio of 20.0% fresh air, and thus categorized as naturally ventilated by the authors. Nitrogen oxide (NO), NO_2, sulfur dioxide (SO_2), and O_3 were measured at the arenas and spectators' seat levels (i.e., 20.0 m above the arena level), simultaneously, and in the immediate outdoors. Fifteen-minute average logging values were recorded in the arenas, while average concentrations were recorded in a path length of 100.0 m with 3-minute intervals in the spectators' seat level. Also, outdoor air pollutants including PM_{10} and CO were measured using a mobile monitoring station with the same logging conditions applied in the arenas. In both halls, the Indoor/Outdoor (I/O) concentration ratio of NO and NO_2 was above

1.0, denoting possible indoor sources. The study concluded that pollutants' stratification during the events was more intense and stable in the naturally ventilated hall, and outdoor pollution significantly affected IAQ of both halls, depending on ventilation type. Moreover, the physical openings' location of buildings, indoor materials, and activities were influencing factors. Although the study conducted comprehensive measurements of indoor parameters in different locations and height levels and measured outdoor parameters as well, it covered only one season (the Winter), and thus did not include seasonal changes in the IAQ analysis.

In another study, Braniš & Šafránek (2011) investigated PM (i.e., $PM_{10\text{-}2.5}$ and $PM_{2.5\text{-}1.0}$) concentrations and compositions children could be exposed to during scheduled physical education in three naturally ventilated elementary school gyms. The schools were located in three different zones of high-traffic, mild-traffic, and rural areas, in the Czech Republic. The samplings were carried out through 20 campaigns, each consisted of 7 to 11 days, from November 2005 to August 2009. In each sampling, a 24-hour mass concentration was measured by a cascade impactor (i.e., a device used to collect samples of particulate substances). The study revealed high concentrations of coarse PM, with the mean weekday I/O ratio of 13.6, 24.9, and 26.7 $\mu g/m^3$ in schools 1 to 3. While outdoor concentrations had no serious contribution to indoor PM levels, occupancy rates and hours spent in the gyms affected PM levels. The coarse and quasi-coarse PM concentrations were higher during occupied days (i.e., school days vs the weekend and holidays). The measurement campaign in school 1 consisted of 89 days, almost twice that of school 2, and school 3 with around 45 days. This uneven distribution of collected data could affect the results. Moreover, a bigger sample size of schools would enrich the strength of the statistical analysis.

A more recent study by Slezakova et al. (2018), measured indoor PM_{10}, $PM_{2.5}$, and ultrafine particulates in four fitness centers (FC1- FC4), in Portugal. The study was conducted over 40 successive days between May to June 2014, to estimate the health risks for staff and users. In addition to a general fitness area in all four centers, FC1 & FC2 contained one classroom and FC3 & FC4 encompassed three studios, devoted to group activities. Continuous measurements were conducted in the general fitness areas, studios, and classrooms, for 24-hour periods with 1-minute logging intervals during the whole week. Also, indoor T and RH levels were measured, and outdoor PM and meteorological data were obtained from local monitoring stations. Maxima daily concentrations were concurrent with the highest attendance rates in the fitness gyms. According to Portuguese legislation (i.e., Portaria n. 353-A/2013, 2013), median PM_{10} levels were lower than the 50.0 $\mu g/m^3$ limit, whereas the median $PM_{2.5}$ surpassed the limit of 25.0 $\mu g/m^3$. Correlation coefficients between ultrafine particulates, T, and RH were statistically significant with low strength and different orientations (i.e., positive versus negative correlations) across the four centers. This study was conducted in only one season, the Summer, and did not cover seasonal variations. Also, the referred standard has been established for commercial and service buildings in general, rather than sports facilities specifically.

A bigger sample size of buildings was investigated by Ramos et al. (2014). The authors characterized IAQ in 11 fitness centers in Portugal, in October 2012. Of the 11 buildings, one was naturally ventilated, two had mixed ventilation systems (i.e., both mechanical and natural), and the remaining were mechanically ventilated. Ramos et al. (2014) measured pollutants including PM_{10}, $PM_{2.5}$, CO, and CO_2, as well as T and RH (in relation to IAQ, rather than a thermal comfort parameter) during the late afternoon and night hours to capture more occupied periods. Outdoor

CO_2, CO, and PM_{10} were also measured. The snapshot measurements were conducted for 60 minutes in the bodybuilding rooms and 45 to 60 minutes in fitness class studios. Three centers were selected for a more detailed study in which a combination of snapshot and continuous measurements was used. High concentrations of CO_2, exceeded the national limit values defined by Portuguese legislation (i.e., Portaria n. 353-A/2013, 2013), whereas CO levels were lower than the limits. The authors reported CO_2 levels between 1,116 ppm to 4,418 ppm, RH levels between 19.0% to 86.0%, and T levels between 15.0 ℃ to 25.0 ℃. The measurements showed increased particulates levels during the occupied hours. This reinforced the need to optimize the HVAC systems, ventilation rates, and occupants' behavior to reduce exposure to air pollutants in fitness centers. The number of buildings investigated in this study is a considerable strength when compared with other studies.

2.3.2.2 Thermal Comfort and IAQ

Alves et al. (2013) investigated comfort and IAQ in one fronton[1] and one gym, at the University of Léon, Spain, in July 2012. They measured T, RH, and CO_2 as the comfort parameters, as well as pollutants like CO, NO_2, and PM_{10} as the IAQ parameters. The gym had no mechanical ventilation and the fronton was ventilated by evenly distributed vents to bring natural fresh air. T, RH, CO_2, and CO were continuously monitored, while NO_2 and PM_{10} were measured by sampling. RH and T levels were between 10.8% and 37.3%, and 20.4 ℃ and 36.6 ℃, respectively. The study concluded that RH levels in both buildings were within the ASHRAE comfort limit (i.e., 30.0% to

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[1] Defined as "a court used as playing area for a variant of paddleball games".

60.0%), but frequent high temperatures exceeding 30.0 ℃ in the daytime made the gym thermally uncomfortable. CO_2 levels ranged from 397.0 ppm to 787.0 ppm, not exceeding 1000.0 ppm. Higher levels of PM_{10} concentrations were measured in the gym (mainly caused by climbing chalk and its resuspension) compared to the fronton, which were also higher than the acceptable level of 50.0 $\mu g/m^3$ established by WHO (2010). The authors used the term "comfort" rather than "thermal comfort" and classified CO_2 as a "comfort" parameter. The 2-week measurement did not allow for a long-term assessment of these aspects.

2.3.3 Mixed Method

Very few studies used a combination of objective and subjective IEQ measures. This subsection reviews those studies that used a mixed-method approach to evaluate the following IEQ aspects.

2.3.3.1 Thermal Comfort

Revel & Arnesano (2014b) surveyed 120 users of a gym and swimming pool in Italy to enquire about their thermal satisfaction, sensation, and preference. On the other hand, T and RH, MRT, and AV were measured over 10-minute intervals. Data collection in the gym was conducted over four days in the Spring. DeltaLog 10 software was used to calculate the PMV in the gym based on those four measured physical parameters as well as metabolic rate and clothing insulation. Around 40% of gym respondents wanted to see "no change" in air temperatures, nearly 30% preferred the air to be "slightly cooler", and 10% wanted it to be "cooler". Measured T and RH levels in the gym were between 15.4 ℃ to 22.0 ℃, and 49.6% to 73.5%, respectively. Daily mean PMV ranged between 0.6 and 1.1, meaning it was predicted that occupants would perceive air as warm and preferer to have lower temperatures. This was in line with the survey's responses, and the authors perceived this as a “good correlation” between participants’ satisfaction and actual thermal conditions. Despite its strengths, the study should have included more extensive field measurements over longer periods to capture temporal variations of subjective and objective thermal comfort parameters. Furthermore, the survey used in this study did not ask about respondents’ satisfaction with RH: an important factor affecting thermal comfort. Therefore, measured RH levels could not be interpreted properly.

2.3.3.2 Thermal Comfort and IAQ

Cianfanelli et al. (2016) evaluated occupants’ thermal comfort and measured bacteria and fungi in two sports facilities (Site I & II), in Italy, between January and May 2015. A total of 58 participants were recruited: 40 persons in Site I, and 18 persons in Site II. The 4-point Likert scale of "dissatisfied", "not very satisfied", "satisfied" and "very satisfied” was used in the questionnaire. One major drawback of this scale is its asymmetrical nature which does not allow for selecting a “neutral” option. Six air samplings were conducted in Site I, including one gym and three dressing rooms, whereas three air samplings were performed in Site II, in two pools and the one dressing room. T, RH, MRT, and AV were monitored by an HD32.3 data logger for 15 minutes with 15-second intervals, to calculate PMV and Predicted Percentage of Dissatisfied (PPD). PPD predicts the percentage of respondents dissatisfied with thermal conditions. T and RH in the gym were around 16.0 °C and 58.0 %, respectively. All PMV values were negative, except in the gym and store, and PPD values were higher than 90% (i.e., at least 90% dissatisfaction was predicted). As per survey results, 55.0% of respondents were “very satisfied” with T and 41.0% were “satisfied”, with no one “dissatisfied”. Moreover, 59.0% were “satisfied” with RH and 23.0% “not very dissatisfied”. Therefore, the inconsistency between PPD and survey responses is noticeable.

Bacterial pollution in different spots was heterogeneous depending on T levels, as very low at 22.0 °C in dressing rooms and very high at 37.0 °C in the gym. The study concluded that the facilities' IAQ complied with national standards for non-industrial primaries.

The literature review revealed an increasing interest in the topic in recent years since the majority of reviewed studies occurred after 2010. Also, none of the reviewed studies were conducted or focused on buildings in North America. Furthermore, studies were mainly concentrated on objective IAQ assessment and pollutants' characterization. The studies' results emphasized the effect of occupancy on sports facilities' indoor environment, as IAQ was affected by occupancy rates and occupants' activities. Lastly, no study relied on subjective assessment alone. Two studies implemented both objective and subjective assessments.

These results show there is a need to assess IEQ in sports facilities in Canada specifically using an objective and subjective mixed-method approach. There is also a need to interpret the objective and subjective results in relation to each other and to evaluate long-term rather than short-term IEQ. There is also a need to measure IEQ aspects beyond just IAQ.

2.4 IEQ Regulations in Sports Facilities

Cianfanelli et al. (2016) investigated national and international IAQ regulations for gyms and pools. The study confirmed that available standards and guidelines are designed for spaces such as offices, commercial buildings, industrial indoor environments, and schools, and that no such references exist for sports facilities in particular.

One of the primary references to evaluate indoor temperatures is the Thermal Environmental Conditions for Human Occupancy, by ASHRAE (2013). However, this standard applies to indoor spaces designed for sedentary activities with metabolic rates of less than 1.2 met. It is thus not a suitable reference to evaluate T levels in gym areas like the ALC where occupants have higher metabolic rates. The Texas Department of Health (2003) specifies the range of 72.0 °F to 76.0 °F (22.2 ℃ to 24.4 ℃) as the Minimum Risk Level (MRL)[2] temperatures in governmental buildings including sports facilities in the Summer. This would also not be an appropriate baseline to assess temperatures in sports facilities because these types of buildings have specific requirements. These facilities have different IEQ requirements than office or residential buildings because of the unique activities that take place within them (Andrade & Dominski, 2018; Revel & Arnesano, 2014b). Also, accepted RH levels in gymnasiums have not been specified in the ASHRAE standard. The Texas Department of Health (2003) specified acceptable RH levels in governmental buildings including sports facilities to be between 30.0% and 60.0%, with 30.0% to 50.0% being the most preferable. Nevertheless, studies like Alves et al. (2013) consider the ASHRAE standard as a baseline to assess thermal comfort in sports facilities.

No standards or guidelines exist in Canada for acceptable CO_2 levels in gymnasiums in particular. Those existing are for other building types. For example, the Exposure Guidelines for Residential Indoor Air Quality Guideline Health Canada (1995a) specified that the accepted long-term CO_2 in residential buildings should be less than 3,500 ppm. However, in its new version: the Residential

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[2] An estimate of daily human exposure that is likely to be without an appreciable risk.

Indoor Air Quality Guideline (Health Canada, 2019), there is no suggested accepted CO_2 level. The Indoor Air Quality in Office Buildings: A Technical Guide (Health Canada, 1995b), devoted to offices, specified 850.0 ppm as the maximum accepted CO_2 levels in offices. The Texas Department of Health (2003) defined that the minimum risk level of 8-hr CO_2 exposure in governmental buildings including sports facilities is 700.0 ppm above outdoor concentrations. This guideline covers other types of buildings like offices and schools. All those buildings along with sports facilities are grouped as governmental buildings. Nevertheless, this categorization is not accurate because occupants' metabolic rates and activities in sports facilities are different from those in offices and schools. Moreover, Texas's climate is very different from Manitoba's, making its recommended levels less applicable in colder climates. Studies reviewed refer to other existing standards or guidelines for acceptable CO_2 levels. For example, Ramos et al. (2014) used the 1,250 ppm limit established by the national Portuguese standard (Portaria n. 353-A/2013 (2013) for commercial and service buildings. Other guidelines like the World Health Organization (2010) have also been used by studies such as Alves et al. (2013) as a benchmark to evaluate IAQ in sports facilities.

2.5 Building Automation Systems

BASs are systems providing automatic control of the interior environment conditions of buildings (Chasta et al., 2016) to facilitate buildings maintenance and configuration conducted by building managers or operators (Kastner et al., 2019). BASs' main functions include heating, ventilation, and air conditioning; domestic hot water; lighting systems control; shading systems control; energy conversion and storage; onsite power generation; communications and security management; and monitoring and data acquisition (Aste et al., 2017). The function of monitoring and data acquisition can help capture the long-term thermal conditions and IAQ in green buildings. This is because green building rating systems require the collection of data using BASs. For example, the Leadership in Energy and Environmental Design (LEED) Building Design and Construction rating system requires that CO_2 monitors in these buildings alert BASs when CO_2 levels exceed specific thresholds (U.S. Green Building Council, 2019a).

Kim et al. (2018) conducted a study focused on personal comfort models. A personal comfort model predicts an individual's thermal comfort perception rather than modeling the average response of all occupants. They categorized data types and collection methods into different categories including thermal comfort perception data (mostly collected using surveys), indoor physical factors (measured using sensors), and mechanical system settings like thermostat setpoints (recorded using BASs). Cauchi et al. (2017) used recorded data by BASs to quantify the costs of occupants' thermal discomfort and develop optimal maintenance strategies that were energy and cost-effective. Gunay et al. (2019) conducted an extensive review of using BASs to provide data for building performance assessments. They found the non-standard format of data tags to be one of the main barriers to the widespread use of BASs as a potential data source. The data framework in BASs is not designed for analytical purposes as the prevailing function is to control and adjust the indoor environment (Gunay et al., 2019).

Cotrufo et al. (2019) used recorded data by BASs to virtually re-calibrate one defective outdoor air temperature sensor and virtually measure temperature and relative humidity in an air handling unit installed in a university building in Montreal, Canada. They used this method to overcome the issue of missing data or low-quality measurements in HVAC monitoring systems.

Tamas et al. (2020) interviewed 170 participants in 23 buildings of a university campus in Canada to explore the relationships between occupants' perceived control and comfort, and their preferences with respect to buildings' automation. Occupants' comfort and control were surveyed based on their level of satisfaction with the workplace, the extent to which conditions were comfortable, and the ability to control and adapt aspects of comfort (e.g., thermal, electric lighting, daylight, acoustic, and air quality). The results showed that the majority of respondents were dissatisfied with building automation and preferred more adjustable and manual (i.e., by themselves) controls. The lack of ability to control and adjust the indoor conditions was the major dissatisfaction reason. Also, participants mentioned they would receive a slow response from facility managers when changes (e.g. adjusting thermostats) were requested. Also, there was a statistically significant moderate correlation between their perception of comfort and their perception of control over their indoor environment.

Kim et al. (2019) surveyed 37 occupants in an office building in California. Occupants were asked to sit on Personal Comfort Systems (PCS) chairs because the study aimed to measure their local heating and cooling needs without influencing others in the same space. These chairs allow individuals to regulate their thermal environment personally through online communication with BASs. In the study, the HVAC data recorded by BASs, and the continuous monitoring of the local thermal environment via both the PCS chairs and independent loggers provided the data needed to assess local thermal conditions. The results revealed that occupants within the same thermal zone experienced different temperatures and had different preferences. Occupants who used PCSs were significantly more satisfied with thermal conditions than those who did not.

The current research aims to use BASs to assess the long-term IEQ conditions in a green sports facility: the Active Living Centre (ALC) of the University of Manitoba, Canada.

CHAPTER 3: METHODOLOGY

This chapter presents the overall methodology implemented in this research, including the description of the studied building as well as the data collection and analysis methods. In the first section, green features of the studied building, some key characteristics of its design, and occupancy patterns are explained. The following section addresses the objective data collection of physical IEQ parameters and the subjective assessment of occupants' IEQ perception. The last section presents the methods used to analyze the physical IEQ data and survey responses.

3.1 Building's Specifications

The Active Living Centre (ALC) is a six-story building located at the Fort Garry Campus of the University of Manitoba, Winnipeg, Canada, with the coordinates of 49° 48' 23.688" N 97° 8' 17.736" W. It was constructed in 2015 and certified as a Leadership in Energy and Environmental Design Silver (LEED Silver) building in 2017 (Canada Green Building Council, 2020).

3.1.1 Green Features

According to the green building rating systems of LEED Canada for New Construction and Major Renovations, the building achieved 50.0 points out of the total possible 110.0 points (Canada Green Building Council, 2020). Table 1 shows all credit categories and the achieved points, based on which the ALC obtained nearly 73% of total possible points for the IEQ credit.

Table 1 Credit categories and points achieved by the ALC as a LEED Silver green building (Canada Green Building Council, 2020).

Credit categories	Possible points	Points achieved	Percentage points achieved
Sustainable Sites	26.0	15.0	57.7%
Water Efficiency	10.0	8.0	80.0%
Energy & Atmosphere	35.0	5.0	14.3%
Materials & Resources	14.0	3.0	21.4%
Indoor Environmental Quality	15.0	11.0	73.3%
Innovation in Design	6.0	5.0	83.3%
Regional Priority	4.0	3.0	75.0%

Table 2 presents the details of the IEQ credit categories exclusively. “Construction IAQ Management Plan” aims to minimize IAQ problems due to construction and renovation. “Low-Emitting Materials” tends to decrease indoor chemical pollutants concentrations. “Indoor Chemical & Pollutant Source Control” evaluates potential indoor air pollutants’ sources. “Thermal Comfort” addresses providing thermal comfort to enhance occupants’ productivity, comfort, and well-being by a permanent monitoring system. “Daylight & Views" aims to connect occupants with the outdoors and introduce daylight into the space. Therefore, IAQ, thermal comfort, and lighting were the IEQ aspects covered in the building’s certification.

3.1.2 Spaces, Air Handling Units, and Mechanical zoning

The ALC houses different spaces and areas as shown in Table 3. However, this research only focuses on two areas: the gym located on the third floor (L300), and the offices that were mostly located on the second floor (L200). The gym was selected because it is a large fitness area occupied by users during the whole day. Moreover, the administrative department and its offices are located on L200.

Table 2 IEQ credit categories and points achieved by the ALC as a LEED Silver green building (Canada Green Building Council, 2020).

IEQ credit categories	Subcategories	Points achieved
Construction IAQ Management Plan	During Construction	1.0
	Before Occupancy	1.0
Low-Emitting Materials	Adhesives & Sealants	1.0
	Paints and Coating	1.0
	Flooring Systems	1.0
	Composite Wood & Agrifibre Products	1.0
Indoor Chemical & Pollutant Source Control		1.0
Thermal Comfort	Design	1.0
	Verification	1.0
Daylight & Views	Daylight	1.0
	Views	1.0

Table 3 Spaces within ALC.

Level	Spaces
000	Crawl space, mechanical and electrical rooms
100	Agora, offices, mechanical and electrical rooms, service desk, Bison’s gym area
200	Offices, multipurpose rooms
300	Main fitness area (gym), offices
400	Running track, mechanical rooms
500	Mechanical rooms

The gym is a large fitness area with approximate dimensions of 82.0 m × 45.0 m and includes different machines and equipment such as treadmills, elliptical, stationary bikes, and free weights. According to the ALC’s web-based facility management application, enteliWEB, the facility has nine air handling units (AHU), AHU1-AHU9, that serve different levels and zones, as shown in Table 4 (University of Manitoba enteliWEB, 2019). Figure 1 displays an example of how enteliWEB presents mechanical zoning and loggers' location in the building. enteliWEB, developed by Delta Controls Inc (Delta Controls Inc, 2019), facilitates the web-based archiving and remote access to the BASs.

Figure 1 shows the mechanical zoning and distribution of temperature loggers (displayed as "T" in the figure) in L300. As shown, four air handling units: AHU5, AHU6, AHU7, and AHU9 serve this level. Rooms 341 and 342 (i.e., the consulting and administration offices) are separate spaces that are rarely used by fitness attendants. These rooms are not part of the gym and were therefore removed from the research. As per Figure 2, there is an open zone in the center of L300 to L400 with a massive ceiling fan that circulates air there. However, the fan was broken in early July 2019 and not fixed until late October 2019. As mentioned in Table 4, AHU4 serves offices on the second floor. Unlike the gym in which no wall-mount CO_2 loggers were installed, both wall-mount T and CO_2 loggers were installed in offices.

Table 4 HVAC zoning and existing loggers in air handling units' ducts of the ALC.

AHU	Zones	Loggers in the return air ducts		
		T	RH	CO_2
AHU1	Bison strength	*Y	Y	Y
AHU2	Agora	Y	Y	Y
AHU3	L200 Multipurpose rooms	Y	Y	** N
AHU4	L200 offices	Y	Y	N
AHU5	L300 West	Y	Y	Y
AHU6	L100/300 Central	Y	N	Y
AHU7	L300/400 East	Y	Y	Y
AHU8	L400 West	Y	Y	Y
AHU9	L300/400 South	Y	Y	Y

*The logger exists in the duct. ** The logger does not exist in the duct.

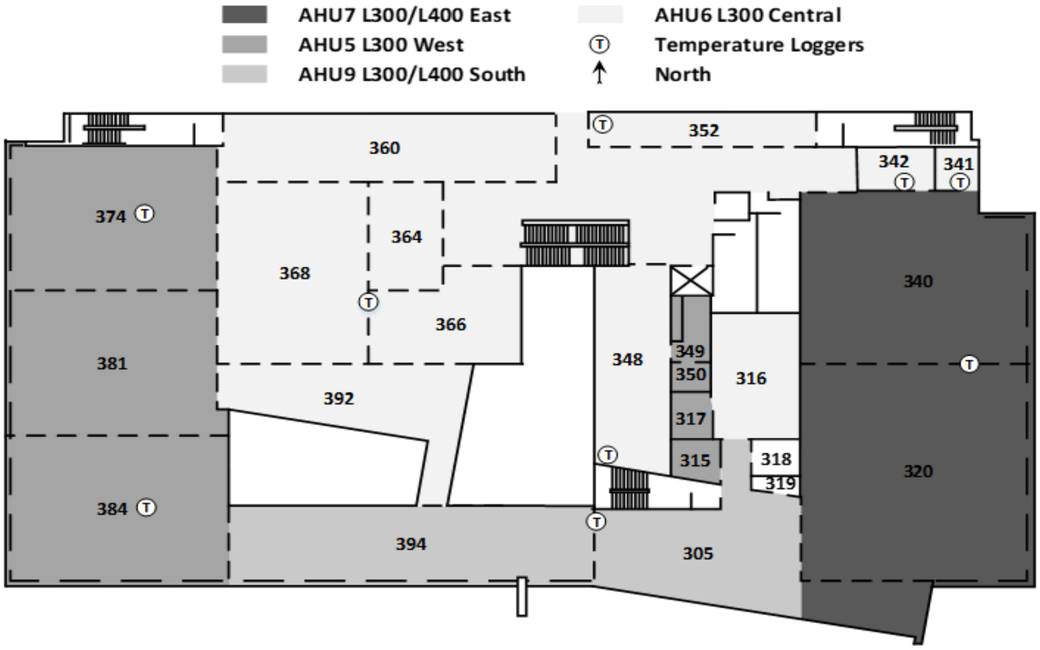

Figure 1 Mechanical zoning in L300 of the ALC (University of Manitoba enteliWEB, 2019).

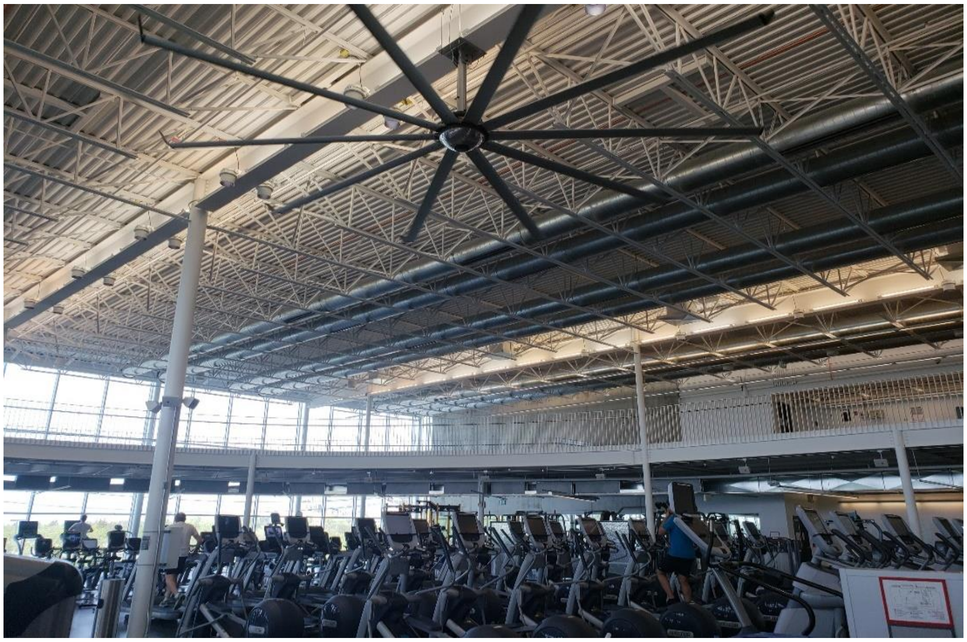

Figure 2 View of the open zone in center of L300 (gym) to L400 (the running track) of the ALC.

A walk-through inspection conducted using the space level condition assessment tool developed by Sadick (2018) showed no issue in the ALC elements’ (e.g., windows, finishing) physical conditions. The inspection was needed to identify possible issues in the physical conditions of the ALC and investigate their potential links to the IEQ assessment later. Sadick (2018) designed and implemented the inspection tool to assess the effect of building elements’ (e.g., walls, floor, door, windows, and finishes) physical conditions on IEQ, in schools in particular.

3.1.3 Occupancy Rate

The literature (e.g., Castro et al. 2015; Braniš and Šafránek 2011; and Slezakova et al. 2018) found a link between occupancy rates and indoor conditions. For instance, Slezakova et al. (2018) found that the maximum concentration of PM occurred on the busiest hours of the gym they studied. Therefore, it was necessary to investigate daily occupancy patterns in the ALC.

Active Living Centre (ALC) users can have access to the facility from 6:00 AM to 10:00 PM. An audit report provided by The Faculty of Kinesiology and Recreation Management of the University of Manitoba (University of Manitoba, 2019) was studied and analyzed to determine the occupancy patterns in the building. The report included members' check-in data on an hourly basis, from October 2017 to February 2019. According to the hourly data, the average daily number of people who checked into the facility between February 2018 and February 2019 was determined as approximately 2,000 persons per day (University of Manitoba 2019). However, a more detailed investigation of the report revealed that the average daily number of facility users in the Summer and Fall 2018 was 1,600 and 2,600 persons per day, respectively. Figure 3 shows the mean hourly number of users between 6:00 AM to 9:00 PM in the Summer and Fall 2018.

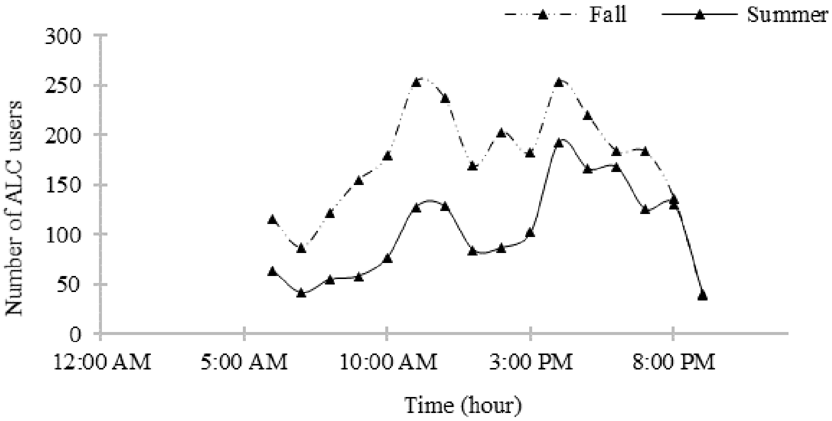

Figure 3 Mean hourly number of ALC users in the Summer and Fall (University of Manitoba, 2019).

As can be seen, hourly occupancy rates of both seasons had a morning peak rate occurring between 11:00 AM to 12:00 PM, and the evening peak rate happening at 4:00 PM (University of Manitoba 2019). Also, the morning peak occurring in the Fall had almost the same occupancy level as the evening peak rate in that season, both at approximately 250 users. In the Summer, the evening peak rate, at around 190 users, was higher than the morning peak rate, at around 130 users. The higher occupancy of the ALC in the Fall compared to the Summer was probably due to the increased number of students, faculty, and staff on campus in the Fall due to the resumption of full-time undergraduate classes in the Fall. The higher occupancy of the ALC on Summer evenings compared to mornings could be due to the tendency for people to wake up later in the Summer due to them taking holidays then and thus their tendency to be more active in the evenings. These occupancy numbers also include users of the Frank Kennedy Centre (FKC) and other zones of the ALC and not just the gym. The FKC is an older three-story sports facility that encompasses three gymnasiums, racquetball, and squash courts. To use the FKC, users must check in from ALC as the two buildings are attached from the ALC's north side. Even though some of the people who enter the ALC do not end up using it, these occupancy patterns are still good indicators of the gym's occupancy, in the Summer and Fall of 2019.

3.2 Data Collection

Data collection in this research relied on a mixed method of using objective physical IEQ measurements and occupants' subjective IEQ perception. This is discussed below.

3.2.1 Physical Indoor Environmental Quality Data

The ALC's facility management application, enteliWEB, provides two types of data: numerical and graphical. The former includes archived recorded values of the building's different performance aspects (e.g.., indoor air T and RH levels), and the latter contains drawing sheets and figures to depict building systems' components, like in Figure 1. The ALC's enteliWEB shows the location of loggers including T, RH, and CO_2 loggers installed in the return air ducts of air handling units. The installed loggers in the ducts were listed in Table 4. In addition to those devices in the ducts, the automation systems included a total of 60 wall-mount T loggers and 29 wall-mount CO_2 loggers throughout the different rooms or zones of the facility. There were no wall-mount RH loggers in the rooms.

To assess IEQ in the gym, the research collected the data recorded by the loggers installed in AHU5, AHU6, AHU7, and AHU9 (Table 4) as well as the wall-mount T loggers located in L300 (Figure 1), as these were serving the gym. There were no wall-mount CO_2 loggers in the gym in L300. All parameters on this floor were monitored every 15 minutes. In contrast, the wall-mount T and CO_2 loggers located in offices, as well as the RH loggers existing in the return air ducts of

AHU4 that serves offices, were used to evaluate T, RH, and CO_2 levels in offices. T and CO_2 loggers in different offices had different recording intervals. For example, the T and CO_2 loggers of Room 214 recorded the values in 10-minute intervals, while the T logger of Room 217 recorded temperatures every 20 minutes. Table 5 summarizes these details based on the studied spaces and parameters.

Table 5 Sources of collected physical indoor environmental quality data.

Space	Investigated parameters	Sources of collected data
Offices	T and CO_2	Wall-mount loggers in each room
	RH	Installed logger in the return air duct of AHU4
Gym	T	Wall-mount loggers on the third floor
	RH and CO_2	Installed loggers in return air ducts of AHU5, AHU6, AHU7, and AHU9

After identifying the loggers and mechanical zonings, the research involved refining and analyzing data available on the web-based tool, enteliWEB, to extract thermal conditions and IAQ trends. This step entailed comparing the list of available trend logs (i.e., the long-term time series of T, RH, and CO_2 levels) on enteliWEB with the list of loggers shown in the drawing sheets as well as schematic figures existing on enteliWEB. It was expected that for each logger in the drawing sheets or figures, one corresponding trend log would be found on enteliWEB. However, some of the loggers had not been set to start the logging, although they were functional. Moreover, some WiFi T loggers had communication problems as they were not able to connect to the network and start logging and recording corresponding trends. All of these limitations resulted in missing data for the studied period.

Of all the T loggers shown in Figure 1, no trending was available for Room 368/366, 352, and 348. Besides, the trending of the T logger located in Room 340/320 was started on August 14, 2019 (after noticing its malfunction by this research). This WiFi logger was one of the loggers with connection problems, and its data were missing for June and July 2019. Data were available only for the loggers in Room 394/305, 384, and 374. Therefore, four of the seven wall-mount T loggers' records were missing in the Summer of 2019. Loggers in Room 341 and Room 342 were not studied because they were located in rooms that were not part of the gym area. As a result, the thermal conditions and IAQ of the gym in the Summer of 2019 were investigated based on the remaining three T loggers in L300 (i.e., Room 394/305, 384, and 374) and the CO_2 and RH loggers in the return air ducts of AHU5, AHU6, AHU7, and AHU9. Because the T logger of Room 340/320 started recording temperatures after August 14th, the temperature dataset of L300 in the Fall season had fewer missing data since it included one more trending by logger 340/320.

The measurement protocols developed by standards like ASHRAE (2013) specify the requirements for measuring and evaluating IEQ. For example, air temperature needs to be measured at three heights: 0.1 m, 0.6 m, and 1.1 m for seated occupants, and 0.1 m, 1.1 m, and 1.7 m for standing occupants (ASHRAE, 2013). However, CO_2 and RH levels of the gym, and RH levels of offices investigated in this research were measured in the return air ducts. Besides, T levels were measured at one height because the loggers were fixed in place. Furthermore, some air handling units served more than one level or zone, as per Table 4 (e.g., AHU6 serves the central zone of both L100 and L300). Consequently, some of the data extracted from the return air ducts did not just measure the conditions in L300. All these limitations and assumptions need to be taken into account when analyzing the extracted data.

3.2.2 Surveys

Two paper-based questionnaires, shown in Appendix B, were used to assess the satisfaction, perception, and preference of gym users and staff regarding the actual IEQ conditions of the ALC in the Summer (i.e., June and July) and Fall (i.e., September and October) of 2019. The questionnaires were administered manually in a paper-based format in order to enable respondents to fill out the surveys while they were in the environment they were assessing.

3.2.2.1 Survey Development

The existing questionnaires used in the literature to evaluate the IEQ of sports facilities (e.g., Cianfanelli et al., 2016; Revel & Arnesano, 2014b) were very short and mostly covered some aspects of thermal comfort such as satisfaction with air temperature and temperature preference. Therefore, the current research's surveys were developed based on the surveys defined by ASHRAE (2013), EPA (2003), and Newsham et al. (2012).

The ASHRAE Standard 55-2013: Thermal Environmental Conditions for Human Occupancy is the standard published by ASHRAE (2013), which determines thermally comfortable indoor conditions. This is one of the standards used to design HVAC systems and building envelopes that meet thermal comfort conditions (U.S. Green Building Council, 2019a). To assess indoor thermal comfort conditions, the standard contains a sample survey. This survey was used to develop the current research surveys. The Standardized EPA Protocol for Characterizing Indoor Air Quality in Large Office Buildings, published by EPA (2003) was also used to develop the research's surveys. This protocol covers the details and procedure for investigating IAQ in EPA's large office buildings and includes a questionnaire as part of it. This questionnaire was used to develop the

IAQ module of the current research's surveys. Another resource used in developing the research's surveys was the study conducted by Newsham et al. (2012) to investigate the performance of green and conventional buildings across Canada and the Northern United States. They collected subjective data by surveying occupants and objective data by measuring physical factors and energy use. The survey was organized into seven modules: 1) Environmental and job satisfaction, demographics, job demands; 2) Organizational commitment, workplace image, internal communications; 3) Acoustics; 4) Thermal comfort; 5) Chronotype, sleep quality, positive/negative feelings (affect); 6) Health; 7) Commuting, environmental attitudes.

The questionnaires developed in this research entailed asking the ALC's occupants about their satisfaction, perception, and preference with respect to thermal comfort and IAQ. Most questions used a 7-point Likert scale, from -3.0 to +3.0, as this was the scale used by resources such as ASHRAE,(2013), EPA (2003), and Newsham et al. (2012). Satisfaction with thermal conditions and IAQ parameters were rated from "-3.0: Very dissatisfied" to "+3.0: Very satisfied". To analyze responses, those who were "Slightly satisfied"," Satisfied", and "Very Satisfied" were grouped into the "Satisfied" category. Similarly, respondents who were "Slightly dissatisfied", "Dissatisfied", and "Very dissatisfied" were grouped into the "Dissatisfied" category whereas those that were "Neutral" were categorized as "Neutral". Furthermore, participants were asked to rate their thermal sensation from "-3.0: Cold" to "+3.0: Hot", their thermal preference from "-3.0: Much cooler" to "+3.0: Much warmer", and the effect of thermal conditions on their abilities as "-3.0: It interferes with my abilities" to "+3.0: It enhances my abilities". In this context, the physical performance of gym users refers to their ability to play sports or exercise in the ALC, whereas the staff's physical performance refers to their ability to execute their daily job duties in their offices.

For thermal sensation, thermal sensations rated as “Slightly warm”, “Warm” and “Hot” were grouped as “Warm”, while the thermal sensations of “Slightly cool”, “Cool”, and “Cold” were classified as “Cool”. Likewise, thermal preferences rated as “Slightly warmer”, “Warmer” and “Much warmer” were categorized as “Warmer”, whereas those rated as “Slightly cooler”, “Cooler” and “Much cooler” were categorized as “Cooler”. “Neutral” was kept as “Neutral” in the both categorizations.

Three questions asked respondents to rate how much they agreed or disagreed (“-3.0: Strongly Agree” to “+3.0: Strongly disagree”) that indoor air was smelly, stuffy, and dusty. Furthermore, participants were asked to rate the effect of thermal conditions and IAQ on their physical performance abilities as “-3.0: It interferes with my abilities” to “+3.0: It enhances my abilities”. Also, there were Yes or No questions about respondents’ tendency to adjust the physical parameters of air temperature, and airflow by themselves, and their past complaints, if any, about the thermal conditions and IAQ of the facility. In order to correlate respondents’ answers with their personal data, a demography module enquiring about their age, gender, and facility usage patterns was also added to the survey.

According to ASHRAE (2013), thermal environment satisfaction surveys can be used to assess thermal conditions in the short-term (i.e., instantaneous) or in the long-term (i.e., over periods such as a season or a year). This research focused on investigating these conditions in the long-term, over two seasons: The Summer and Fall 2019. June and July of 2019 were considered as the Summer season, and September and October of 2019 were considered as the Fall season. The surveys were therefore conducted twice: in the Summer season, specifically in July of 2019, and in the Fall season, specifically in October of 2019.

3.2.2.2 Sample Size

As explained before, nearly 1,600 persons per day visited the facility in the Summer and 2,600 in the Fall, resulting in a total of 97,000 and 158,000 ALC users during the Summer and Fall, respectively. According to sampling size criteria by Rea & Parker (2014), the needed sample to survey in the Summer and Fall would be 383 and 384 persons, respectively, considering a marginal error of 5.0%, a confidence level of 95.0%, and total populations of 97,000 (in the Summer) and 158,000 (in the Fall), respectively. This does not take into account the fact that some of the users entering the ALC were there to use the FKC or other zones of the ALC rather than the ALC's gym. Many of the users were also repeat visitors as they used the gym on a daily or weekly basis. On the other hand, for populations larger than 20,000, the sample size does not change considerably (Rea & Parker, 2014). For example, at a confidence level of 95.0% and marginal error of 5.0%, the sample sizes for populations of 50,000 individuals and 100,000 individuals are 382 and 383 persons, respectively (Rea & Parker, 2014). Therefore, the determined sample sizes of 383 and 384 persons for the Summer and Fall seasons can be considered as the correct sample sizes.

Gym users were surveyed in L300, between 11:00 AM and 7:00 PM, from July 8th to 11th, 2019, as the Summer data collection period; and from October 21st to 24th, 2019, as the Fall data collection period. To recruit participants, a booth was set up between zones 364 and 366 (shown in Figure 1) of L300. The booth mainly consisted of a desk for participants' convenience and an easel to promote the survey and research. Also, posters about the survey and research were posted in different locations of the ALC during the data collection period for that same purpose.

The questionnaires and the process for recruiting participants, surveying, and analyzing the results were approved by the Education/Nursing research ethics Board (ENREB) (Protocol # E2018:104 (HS22465)) and the Survey Review Committee of the University of Manitoba. The Survey Review Committee's approval was needed as the research entailed surveying University of Manitoba's (UofM) students and staff rather than people outside the UofM campus. The participants' consent forms and ENREB approval are provided in Appendices A, and C, respectively. According to Appendix A, a gym user interested in filling out the survey was asked to sign the users' consent form first, fill out the anonymous survey next, seal each form and survey and then place each in one of two boxes on the desk. One of the boxes was for consent forms; the other for surveys. This would ensure that respondents' confidentiality is preserved and that no link could be made between the identity of respondents and their answers. Each participant needed on average 10 to 15 minutes to fill out the questionnaire. Staff participation took place in their offices with no need for a booth. They also would need to hand over the staff's consent form and staff's questionnaire separately, as explained. They needed almost the same time to answer the questions. Before starting to survey staff members, the facilities director of the Faculty of Kinesiology and Recreation Management of the University of Manitoba emailed the faculty's staff including the ALC's staff to inform them of the upcoming survey in order to increase participation. In the surveying event, staff members were approached in their offices and asked about their tendency to take part in the survey. After declaring their interest, they were given the consent form and questionnaire. While a few filled out the form and questionnaire right away, some asked to answer the questions later. Therefore, their consent forms and questionnaires were picked up at their convenience. In both situations, the staff were asked to seal the forms and questionnaires and place them in their specific boxes.

3.3 Data Analysis

This section describes the methods used to analyze the physical indoor environmental quality data on one hand, and survey responses on the other, in the Summer, Fall, and in the Summer versus Fall seasons. It also explains evaluating the links between these two groups of data.

3.3.1 Physical Indoor Environmental Quality Data

After refining the raw data extracted from enteliWEB, Leard Statistics (2019) and the software IBM SPSS Statistics 25 were used to analyze the data trends statistically. The statistical significance of results was evaluated at $p = 0.05$ and a confidence level of 95.0%. The analysis involved calculating descriptive statistics based on 15-minute records for L300, and the average of 10-minute, 15-minute, and 20-minute records for L200. It also involved calculating 1-hour averages of T, RH, and CO_2 for a representative 24-hour period in June, July, September, and October. To extract these trends, the averages of all records in one hour (e.g. four 15-minute records or three 20-minute records) were calculated for each hour of each day in June, July, September, and October (e.g. 1:00 PM of all days). Next, all concurrent 1-hour average levels throughout a month (e.g., 30 averages for 1:00 PM in June) were used to calculate the mean hourly levels (e.g., the average concentration of CO_2 at 1:00 PM in June).

Paired-samples t-tests were used to determine whether the differences between T, RH, and CO_2 records in June versus July and September versus October were statistically significant. In cases outliers were detected, the inspection of the dataset was needed to evaluate whether the observed outliers were due to an error in data entry, measurements, or unusual values in order to remove them from the dataset. Otherwise (i.e., if the observed outliers were because of differences between the records), they would be kept in the analysis. To investigate the statistical significance of seasonal differences, paired-samples t-tests were also applied to capture the differences between the Summer versus Fall of 2019. In presenting paired-samples t-tests results, data are mean ± standard deviation, unless otherwise stated. Furthermore, the effect size of *d* is a measure of the practical significance of the mean difference (Leard Statistics, 2019). According to this criterion, the *d* values equal to or less than 0.2, 0.5, and 0.8 represent a practical small, medium, and large significance of a mean difference, respectively.

As mentioned previously, no specific standards or guidelines exist for acceptable levels of thermal comfort and IAQ parameters in fitness areas. Therefore, this research's parameters were compared to those measured by other studies to interpret the obtained results.

3.3.2 Surveys

Leard Statistics (2019) and the software IBM SPSS Statistics 25 were used to analyze survey responses statistically. Each question's responses were defined according to their characteristics as variables. For example, responses using a 7-point scale were defined as "Ordinal" due to their sequential feature. Other responses that were qualitative with no sequence, such as the questions about gender or the tendency to change temperature or airflow were defined as "Nominal" because of the answers. Nominal variables with two answers like Yes or No were defined as "Dichotomous".

The Spearman rank-order correlation test was used to evaluate correlations between pairs of ordinal variables. As an example, the test investigated the correlation between satisfaction with air temperature and satisfaction with relative humidity, as the answer to both questions was ordinal and rated from -3.0 to +3.0. Similarly, other investigated correlations included the correlation between different aspects of thermal conditions such as satisfaction with air temperature and satisfaction with airflow, and satisfaction with air temperature and temperature preference. Moreover, the correlation between different aspects of IAQ like satisfaction with IAQ and the perception of air smell, and satisfaction with IAQ and the perception of IAQ effect on the physical performance were tested. One of the main assumptions of this test is the existence of a monotonic relationship between variables (Leard Statistics, 2019). If the assumption was not met, the Mantel-Haenszel test of trend was used as an alternative. For those variables that were statistically significantly correlated, ordinal logistic regression was used to evaluate the effects of independent variables on a dependent variable. To satisfy the test's requirement, the independent variables were treated as nominal variables even though they were initially ordinal. When the assumption of proportional odds was not met, multinomial logistic regression was used instead in which dependent variables were changed to nominal. Lastly, the rank biserial correlation test was used to evaluate the correlation between "Dichotomous" and "Ordinal" variables (Leard Statistics, 2019). The correlation between thermal sensation from one hand (i.e., the ordinal variable) and different dichotomous aspects of gender, the tendency to adjust air temperature and airflow, and complaining about thermal conditions and IAQ were evaluated using this test. Gender was considered a dichotomous variable (although the options for answers were more than two), because only one respondent in the Summer chose an answer different from Male or Female. Also, the correlation between other ordinal aspects (of thermal conditions as well as IAQ) and the mentioned dichotomous aspects were tested using a rank biserial correlation test.

The Kruskal-Wallis H test was also run to evaluate the seasonal differences of participants' responses between the Summer and Fall of 2019. The Kruskal-Wallis H test is a nonparametric test that can be used to determine if there are statistically significant differences between two or more groups of an independent variable on a dependent variable (Leard Statistics, 2019). As the surveys were conducted in two seasons, the number of groups for the dependent variable of the season was two. Ordinal independent variables included different thermal conditions and IAQ parameters. The test was used to evaluate seasonal differences in thermal condition aspects. This included seasonal differences of participants' satisfaction with air temperature, relative humidity, airflow, and surface temperature, their thermal sensations, preference, and the perception of thermal conditions effect on their physical performances. Besides, the test was applied to evaluate seasonal differences in IAQ aspects. This included seasonal differences of participants' satisfaction with indoor air quality, the perception of air smell, air stuffiness, and air dustiness, as well as the perception of IAQ effect on their physical performance.

The statistical significance of the results was evaluated at $p = 0.05$ and a confidence level of 95.0%. The strength of the calculated correlation coefficients was interpreted based on Table 6 (Evans, 1996). Only descriptive statistics and correlation coefficients were used to evaluate staff's responses as the smaller sample size in comparison to that of gym users and the inconsistency of the results did not allow for further analysis.

Table 6 Strength levels corresponding to the correlation coefficient (Evans, 1996).

Correlation coefficient	Strength level
0.00 – 0.19	Very week
0.20 – 0.39	Week
0.40 – 0.59	Moderate
0.60 – 0.79	Strong
0.80 – 1.00	Very strong

3.3.3 Surveys Feedback Versus Actual Condition

The respondents' subjective IEQ feedback was assessed in relation to the captured actual physical IEQ data, to interpret the IEQ of the ALC comprehensively and rationalize occupants' perception and preference. For this purpose, the satisfaction rate with IAQ and respondents' distribution based on this aspect were linked to CO_2 levels as the indicator of IAQ. Moreover, three aspects of satisfaction rate with air temperature, thermal sensation, and thermal preference were assessed in relation to air T trends. Lastly, the satisfaction rate with relative humidity was linked to RH levels in the ALC.

To provide a more in-depth interpretation of IEQ in the ALC, both the subjective and objective findings in the current research were also compared to the other relevant studies' results. Since it was not practical to survey occupants more frequently in the Summer and Fall, the temporal scope of physical objective data collection did not match the subjective data collection. Physical IEQ data collected in June and July were assessed in relation to the survey conducted in one week of July. Moreover, physical IEQ data collected in September and October were assessed in relation to the survey conducted in one week of October. This would affect the reliability of the results.

CHAPTER 4: RESULTS & DISCUSSION

The results presented in this chapter are divided into three main sections: The Summer, Fall, and the comparison between the Summer and Fall results. Each section presents the results of objective and subjective data analysis separately and in relation to each other.

4.1 Summer

This section presents the results of the surveys conducted in July 2019 as well as the physical IEQ data collected for T, RH, and CO_2 collected in June and July 2019 (as summarized in Table 5). In the last subsection, the feedback received via the surveys is compared to the actual physical IEQ environmental data to interpret the IEQ condition in the ALC.

4.1.1 Physical Indoor Environmental Quality Data

This subsection presents the results of analyzing T, RH, and CO_2 levels in the ALC in the Summer (i.e., June and July) of 2019. Descriptive results are provided and are then followed by inferential statistical results.

4.1.1.1 Descriptive Results

Table 7 shows the descriptive statistics for the 15-minute recorded CO_2, RH, and T levels in the gym, in June versus July of 2019. The maximum CO_2 concentration in July was almost 100 ppm higher than its value in June, and the minimum concentration was nearly 20 ppm less than its corresponding value in June. The difference between mean concentrations was around 39 ppm.

Table 7 Descriptive statistics on CO_2, RH, and T levels in the gym, Summer 2019.

	Statistics	CO_2 (PPM)		RH (%)		T(°C)	
		June	July	June	July	June	July
Gym	Min	423.97	401.26	25.45	42.05	18.86	19.20
	Max	696.32	799.49	77.45	79.72	21.02	21.14
	Mean	491.04	529.83	52.19	65.85	19.64	19.80
	Std. Dev	57.07	88.48	11.92	8.99	0.38	0.29
Offices	Min	434.78	420.47	18.49	35.47	20.11	20.53
	Max	626.86	695.34	72.04	76.48	21.69	21.57
	Mean	501.46	524.21	43.36	58.52	21.03	20.95
	Std. Dev	44.68	68.77	12.21	10.39	0.30	0.21

Figure 4 shows the mean 1-hour CO_2, RH, and T levels in the gym for a representative day in June and July 2019, and their mean values (i.e., the mean of June and July) considered as the Summer. According to Figure 4(c), CO_2 concentrations increased between 6:00 AM and 1:00 PM; were constant between 1:00 PM to 3:00 PM; and increased again between 3:00 PM to 6:00 PM, with the peak concentration occurring around 6:00 PM. This pattern was in line with the occupancy trend observed in the Summer and depicted in Figure 3. As per Figure 3, the maximum number of ALC users in the Summer was found at 4:00 PM and the second peak number was observed at 6:00 PM. All average hourly CO_2 levels were higher in July than in June.

According to Table 7, there was no considerable difference in maximum RH levels between June and July. Nevertheless, the minimum and mean RH levels were nearly 17% and 14% higher, respectively, in July than the values in June. As shown in Figure 4(b), mean hourly RH levels were almost constant in June and July, even though measured levels were approximately 15% higher in

July than June. This could be due to higher outdoor RH levels in July compared to June (Climate Data Canada, 2020).

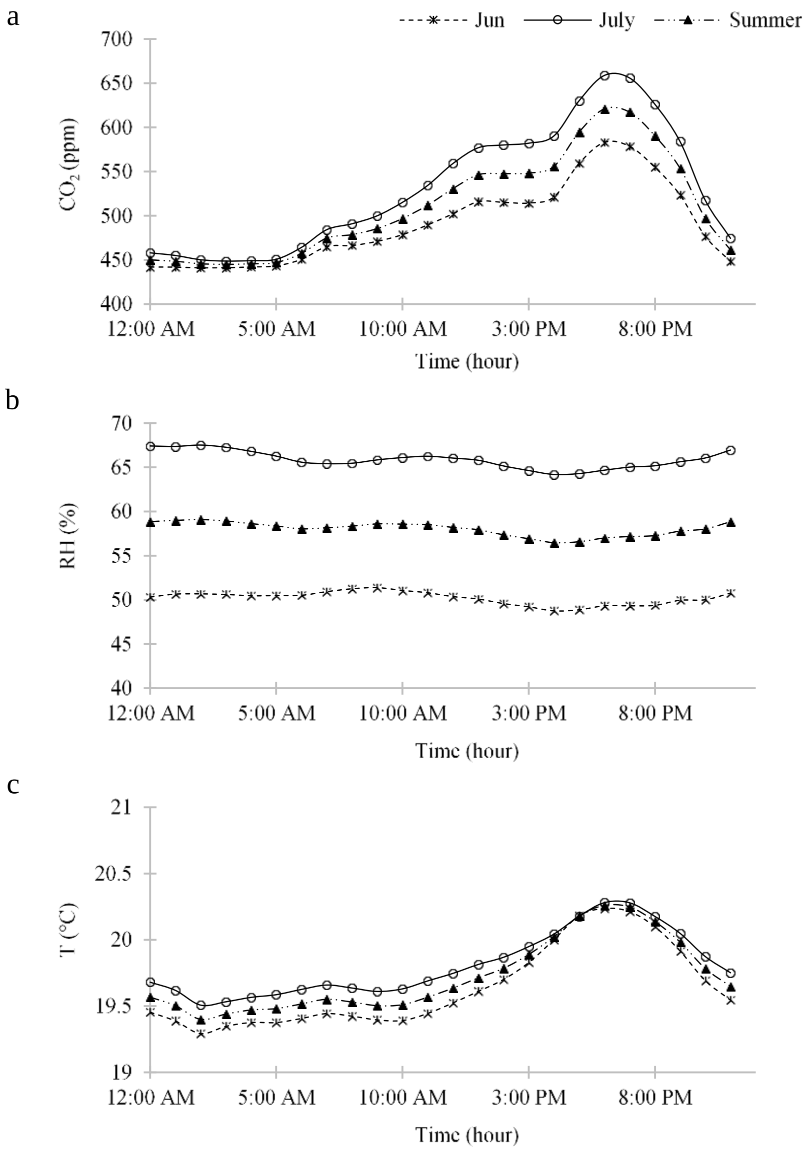

Figure 4 Variations of mean hourly a) CO_2, b) RH, and c) T in the gym, Summer 2019.

According to Table 7, both mean and maximum 15-minute T records in the gym were nearly similar in June and July. As can be seen in Figure 4(c), the peak 1-hour temperatures were approximately the same in June and July, but non-peak occupied hours had slightly higher temperature levels in July compared to June. Therefore, gym users experienced almost similar temperatures in peak occupancy hours in the evenings of the Summer of 2019. Figure 4(a) and Figure 4(c) demonstrate that CO_2 and T levels had similar patterns in the daytime. Since CO_2 levels were affected by the attendance rate, T levels could also be related to the number of users.

As per Table 7, 15-minute CO_2 concentrations in the offices were also higher in July than in June, with a mean difference of nearly 23 ppm. Figure 5(a) depicts that 1-hour CO_2 concentrations were higher in July. They slightly increased from 6:00 AM to 2:00 PM, remained constant between 2:00 PM and 5:00 PM, and increased again, with the maximum level of nearly 600 ppm observed between 6:00 PM and 7:00 PM. The increasing trend from morning to afternoon is in line with occupants' presence in the offices during working hours.

As shown in Table 7, the mean 15-minute RH level in the offices was also higher in July, implying a more humid environment. Similar to the gym, mean 1-hour RH levels in the offices were almost constant in June and July, as shown in Figure 5(b), even though measured levels were approximately 15% higher in July. This finding could be due to higher outdoor RH levels in July compared to June (Climate Data Canada, 2020).

According to Table 7, the mean 15-minute T levels in the offices was higher in June than in July, with the value of 21.3 °C versus 20.95 °C, respectively. As per Figure 5(c), temperature levels in the offices rose from 06:00 AM to 1:00 PM and decreased afterward. Peak temperatures were the same in June and July. The difference between June and July records was mostly during non-peak occupied hours in the morning.

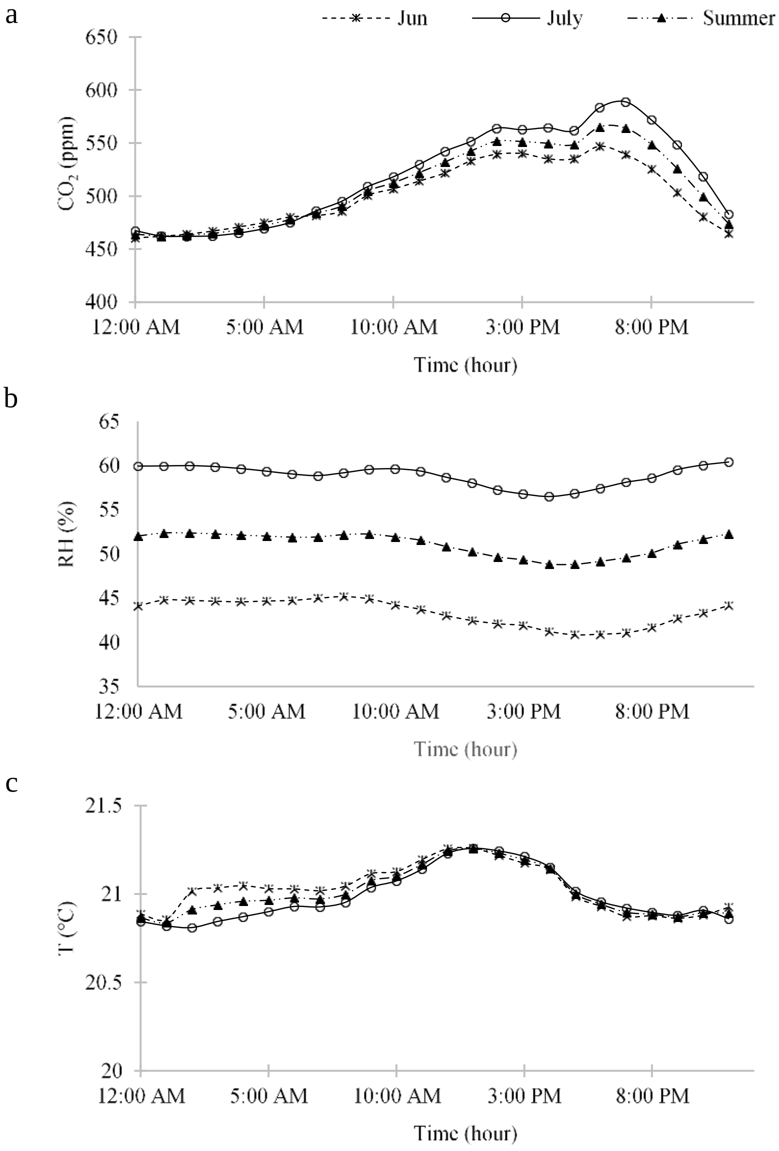

Figure 5 Variations of mean hourly a) CO_2, b) RH, and c) T in the offices, Summer 2019.

4.1.1.2 Inferential Statistics

A paired-samples t-test was used to determine whether there was a statistically significant mean difference between CO_2 levels of the gym in June and July of 2019. Although 27 outliers were detected, the inspection of the dataset showed that outliers were observed because of the differences between the June and July records, rather than due to an error in data entry, measurements, or unusual values. Hence, they were kept in the analysis. Unlike the non-normality of the distribution assessed by visual inspection of a Normal Q-Q Plot, it was decided to continue using the test as it is robust to handle this violation (Leard Statistics, 2019). The results showed that CO_2 concentrations in the gym (L300) were higher in July (529.83 ± 88.48 ppm) than June (491.04 ± 57.07 ppm), a statistically significant increase of 38.79 ± 1.33 ppm, $t\,(2687) = 29.17$, $p < 0.0005$, $d = 0.56$. As the test showed, the significance of the differences between CO_2 levels in June and July was more than medium since the effect size, d, was 0.56.

A paired-samples t-test was also used to determine whether there was a statistically significant mean difference between RH levels of the gym in June and July of 2019. Only five outliers were detected by visual inspection of a boxplot. However, they were kept in the analysis since they were due to the difference between recorded RH values. No error in data entry and measurements, or unusual values resulted in outliers.

The assumption of normality was violated, as assessed by a Normal Q-Q Plot. However, as explained earlier, the paired-samples t-test can still be used as it can handle this violation (Leard Statistics, 2019). RH levels in L300 were higher in July (65.85 ± 8.99%) as opposed to June (52.19

± 11.92%), a statistically significant increase of 13.66 ± 0.33%, *t* (2591) = 41.90, $p < 0 .0005$, $d = 0.82$. The effect size of 0.86 implied a large mean difference between RH levels in June and July.

The last test aimed to assess whether there was a statistically significant mean difference between T levels in the gym in June and July of 2019. Thirty-eight outliers were detected by visual inspection of a boxplot, but they were kept in the dataset for the same reason as for CO_2 and RH. Also, the assumption of normality was violated, as assessed by a Normal Q-Q Plot, but the test was still used just like for CO_2 and RH. Temperatures in L300 were higher in July (19.80 ± 0.29 ℃) than in June (19.64 ± 0.38 ℃), a statistically significant increase of 0.17 ± 0.0055 ℃, *t* (2879) = 30.42, $p < 0.0005$, $d = 0.57$. The practical importance of the difference in mean temperatures was medium, according to the effect size 0.57.

4.1.2 Survey

This section presents the Summer survey results. These include descriptive results extracted from filled out questionnaires to describe occupants' perceptions of IEQ in the gym, and the statistical tests results of analyzing different aspects of those perceptions.

4.1.2.1 Descriptive Results

Only 104 gym users filled out the questionnaire, which was smaller than the needed size of 383 participants. The daily number of participants had a decreasing trend from July 8th to 11th. This could be due to the fact that many gym users visited the gym regularly during the week. Most of these repeat gym users would have filled out the survey earlier in the week, thus the lower number of participants at the end. A total of eight staff members took part in the Summer office survey.

Table 8 shows the distribution of respondents by age and gender. Almost 40% of gym users were 21-30 years old and 65% of them were male. Fifty percent of the staff were 21-30 years old and nearly 90% were male. Although the ALC is located on a university campus and the majority of its gym users are students; university staff, alumni, as well as off-campus gym users also use the facility. According to the received responses, nearly 60% of respondents were students, while a total of 37.5% were alumni, faculty, and staff members.

Table 8 Distribution of respondents by age and gender, Summer 2019.

Age	Gym users (n=109)	Staff (n=8)	Gender	Gym users (n=109)	Staff (n=8)
18-20	21.2%	12.5%	Female	31.7%	12.5%
21-30	38.5%	50.0%	Male	65.5%	87.5%
31-40	10.6%	0.0	Other	1.0%	0.0
41-50	4.8%	37.5%			
More than 50	19.2%	0.0			

Table 9 shows respondents' distribution based on facility usage patterns including the start time of their visit (Start_Sess), the duration of each visit (Visit_Dur), the number of visits per week (Num_Visit), and the length of time the respondents have been using the facility since their very first visit (Use_Sinc).

Table 9 Distribution of gym user respondents based on facility usage patterns, Summer 2019.

Start_Sess		Visit_Dur (hour)		Num_Visit (/week)		Use_Sinc (month)	
Before 9 AM	12.5%	< 0.5	2.9%	< 1	1.9%	<3	6.7%
9 AM - 12 PM	10.6%	0.5 to 1	23.1%	1	1.9%	3-6	4.8%
12 PM - 3 PM	21.2%	1-2	59.6%	2-3	33.7%	6-12	18.3%
3 PM - 5 PM	18.3%	> 2	14.4%	> 3	62.5%	>12	68.3%
5 PM - 7 PM	32.7%						
After 7 PM	3.8%						

According to Table 9, more than one-third of the gym users visited the facility between 5:00 PM and 7:00 PM. This finding was in line with the reported daily occupancy patterns by the University of Manitoba (2019) in which the maximum occupancy level in the Summer was observed at 4:00 PM, while 5:00 PM and 6:00 PM had the second-highest occupancy rates (Figure 3). Knowing the fact that around 60% of respondents were students and 37.5% were also affiliated with the University of Manitoba, they would possibly prefer to exercise after working hours (i.e., in the evening). Approximately, 60% of respondents visited the ALC for one to two hours at a time, and nearly 62% visited the ALC more than three times per week. Around 68% had been using the ALC for more than one year. The survey results also showed that 75% of the staff had been working in the facility for more than one year, and 87.5% for more than 30 hours a week.

Table 10 summarizes respondents' ratings with respect to their satisfaction, perception, and preference with different aspects of the thermal conditions of the ALC in the Summer of 2019. These aspects included satisfaction with air temperature (SAT_T), satisfaction with relative humidity (SAT_RH), satisfaction with airflow (SAT_AirFlow), satisfaction with surface temperature (SAT_TSurf), thermal sensation (T_Sense), preferred temperature (T_Pref), and the effect of thermal conditions on their physical performance (T_Perform).

According to Table 10, the results showed that both the mean satisfaction rate with air temperature (SAT_T) and relative humidity (SAT_RH) were -0.22, and the mean satisfaction rate with airflow (SAT_AirFlow) was -0.18, all of which were between “Slightly dissatisfied (-1.0)” and “Neutral (0.0)”, and closer to “Neutral (0.0)”. On the other hand, the mean satisfaction rate with surface temperature (SAT_TSurf) was 0.56, which was between “Neutral (0.0)” and “Slightly satisfied

(+1.0)”. These numbers imply that occupants were somewhat satisfied with surface temperature and less satisfied with air temperature, relative humidity, and airflow in the ALC in the Summer of 2019. The mean thermal sensation (T_Sense) was 0.65 and thus between “Neutral (0.0)” and “Slightly warm (+1.0)”. Moreover, gym users preferred temperature to be slightly cooler as their mean rating of T_Pref was -0.80, which was close to “Slightly cooler (-1.0)”. Respondents’ temperature preference was in line with thermal sensation since they perceived air as somewhat warm and thus preferred lower temperatures. Lastly, they perceived that the thermal conditions in the ALC had partly a negative effect on their abilities to exercise there since they rated T_Perform as -0.40 (between -1.0 and 0.0). This perceived partial negative effect could be due to relatively lower satisfaction with air temperature, relative humidity, and airflow. The maximum and minimum values in Table 10 demonstrate that some gym users selected the highest and lowest possible rates. Temperature preference and satisfaction with airflow had the lowest and highest standard deviations of 1.29, and 1.82, respectively, indicating the lowest variations in responses to temperature preference and the highest variation in responses to satisfaction with airflow.

Staff’s descriptive statistics in Table 10 showed that all mean satisfaction rates were between “Neutral (0.0)” and “Slightly satisfied (+1.0)”, while their SAT_RH and SAT_AirFlow had the highest and lowest mean rates of 0.63 and 0.13, respectively. The maximum rate of T_Sense chosen by the staff was “Neutral (0.0)”, indicating that none of them perceived the air as warm. The mean T_Sense of -1.62, which was in the range of “Cool (-2.0)” to “Slightly cool (-1.0)” showed that the staff found their offices to be cool.

Table 10 Descriptive statists on respondents' thermal conditions perceptions, Summer 2019.

Respondents	Statistics	SAT_T	SAT_RH	SAT_AirFlow	SAT_TSurf	T_Sense	T_Pref	T_Perform
Gym users (*n=104)	Min	-3.0	-3.0	-3.0	-3.0	-3.0	-3.0	-3.0
	Max	3.0	3.0	3.0	3.0	3.0	3.0	3.0
	Mean	-0.22	-0.22	-0.18	0.56	0.65	-0.80	-0.40
	Std. Dev	1.73	1.75	1.82	1.41	1.63	1.29	1.43
Staff (n=8)	Min	-3.0	-2.0	-2.0	-2.0	-3.0	-2.0	-2.0
	Max	3.0	3.0	3.0	3.0	0.0	3.0	3.0
	Mean	0.25	0.63	0.13	0.25	-1.62	0.00	0.13
	Std. Dev	2.12	1.68	1.73	1.90	1.06	1.85	1.46

*Number of participants

On the other hand, the mean T_Pref was “Neutral (0.0)”, implying that the staff on average would not like to see any changes to their offices' temperatures, which can be interpreted as them being happy with their offices being cool. They also perceived that the offices’ thermal conditions did not affect their physical performance as the mean T_Perform was 0.13, and thus very close to “Neutral (0.0)”. Standard deviation values showed that thermal sensation rates had the lowest variations at 1.06, indicating that among all seven aspects, the closest responses to the mean value were observed in this aspect. This explains why there was consensus on perceiving air in the range of “Cool (-2.0)” to “Slightly cool (-1.0)”. The high standard deviation of 2.12 with respect to satisfaction with air temperature (SAT_T) was noticeable, leading to a mean satisfaction rate with an air temperature of 0.25. Therefore, staff in different offices had very different levels of satisfaction with air temperature.

According to the results, staff respondents were more satisfied with thermal conditions (except for surface temperature) and perceived the air as cooler, compared to gym users, in the Summer of 2019.

Table 11 summarizes respondents’ feedback with respect to IAQ, including the level of satisfaction with IAQ (SAT_IAQ), whether the air was smelly (Air_Smell), stuffy (Air_Stuffy), and dusty (Air_Dusty), and the effect of IAQ on respondents’ physical performance (IAQ_Perform). On average, gym users rated their satisfaction with IAQ as 0.71, which was between “Neutral (0.0)” to “Slightly satisfied (+1.0)”.

Table 11 Descriptive statistics of respondents' IAQ perceptions, Summer 2019.

Respondents	Statistics	SAT_IAQ	Air_Smell	Air_Stuffy	Air_Dusty	IAQ_Perform
Gym users (n=104)	Min	-3.0	-3.0	-3.0	-3.0	-3.0
	Max	3.0	3.0	3.0	3.0	3.0
	Mean	0.71	0.98	0.12	1.31	0.07
	Std. Dev	1.77	1.75	1.88	1.64	1.36
Staff (*n=8)	Min	-2.0	-1.0	-3.0	-1.0	-2.0
	Max	3.0	3.0	3.0	3.0	3.0
	Mean	1.75	1.75	1.00	1.63	0.13
	Std. Dev	1.58	1.48	1.92	1.41	1.36

Also, gym users did not believe that the air was smelly or dusty since the average rates of Air_Smell and Air_Dusty were 0.98 and 1.31 (close to “Slightly disagree: (+1)”), respectively. However, Air_Stuffy had the lowest score of 0.12 (close to “Neutral (0.0)”) among these three, which suggests gym users did not agree or disagree that the air was stuffy in the third level of ALC in the Summer 0f 2019. On average, IAQ had almost no effect on users' physical performance since the mean rate of IAQ_Perform, 0.07, was close to 0.0 or “No effect”.

The mean rate of staff's SAT_IAQ was 1.75, which is mostly close to “Satisfied (+2.0)”. None of the staff was “Very dissatisfied”. Respondents also did not agree that the air was smelly, dusty, and stuffy, as the mean rates of Air_Smell, Air_Dusty, and Air_Stuffy were 1.75, 1.63, and 1.0, respectively, all of which were in the range of “Slightly disagree” (+1.0)” to “Disagree” (+2.0)”. Although the responses to these three aspects implied that staff did not perceive the air as smelly, dusty, or stuffy, the lower mean rate of Air_Stuffy indicates respondents were more concerned about air stuffiness compared to air smell and dustiness. Similar to gym users, IAQ had almost no positive or negative effect on the staff's physical performance as the mean IAQ_Perform was 0.13, close to "No effect (0.0)".

Overall, staff respondents were more satisfied with IAQ compared to gym users, in the Summer of 2019.

Table 12 shows the distribution of respondents based on their level of satisfaction with various parameters. In this table, "Dissatisfied" includes three rates of "Very dissatisfied", "Dissatisfied", and "Slightly dissatisfied", while "Satisfied" includes three rates of" Very satisfied", Satisfied", and "Slightly satisfied".

Table 12 Distribution of respondents based on thermal conditions and IAQ perceptions, Summer 2019.

Respondents	Rating	SAT_T	SAT_RH	SAT_AirFlow	SAT_TSurf	SAT_IAQ
Gym users (n=104)	Dissatisfied	48.1%	44.2%	46.2%	16.3%	29.8%
	Satisfied	31.7%	29.8%	35.6%	40.4%	58.7%
	Neutral	19.2%	25.0%	17.3%	42.3%	9.6%
Staff (n=8)	Dissatisfied	37.5%	25.0%	25.0%	37.5%	12.5%
	Satisfied	50.0%	50.0%	25.0%	37.5%	87.5%
	Neutral	12.5%	25.0%	50.0%	25.0%	0.0

Approximately, 59% of gym users were "Satisfied" with IAQ (SAT_IAQ), whereas nearly 32% were "Satisfied" with air temperature (SAT_T). The users were mostly "Dissatisfied" with air temperature (48.1%) as opposed to surface temperature (SAT_TSurf) (16.3%). In the questionnaire, two questions enquired about whether gym users had complained about the thermal conditions and IAQ of the ALC to the staff or managers. Although nearly 90% explained they had never complained about the ALC's thermal conditions and IAQ, around 60% explained they would like to change the facility's temperature and airflow. These answers were in line with occupants' lower rate of satisfaction with air temperature, relative humidity, and airflow.

Cianfanelli et al. (2016) studied two sports facilities in Italy between January and May 2015 and found that 55% of gym users were "Very satisfied" with air temperature, 41% were "Satisfied", and no one was "Dissatisfied". Moreover, 59% were "Satisfied" with air humidity and 23% were "Not very dissatisfied". The responses used a four-point scale of "Dissatisfied", "Not very satisfied", "Satisfied" and "Very satisfied". The gym users' lower rate of satisfaction with air temperature and relative humidity contrasts with results by Cianfanelli et al. (2016). An important difference between those two studies is that the ALC's data were collected in the Summer, while Cianfanelli et al. (2016) surveyed the participants between January and May. These seasonal differences should be taken into account. Other factors such as the buildings' design (HVAC systems specifically) could also contribute to the difference between dissatisfaction rates in the two studies. As mentioned previously, the ASHRAE standard (ASHRAE 2013) contains a thermal satisfaction survey for the long-term assessment of occupants' satisfaction with thermal comfort. The standard specifies that a rating between "Neutral (0.0)" to "Very satisfied (+3.0)" indicates a satisfactory thermal environment. A benchmark study by the Centre of Built Environment (CBE) and referred by ASHRAE (2013) showed that 40% of respondents rated their satisfaction level below that acceptable threshold (i.e., below satisfaction level of 0.0 to +3.0). In the current research, almost 48% of respondents rated their satisfaction with temperature below that threshold of 0.0 to +3.0, as shown in Table 12. Therefore, the dissatisfaction rate of gym users was even higher than the mentioned benchmark study.

With respect to staff, as shown in Table 12, the majority of them (87.5%) were satisfied with IAQ, while 50.0% were satisfied with air temperature and relative humidity, and 25.0% with airflow. Considering that the ALC is a relatively new building (i.e., built in 2015) with a green design with specific IAQ requirements (as listed in Table 2), a high number of respondents being “Satisfied” with SAT_IAQ was expected. Among the five factors shown in Table 12, the number of staff respondents who were “Dissatisfied” with surface temperature and air temperature was the highest (i.e., both at 37.5%). Twenty-five percent of the staff declared they had complained about the thermal conditions of their offices, but no one had complained about indoor air quality. Moreover, 87.5% said they would like to be able to adjust their offices’ temperature by themselves, while 50% answered Yes to the same question about having the ability to adjust airflow themselves. These outcomes demonstrate the tendency for occupants to have direct control of their environment. Only 37.5% of the staff rated their satisfaction with air temperature below the accepted threshold defined by ASHRAE (2013) and explained earlier. This result was better than the reported 40% dissatisfaction in the CBE survey benchmark database.

Table 13 shows that more than half of the gym users believed the air was “Warm” (i.e., “Slightly Warmer”, “Warmer”, and “Hot”) and around 61% preferred it to be “Cooler” (i.e., “Slightly cooler”, “Cooler”, and “Much cooler”). As discussed in the second chapter, Revel & Arnesano (2014b) showed that around 40% of gym respondents in Italy wanted to have “No change” in air temperatures whereas nearly 30% preferred the air to be “Slightly cooler”, and 10% wanted it to be “Cooler”, in April. Therefore, a total of 40% preferred cooler air compared with 61% in the ALC.

Table 13 Distribution of respondents based on thermal sensations and preferences, Summer 2019.

Respondents	T_Sense		T_Pref	
Gym users (n=104)	Warm	53.8%	Cooler	61.5%
	Cool	25.0%	Warmer	14.4%
	Neutral	18.3%	Neutral	23.1%
Staff (n=8)	Warm	0.0	Cooler	50.0%
	Cool	87.5%	Warmer	37.5%
	Neutral	12.5%	Neutral	12.5%

Although T levels in the gym were lower than in the offices, as shown in Table 7, 25% of gym users perceived the gym as “Cool” as opposed to 87.5% of the staff that believed that their offices were “Cool”. This major difference could be the result of higher metabolic rates for gym users as well as higher RH levels in the gym affecting users’ thermal sensation. Fifty percent of staff wanted the air to be “Cooler”, and 37.5% preferred “Warmer” air. Interestingly, even though 87.5% of all staff believed that their offices were “Cool”, only 37.5% preferred “Warmer” air.

4.1.2.2 Inferential Statistics

This subsection investigates the potential relationships between questionnaire responses’ different aspects in the Summer season.

4.1.2.2.1 Demography

The Spearman rank-order correlation test showed that gym users’ age was not statistically significantly correlated with thermal comfort parameters such as satisfaction with air temperature, relative humidity, airflow, and surface temperatures, as well as thermal sensation, thermal preference, and perception of the effect of thermal conditions on users’ performance. Age was also not statistically significantly correlated with IAQ parameters such as satisfaction with indoor air quality and perception of the effect of IAQ on users' performance. Almost 70.0% of respondents had been using the facility for more than one year, but there was no statistically significant correlation between how long they had been using the facility for and their satisfaction with any of these parameters. Furthermore, the duration of each visit, the number of visits per week, and the start time of sessions were not statistically significantly correlated with thermal comfort and IAQ aspects. The rank biserial correlation showed there was no statistically significant correlation between gender and any of the ordinal variables related to thermal comfort and IAQ. Indraganti et al., (2015) investigated thermal comfort in offices in India and found that females, young subjects, and people with low body mass index had higher comfort temperatures than males, older people, and obese occupants respectively. However, female respondents in the current research had higher thermal sensation than male respondents (i.e., 0.9 vs 0.5, both between "Neutral (0.0)" to "Slightly warm (+1.0)"). Their satisfaction with air temperature was lower than male participants (i.e., -0.51 vs -0.09, as between "Slightly dissatisfied (-1.0)" to "Neutral (0.0)"), and their satisfaction with relative humidity was lower than male participants (i.e., -0.57 vs -0.07, as between "Slightly dissatisfied (-1.0)" to "Neutral (0.0)"). Also, female respondents had a lower satisfaction rate with air quality (i.e., 0.36 vs 0.88, both between "Neutral (0.0)" to "Slightly satisfied (+1.0)"). Thermal sensation increased with age (i.e., 0.5 for respondents between 18 to 30, and 0.95 for respondents older than 50, both between "Neutral (0.0)" to "Slightly warm (+1.0)"). Overall, despite the lack of statistically significant correlations between demographics factors and IEQ satisfaction and perception, the results showed that younger and male respondents had lower thermal sensations than older and female respondents, respectively. Staff's data were not assessed in this section, because the sample size was far too small to enable this type of analysis.

4.1.2.2.2 Thermal Comfort

As per Table 14, the Spearman rank-order correlation test showed that gym users' satisfaction with air temperature (SAT_T) was statistically significantly correlated to their satisfaction with relative humidity (SAT_RH), airflow (SAT_AirFlow), and surface temperature (SAT_TSurf), with correlation coefficients of 0.63, 0.60, and 0.40, respectively. The first correlation was strong, while the other two were moderate. These correlations were expected because air temperature, relative humidity, air velocity, and mean radiant temperature (which is affected by surface temperature) are the physical factors that define thermal comfort. Moreover, users' SAT_T was statistically significantly correlated with their perception of thermal condition effect on their performance (T_Perform) and temperature preference (T_Pref). The first correlation of 0.64 was strong, while the second one, 0.36, was weak.

Unlike the users' responses, there was no statistically significant correlation between the staff's SAT_T and SAT_AirFlow. Albeit, two statistically significant strong correlations of 0.91 and 0.79 existed between their SAT_T and SAT_RH, and between their SAT_T and SAT_TSurf, respectively. The inconsistency between users and staff's survey results could be due to the smaller sample size of staff.

Table 15 is focused on the correlations between respondents' thermal sensation and their perception of other thermal condition aspects. Gym users' thermal sensation (T_Sense) was statistically significantly correlated to their satisfaction with air temperature (SAT_T), relative humidity (SAT_RH), and airflow (SAT_AirFlow).

Table 14 Correlations of different aspects of respondents' thermal conditions perceptions, Summer 2019.

Respondents	Statistical parameters	SAT_T SAT_RH	SAT_T SAT_AirFlow	SAT_T SAT_TSurf	SAT_T T_Perform	SAT_T T_Pref
Gym users (n=104)	Correlation coefficient	0.63	0.6.0	0.40	0.64	0.36
	P-value	<0.0005	<0.0005	<0.0005	<0.0005	<0.0005
Staff (n=8)	Correlation coefficient	0.91	Not correlated	0.79	Not correlated	Not correlated
	P-value	<0.05		<0.05		

Table 15 Correlations of thermal sensation and other thermal conditions perceptions, Summer 2019.

Respondents	Statistical Parameters	T_Sense SAT_T	T_Sense SAT_RH	T_Sense SAT_AirFlow	T_Sense T_Pref	T_Sense T_Perform	T_Sense SAT_TSurf
Gym users (n=104)	Correlation coefficient	-0.50	-0.48	-0.40	-0.56	0.33	Not correlated
	P-value	<0.0005	<0.0005	<0.0005	<0.0005	<0.01	
Staff (n=8)	Correlation coefficient	Not correlated	Not correlated	0.74	Not correlated	0.90	0.87
	P-value			<0.05		<0.05	<0.05

Given that thermal comfort is the subjective sensation of thermal condition expressed as thermal sensation and is affected by air temperature, relative humidity, air velocity, and mean radiant surface temperature, these correlations were expected. All three correlations were negative and moderate as -0.50, -0.48, and -0.48, respectively. The negative correlations here imply an inverse relationship between T_Sense scaled from "-3.0: Cold" to "+3.0: Hot" and SAT_T, SAT_RH, SAT_AirFlow, all of which were scaled from "-3.0: Very dissatisfied" to "+3.0: Very Satisfied". Higher rates of thermal sensation (i.e., rates closer to "Hot") are expected to be associated with lower rates of satisfaction (i.e., the rates closer to "Very dissatisfied"). Likewise, there was a statistically significant negative moderate correlation of -0.56 between T_Sense and temperature preference (T_Pref), and a statistically significant positive weak correlation of 0.33 between T_Sense and the perception of the effect of thermal condition on users' physical performance (T_Perform). The negative correlation between T_Sense and T_Pref implied that higher sensations of temperatures led to preferences for lower temperatures. Gym users who rated their T_Sense between "Neutral" to "Hot", preferred temperatures between "Neutral" to "Much cooler". Users' T_Sense was not correlated with their satisfaction with surface temperature (SAT_TSurf). They would not probably consider surface temperature when thinking about their thermal sensation.

With respect to staff's results in Table 15, no statistically significant correlation was observed between their thermal sensation (T_Sense) on one hand and their satisfaction with air temperature SAT_T, relative humidity (SAT_RH), and temperature preference (T_Pref), on the other hand. The lack of correlation between T_Sense and T_Pref in Table 15 can be seen in the fact that although 87.5% of staff respondents perceived air as "Cool", and their mean thermal sensation vote was -1.62, between "Cool (-2.0)" to "Slightly cool (-1.0)", 50% still wanted the air to be

“Cooler”, while the mean rate of temperature preference by all staff respondents was 0.0 or “Neutral”. This observation that the staff had very different thermal comfort perceptions and preferences was not expected. A larger sample size of staff respondents would have helped identify whether these unexpected results were still valid, and would have thus highlighted the importance of the personal comfort models developed by Kim et al., (2018). Staff perceived that cool air positively affected their performance, as the strong statistically significant correlation of 0.90 between their T_Sense and T_Perform showed. Moreover, T_Sense and SAT_AirFlow, as well as T_Sense and SAT_TSurf were statistically significantly correlated, with strong correlation coefficients of 0.74, 0.90, 0.87, respectively. These results are also inconsistent with those for gym users’ feedback, as their comparison in Table 15 shows. A larger sample size of staff would probably provide a better distribution of responses.

In the next step, ordinal logistic regression was used to assess the effect of gym users’ satisfaction with air temperature (SAT_T), relative humidity (SAT_RH), and airflow (SAT_AirFlow) on thermal sensation (T_Sense) as the measure of thermal comfort. Multicollinearity was observed as the tolerance values of relative humidity were less than 0.1. Therefore, this variable was removed from the model, and the test was repeated. The assumption of proportional odds was not met, as assessed by a full likelihood ratio test comparing the fitted model to a model with varying location parameters $\chi 2(60) = 98.34$, $p < 0.05$. To deal with this violation of the test’s assumptions, multinomial logistic regression was run in the next step. Eight outliers were detected as assessed by visual inspection of box plots. However, the outliers were kept in the dataset because they were not due to errors in data entry, or unusual values, but were among options in the survey that respondents could choose from when answering questions. Both Pearson and Deviance goodness-of-fit tests indicated that the model was not a good fit to the observed data. Besides, none of the variables of SAT_T or SAT_RH had a statistically significant effect on thermal sensation. This result denotes that it was not possible to predict T_Sense based on the received responses on SAT_T and SAT_RH.

In another test, ordinal logistic regression was run to determine the effect of gym users' satisfaction with air humidity (SAT_RH), airflow (SAT_AirFlow), and surface temperatures (SAT_TSurf) on their satisfaction with air temperature (SAT_T). Multicollinearity was observed as the tolerance values of SAT_RH were less than 0.1. To deal with this violation of the test's assumption, SAT_RH was removed from the model. The assumption of proportional odds was thus met, as assessed by a full likelihood ratio test comparing the fitted model to a model with varying location parameters, $\chi^2(60) = 44.60$, $p = 0.93$. The deviance goodness-of-fit test indicated that the model was a good fit to the observed data, $\chi^2(162) = 121.98$, $p = 0.99$. The final model statistically significantly predicted the dependent variable over and above the intercept-only model, $\chi^2(12) = 66.61$, $p < 0.0005$. SAT_AirFlow had a statistically significant effect on the prediction of SAT_T, Wald $\chi^2(6) = 29.12$, $p < 0.0005$. The odds of users "Very dissatisfied" with airflow who rated their satisfaction with air temperature as "Very satisfied" was 0.04 (95% CI, 0.00 to 0.04) times of who rated SAT_AirFlow as "Very satisfied", a statistically significant effect, $\chi^2(1) = 19.57$, $p < 0.0005$. This meant that gym users who rated their satisfaction with airflow as "Very satisfied" were 25 times more likely to find temperature as very satisfactory as opposed to users who were "Very dissatisfied" with airflow. The odds of gym users "Satisfied" with airflow who rated their satisfaction with air temperature as "Very satisfied," was 0.08 (95% CI, 0.009 to 0.76) times those who rated SAT_AirFlow as "Very satisfied", a statistically significant effect, $\chi^2(1) = 4.87$, p

=0.027. It implies that gym users who rated their satisfaction with airflow as “Very satisfied” were 11.9 times more likely to find temperature as very satisfactory as opposed to users who were “Satisfied” with airflow. Tests of Model Effects showed that satisfaction with surface temperatures did not have a statistically significant effect on the prediction of satisfaction with air temperature, Wald $\chi^2(6) = 2.63$, p=0.85.

Ordinal logistic regression was not applied to the staff’s feedback since the sample size was too small, and three out of six paired aspects were not statistically significantly correlated, as shown in Table 15.

4.1.2.2.3 Indoor Air Quality

The Spearman rank-order correlation test showed that gym users’ satisfaction with indoor air quality (SAT_IAQ) was statistically significantly correlated to their rating of air stuffiness (Air_Stuffy), as the statistically significant strong correlation of 0.63 in Table 16 shows. Also, the users’ SAT_IAQ was statistically significantly correlated with their perception of air smell (Air_Smell), with a moderate correlation coefficient of 0.49. As per Table 16, the gym users’ SAT_IAQ was also statistically significantly correlated with their perception of air dustiness (Air_Dusty), with a moderate correlation coefficient of 0.56. Moreover, there was a statistically significant moderate correlation of 0.46 between their SAT_IAQ and the perception of IAQ effect on their performance (IAQ_Perform).

Table 16 Correlations of different aspects of respondents' IAQ perceptions, Summer 2019.

Respondents	Statistical parameters	SAT_IAQ Air_Smell	SAT_IAQ Air_Stuffy	SAT_IAQ Air_Dusty	SAT_IAQ IAQ_Perform
Gym users (n=104)	Correlation coefficient	0.49	0.63	0.56	0.46
	P-value	<0.0005	<0.0005	<0.0005	<0.0005
Staff (n=8)	Correlation coefficient	Not correlated	0.77	Not correlated	0.82
	P-value		<0.05		<0.05

Unlike users, the staff's SAT_IAQ was not statistically significantly correlated with their perception of Air_Smell and Air_Dusty. Nevertheless, the staff's SAT_IAQ was statistically significantly correlated with the perception of Air_Stuffy, and IAQ_Perform, with strong correlation coefficients of 0.77 and 0.82, respectively. Staff's descriptive results in Table 11 showed that the mean rate of IAQ_Perform was 0.13 (i.e., close to "No effect"), while the mean rate of SAT_IAQ was 1.75 (i.e., close to "Satisfied"). Therefore, the strong correlation between SAT_IAQ and IAQ_Perform was not expected. However, the strong correlation coefficient of 0.77 between satisfaction with IAQ and the perception of air stuffiness is consistent with the mean rate of 1.0 for Air_Stuffy (i.e., "Slightly disagree" that air was stuffy) and the mean rate of 1.75 for SAT_IAQ (i.e., close to "Satisfied"). As per Table 12, 87.5% of staff were satisfied with IAQ in the offices.

The Ordinal logistic regression test used to assess the effect of respondents' ratings of air smell (Air_Smell), air stuffiness (Air_Stuffy), and air dustiness (Air_Dusty) on their satisfaction with indoor air quality (SAT_IAQ) showed that all tolerance values were more than 0.1, and that multicollinearity did not exist. However, the assumption of proportional odds was not met, and multinomial logistic regression was run instead. No multicollinearity and no outliers were observed. Pearson and Deviance Chi-Square values revealed different results of the goodness of the model fit. The Pearson goodness of fit showed the model did not fit the data well, $\chi^2(252) = 498.13$, $p < 0 .0005$. On the other hand, the deviance goodness of fit showed the model fit the data well, $\chi^2(252) = 167.02$, $p =0.89$. These two measures might not always give the same results (Leard Statistics, 2019). Model Fitting Information showed that the full model did not statistically significantly predict the dependent variable better than the intercept-only model, $\chi^2(108) = 122.34$, $p > 0.05$. Only Air_Dusty was statistically significant in the model prediction, $\chi^2(36) = 171.26$, $p < 0.0005$. Parameters estimates showed that the only statistically significant coefficients were Air_Dusty = 0.0, $p = 0.048$, for rating SAT_IAQ as “Very dissatisfied” in comparison with “Very satisfied”, Air_Stuffy = -1.0, $p = 0.034$ for rating SAT_IAQ as “Slightly dissatisfied” in comparison with “Very satisfied”, and Air_Stuffy = -1.0, $p = 0.048$ for rating SAT_IAQ as “Satisfied” in comparison with “Very satisfied”. This effectively meant it was more likely that gym users would feel “Very dissatisfied” with indoor air quality rather than “Very satisfied” if they were “Neutral” regarding the perception of air dustiness. Moreover, it was more likely that gym users would feel “Slightly dissatisfied” with IAQ rather than “Very satisfied” if they “Slightly agreed” that air was stuffy. Finally, it was more likely that the users would feel “Satisfied” with IAQ rather than “Very satisfied” if they “Slightly agreed” that air was stuffy.

Ordinal logistic regression was not used to assess the staff’s responses for investigating the effects of three perceptions (i.e., air smell, air stuffiness, and air dustiness) on their satisfaction with indoor air quality. Among those three items, staff ‘SAT_IAQ was only statistically significantly correlated with Air_Stuffy, as Table 16 showed before. Therefore, testing the combined effect of

Air_Dusty, Air_Stuffy, and Air_Smell perceptions on SAT_IAQ would not lead to meaningful results.

4.1.2.2.4 Thermal Comfort and Indoor Air Quality

The Spearman rank-order correlation test revealed there was a statistically significant moderate positive correlation between gym users' satisfaction with indoor air quality and their satisfaction with the aspects of air temperature, relative humidity, and airflow, as can be seen in Table 17. Besides, there was a statistically significant strong positive correlation between their perception of the effect of IAQ on their performance and their perception of the effect of thermal conditions on their performance. This confirms the importance of both thermal comfort and IAQ and the need to take both into account to ensure effective IEQ. Regarding staff's responses, none of the items were statistically significantly correlated together as shown in Table 17. Again, this could be due to the small number of staff respondents surveyed.

Table 17 Correlations of respondents' thermal comfort and IAQ perceptions, Summer 2019.

Respondents	Statistical parameters	SAT_IAQ SAT_T	SAT_IAQ SAT_RH	SAT_IAQ SAT_AirFlow	IAQ_Perform T_Perform
Gym users (n=104)	Correlation coefficient	0.58	0.55	0.49	0.67
	P-value	<0.0005	<0.0005	<0.0005	<0.0005
Staff (n=8)	Correlation coefficient	Not correlated	Not correlated	Not correlated	Not correlated
	P-value				

Overall, the inferential statistics results show a more consistent trend in gym users' responses compared to staff's responses. Gym users' satisfaction with air temperature was statistically significantly correlated to the other factors of thermal conditions (i.e., satisfaction with relative humidity, airflow, and surface temperature, as well as the perception of thermal condition effect on their performance, and temperature preference). Moreover, their thermal sensation was statistically significantly correlated to their satisfaction with air temperature, relative humidity, and airflow. Also, gym users' satisfaction with indoor air quality was statistically significantly correlated to their perception of air stuffiness, air smell, air dustiness, and the effect of IAQ on their performance. Lastly, gym users' satisfaction with indoor air quality was statistically significantly correlated to their satisfaction with thermal conditions aspects. No such trends were observed for staff's responses.

4.1.3 Surveys Feedback Versus Actual Conditions

Table 18 shows gym users' satisfaction with IAQ versus 15-minute CO_2 records, in the Summer of 2019. As per Table 18, 58.7% of the users were "Satisfied" with IAQ, when the maximum 15-minute CO_2 levels were 696.32 ppm and 799.49 ppm in June and July, respectively. According to Figure 4(a) shown previously, the maximum 1-hour mean CO_2 concentration in the Summer of 2019 was 620 ppm.

Table 18 Gym users' satisfaction with IAQ linked to physical CO_2 levels, Summer 2019.

SAT_IAQ				**15-minute CO_2 (ppm)**		
Statistics on ratings		Gym users distribution (n=104)		Statistics on values	June	July
Min	-3.0	Dissatisfied	29.8%	Min	423.97	401.26
Max	3.0	Satisfied	58.7%	Max	696.32	799.49
Mean	0.71	Neutral	9.62%	Mean	491.04	529.83
Std. Dev	1.77			Std. Dev	57.07	88.48

Alves et al. (2013) reported the minimum, maximum, and mean CO_2 concentrations in a gymnasium as 397.0 ppm, 787.0 ppm, and 468.0 ppm, respectively. Ramos et al. (2014) measured a number of indoor air pollutants in 11 gyms in Portugal and reported CO_2 levels between 1,116.0 ppm to 4,418.0 ppm. Therefore, CO_2 concentrations in the ALC were closer to the first study and less than the second. Interestingly, the 15-minute CO_2 levels in the studied gym of the ALC in the Summer of 2019 never exceeded 800.0 ppm. Hence, there was a consistency between the objective results of IAQ physical measurements and the subjective results obtained by surveys. Based on recorded CO_2 levels and the users' perception, the gym's IAQ appeared to be relatively satisfactory in the Summer of 2019. Although nearly 30% of gym users were categorized as "Dissatisfied" (i.e., including "Very dissatisfied", "Dissatisfied", and "Slightly dissatisfied") with IAQ, nearly 55% in this category chose "Slightly dissatisfied", and a total of 45% were "Very dissatisfied" or "Dissatisfied" with IAQ.

Table 19 shows gym users' satisfaction with relative humidity (SAT_RH) versus the 15-minute RH records, in the Summer of 2019. As per Table 19, 44.2% of the users were in the category of "Dissatisfied" with RH levels in the gym in the Summer of 2019. This occurred at a time the mean 1-hour RH levels were nearly 60%, as can be seen in Figure 4(b). About 70% of the 15-minute recorded RH levels in the return air ducts investigated in L300 were higher than 60% in July, whereas only 33% of RH levels in AHU5 and AHU7, and 22% of RH levels in AHU9 were above 60%, in June. Besides, Figure 4(b) showed that all average values in July were higher than 60%.

Table 19 Gym users' satisfaction with RH linked to physical RH levels, Summer 2019.

SAT_RH					**15-minute RH (%)**		
Statistics on ratings		Gym users Distribution (n=104)			Statistics on values	June	July
Min	-3.0	Dissatisfied	44.2%		Min	25.45	42.05
Max	3.0	Satisfied	29.8%		Max	77.45	79.72
Mean	-0.22	Neutral	25.0%		Mean	52.19	65.85
Std. Dev	1.75				Std. Dev	11.92	8.99

These high RH levels explain occupants' low satisfaction with RH levels in the gym. In looking at the literature, Alves et al. (2013) reported that the minimum, maximum, and mean RH levels for a gymnasium were 10.8%, 37.3%, and 25.8%, respectively. Four-day measurements in a gym by Revel & Arnesano, (2014b) showed that the minimum, maximum, and mean RH levels were 49.6%, 73.5%, and 57.1%, respectively. Cianfanelli et al. (2016) reported RH at 58.6% in a gymnasium in Italy. Ramos et al. (2014) measured RH levels in 11 gyms in Portugal and found the values to be between 19% and 86%. The current research showed that RH levels in the ALC's gym in the Summer of 2019 were far higher than the value reported by Alves et al. (2013), but closer to the levels observed by Revel and Arnesano (2014). It can be concluded that the lower percentage of satisfied respondents with RH (29.8%) and their mean rate of -0.22 are consistent with the mean RH levels of 60%, in the Summer of 2019. Lower RH values would improve thermal comfort in the ALC. Moreover, the various ranges of RH levels measured in different studies reinforce the need to establish standards and guidelines for acceptable RH levels in the fitness areas specifically.

Comparing Figure 4(c) with Table 20 reveals that 48.1% of gym users were dissatisfied with the range of mean 1-hour temperatures as 19.4 ℃ to 20.26 ℃ observed for a representative 24-hour period in the Summer of 2019. The maximum level of 20.26 ℃ was recorded at 6:00 PM. According to Table 20 and Figure 4(c), the maximum 15-minute recorded temperatures in June and July 2019 were almost 21 ℃, and the mean 1-hour temperatures in July were slightly higher than in June. These temperature levels could be the reason that 53.8% of gym users rated their thermal sensation as “Warm” and 61.5% preferred to have a “Cooler” environment.

Alves et al. (2013) reported that the minimum, maximum, and mean T levels in a gymnasium as 20.4 ℃, 36.6 ℃, and 29.0℃, respectively. Four-day measurements in a gym by Revel and Arnesano (2014 b) showed that the minimum, maximum, and mean T levels were 15.4 ℃, 22.0 ℃, and 19.9 ℃, respectively. Cianfanelli et al. (2016) reported T as 16.5 ℃ in a gymnasium in Italy. Ramos et al. (2014) measured T levels in 11 gyms in Portugal and found the values to be between 15.0 and 25.0 ℃. Temperatures in the ALC were lower than the values reported by Alves et al. (2013) and Revel and Arnesano (2014 b). However, the survey results, as summarized in Table 20, show that those temperature levels led to unsatisfactory thermal conditions for 44% of gym users in the ALC, thus the need to improve the facility’s thermal comfort. On the other hand, these various ranges of temperature levels measured in different studies reinforce the need to establish standards and guidelines for acceptable temperatures in fitness areas specifically.

Overall, the results show that the gym’s CO_2 levels provided relatively satisfactory IAQ, while RH and T levels resulted in a less satisfactory thermal conditions in the gym in the Summer 2019.

Table 20 Gym users' satisfaction, perception, and preference with respect to T, linked to physical T levels, Summer 2019.

SAT_T				**T_Sense**		**T_Pref**		**15-minute T(°C)**		
Statistics on ratings		Gym users distribution (n=104)		Gym users distribution (n=104)		Gym users distribution (n=104)		Statistics on values	June	July
Min	-3.0	Dissatisfied	48.1%	Warm	53.8%	Cooler	61.5%	Min	18.86	19.20
Max	3.0	Satisfied	31.7%	Cool	25.0%	Warmer	14.4%	Max	21.02	21.14
Mean	-0.22	Neutral	19.2%	Neutral	18.3%	Neutral	23.1%	Mean	19.64	19.80

4.2 Fall

Unlike the Summer in which 104 respondents filled out the survey in the gym, only 49 users completed the survey in the Fall. In the following subsection, the results of the surveys conducted in October 2019 as well as the data collected for T, RH, and CO_2 in the Fall are presented. In the last subsection, the feedback received from the survey is compared to the actual physical environmental data.

4.2.1 Physical Indoor Environmental Quality Data

This section presents the results of analyzing collected T, RH, and CO_2 data in the ALC in the Fall of 2019. It starts by presenting the results of the descriptive statistics, followed by the results of the inferential statistics.

4.2.1.1 Descriptive Results

Table 21 shows the descriptive statistics for the 15-minute recorded T, RH, and CO_2 data in the gym, in September versus October 2019. Overall, the studied gym was warmer, more humid, and had higher CO_2 concentrations in September than in October.

As per Table 21, CO_2 concentrations in the gym were higher in September than in October 2019 since the mean CO_2 concentrations were 539.96 ppm and 502.97 ppm in September and October, respectively. Figure 6 shows the mean 1-hour CO_2, RH, and T in the gym for a representative day in September, October, and in the Fall (i.e., as the mean values of September and October). According to Figure 6(a), the 24-hour trend of CO_2 had two maximum points, the first around noon and the second in the evening, between 6:00 PM and 7:00 PM.

Table 21 Descriptive statistics on CO_2, RH, and T levels in the gym, Fall 2019.

Spaces	Statistics	CO_2 (PPM)		RH (%)		T(°C)	
		September	October	September	October	September	October
Gym	Min	416.20	405.71	26.27	19.58	19.100	19.23
	Max	901.75	723.04	76.39	52.34	22.37	21.31
	Mean	539.96	502.97	53.73	33.53	21.1	20.03
	Std. Dev	102.09	77.82	12.73	5.77	0.68	0.31
Offices	Min	423.81	429.76	24.78	18.62	20.55	20.84
	Max	789.44	675.52	73.27	43.93	22.22	21.55
	Mean	542.12	501.66	47.48	28.87	21.29	21.05
	Std. Dev	95.13	61.36	12.29	3.930	0.30	0.14

Figure 6(a) confirms that CO_2 concentrations were higher in September than in October, while the apex did not exceed 650 ppm in September. The graph clearly shows that the difference in CO_2 concentrations between occupied and unoccupied hours during the day was less than 200 ppm. This observation implies that the HVAC systems controlled CO_2 levels properly during the day. According to the extracted attendance patterns, the number of ALC users in September was nearly 1200 persons more than in October (University of Manitoba, 2019). This could be due to users being less busy with studies early in the semester. Therefore, higher CO_2 levels in September were expected.

According to Table 21, the minimum, maximum, and mean 15-minute RH levels in the gym were higher in September as well. The mean RH level in September was 53.73%, which was around 20% higher than in October. Also, the maximum RH level in September was almost 24% higher than in October. Figure 6(b) presents variations of mean 1-hour RH levels in September, October, and in the Fall (i.e., as the mean values of September and October). As per Figure 6(b), all RH levels were higher in September than in October. In addition, the variations in RH levels in a 24-hour period were less than 5%, in both September and October, with the two maximum points observed around noon and 8:00 PM.

Lastly, the gym's mean temperature in September was nearly 1 °C higher in September than in October, as shown in Table 1. As per Figure 6(c), the maximum temperature of approximately 20.40 °C was observed at 1:00 PM in both September and October, while temperatures were higher in September, overall. The difference between September and October's temperatures was more evident from 8:00 AM to 11:00 AM and from 5:00 PM to 10:00 PM. This observation was in line with attendance rates in the Fall. According to Figure 3, the peak attendance rate in the morning was at 11:00 AM in both Summer and Fall, with nearly 126 more persons in the Fall. Also, the peak attendance rate in the evening occurred at 4:00 PM in both Summer and Fall, with 60 more persons in the Fall. The peak temperatures of both seasons were almost concurrent with the first peak point of CO_2 levels occurring at the morning peak attendance rate. Therefore, CO_2 and T levels seem to have been directly affected by the number of occupants.

The overall trends were the same in the offices, with CO_2, RH, and T levels in those spaces (Table 21) being higher in September than in October, as shown in Table 21. Figure 7 shows the mean 1-hour CO_2, RH, and T trends for offices. According to Figure 7(a), CO_2 levels increased from 6:00 AM to 12:00 PM in both months. The values were almost constant between 12:00 PM and 8:00 PM in September, while had a slightly decreasing trend between 12:00 PM and 8:00 PM in October. CO_2 levels were higher in September than in October, overall. As per Figure 7(b), RH levels were constant, and almost 20% higher in September than in October. According to Figure

7(c), temperatures were higher in September, with the maximum recorded T of approximately 21.50 °C observed between 12:00 PM and 1:00 PM.

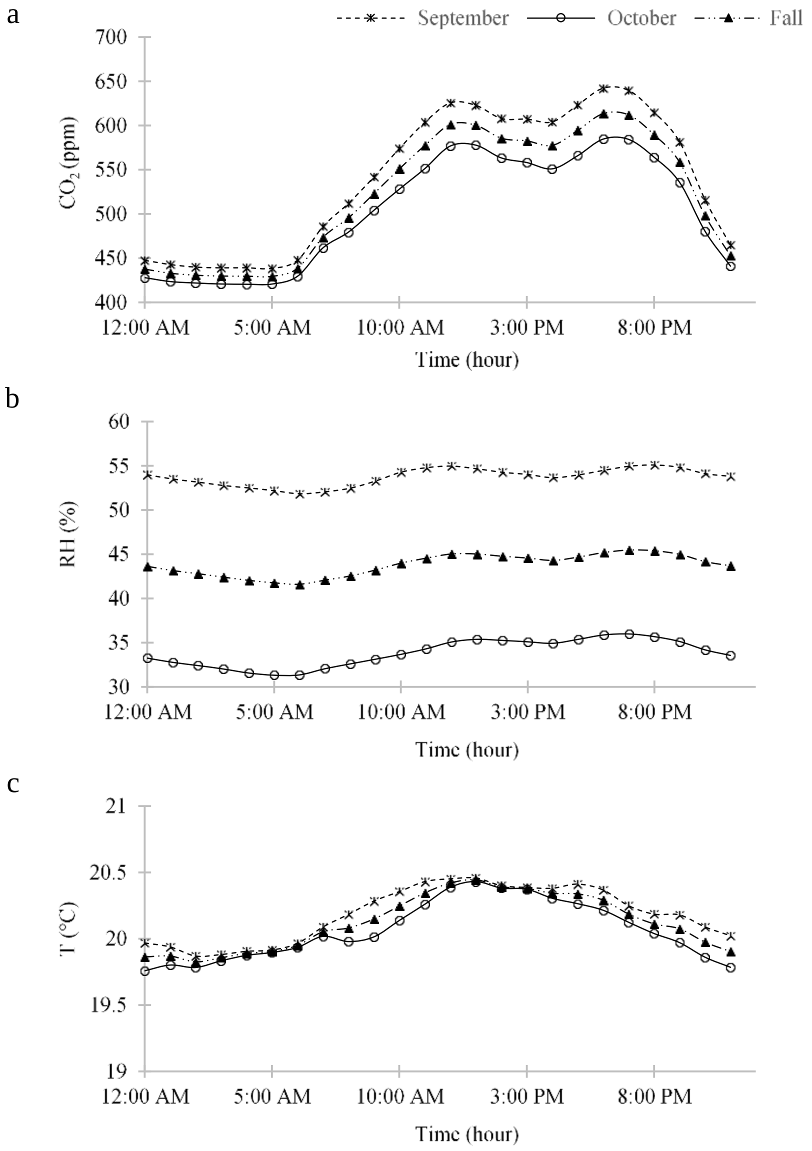

Figure 6 Variations of mean hourly a) CO_2, b) RH, and c) T in the gym, Fall 2019.

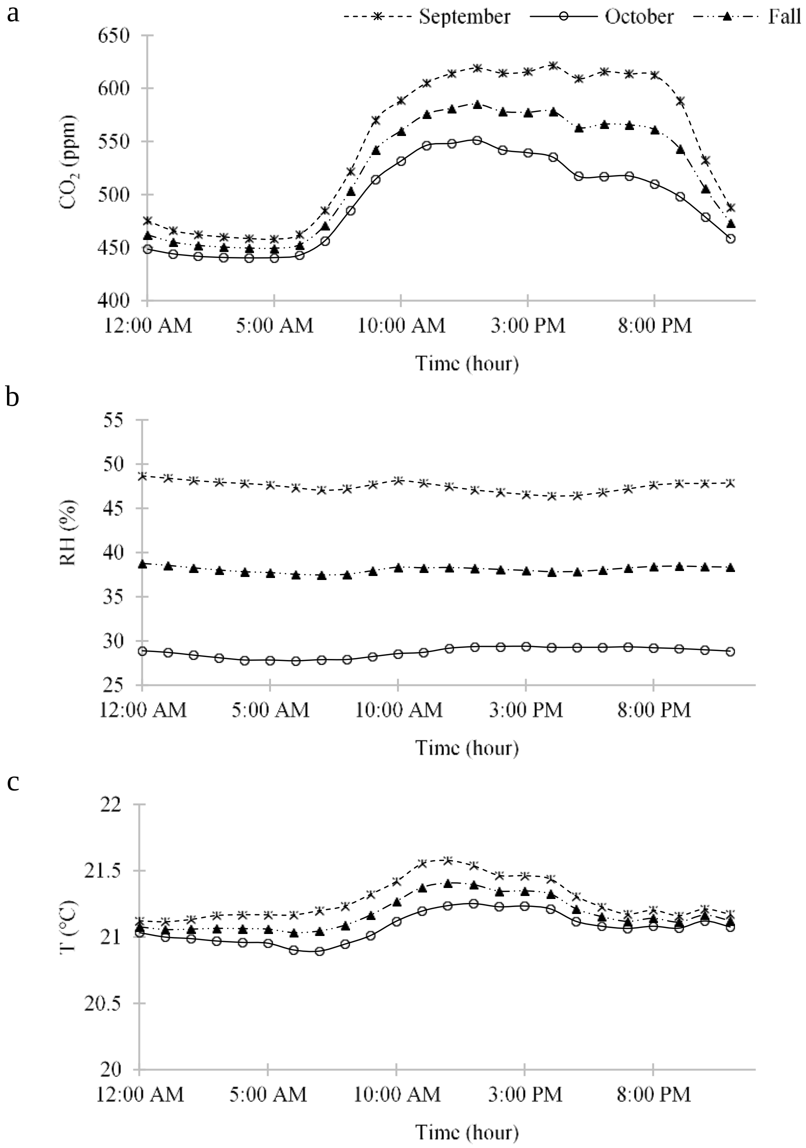

Figure 7 Variations of mean hourly a) CO$_2$, b) RH, and c) T in the offices, Fall 2019.

4.2.1.2 Inferential Statistics

A paired-samples t-test was used to determine whether there was a statistically significant mean difference in the gym's CO$_2$ levels in September versus October of 2019. Although 22 outliers were detected, the inspection of their values revealed they were not due to an error in data entry, measurements, or unusual values, but because of differences between September and October records. Hence, they were kept in the analysis. The assumption of normality was met, as assessed by visual inspection of a Normal Q-Q Plot. CO_2 levels were higher in September (539.98 ± 102.09 ppm) than in October (502.14 ± 77.60 ppm), a statistically significant increase of 37.84 ppm (95.00% CI, 34.87 to 40.82), t (2879) = 24.92, $p < 0.0005$, $d = 0.46$. The effect size of 0.46 represents practical medium importance of the difference between CO_2 levels in September and October. As discussed before, higher CO_2 levels in September were in line with the higher number of ALC users in that month, compared to October.

In the second test, another paired-samples t-test was used to investigate whether there was a statistically significant mean difference between RH levels in September and October. No outliers were detected by visual inspection of a boxplot. The assumption of normality was violated, as assessed by a Normal Q-Q Plot. However, the test was run regardless of this violation as the paired-samples t-test is robust to handle this violation (Leard Statistics, 2019). RH levels were lower in October (33.82 ± 5.60%) as opposed to September (53.73 ± 12.73%), a statistically significant decrease of 19.91 % (95.0% CI, 19.50 % to 20.31 %), t (2879) = 96.14, $p < .0005$, $d =1.79$. The effect size of 1.79 shows RH levels were strongly different in September and October.

The last paired-samples t-test was used to determine whether there was a statistically significant mean difference in the gym's temperatures between September and October. Fourteen outliers were detected. The inspection of their values revealed they were not due to an error in data entry, measurements, or unusual values, but because of differences between the September versus October records. Therefore, the outlies were kept in the analysis. The assumption of normality was violated, as assessed by the Normal Q-Q Plot. However, the test was run regardless of this violation as the paired-samples t-test is robust to handle this violation (Leard Statistics, 2019). Temperatures were higher in September (20.1 ± 0.67 °C) as opposed to the October (20.04 ± 0.31 °C), a statistically significant increase of 0.06 °C (95% CI, 0.03 °C to 0.09 °C), $t(2015) = 3.86$, $p < .0005$, $d = 0.08$. Although a statistically significant difference was found between the mean temperatures in September and October, this difference of 0.06 °C is very small and is thus not practically important. The effect size of 0.08 confirms that this statistically significant difference is not practically important. However, this difference was in line with the higher attendance rates in September as opposed to October.

4.2.2 Surveys

This section presents the results of the survey conducted in the Fall of 2019. These include descriptive results extracted from filled out questionnaires to describe occupants' perceptions of IEQ in the gym, and the statistical test results of analyzing different aspects of those perceptions.

4.2.2.1 Descriptive Results

Even though the total attendance rate in the gym was higher in the Fall than in the Summer, only 49 gym users participated in the Fall survey, which was less than half of those who participated in the Summer. Many had already completed the Summer survey and were thus not interested in retaking it. The majority of the ALC gym users were University of Manitoba students who probably wanted to make the best use of their exercising time and were not interested in taking time to fill out a survey. A total of seven staff members took part in the Fall office survey.

Table 22 shows the distribution of respondents by age and gender. Similar to the Summer, almost 41% of gym users were between 21 and 30 years old and more than 60% of them were male.

Table 22 Distribution of respondents by age and gender, Fall 2019.

Age	Gym users (n=49)	Staff (n=7)	Gender	Gym users (n=49)	Staff (n=7)
18-20	10.2%	0.0	Female	30.6%	28.6%
21-30	40.8%	42.9%	Male	67.3%	71.4%
31-40	26.5%	0.0	Other	0.0	0.0
41-50	6.1%	42.9%			
More than 50	12.2%	14.3			

Unlike the Summer in which around 33% of the users chose 5:00 PM to 7:00 PM as their visiting time, the majority of the users in the Fall (40.8%) visited the ALC between 12:00 PM and 3:00 PM (Table 23), and around 29% between 5:00 PM and 7:00 PM.

Table 23 Distribution of users based on facility usage patterns, Fall 2019.

Start_Sess		Visit_Dur (hour)		Num_Visit (/week)		Use_Sinc (month)	
Before 9 AM	8.2%	< 0.5	2.0%	< 1	0.0	<3	12.2%
9 AM - 12 PM	8.2%	0.5 to 1	16.3%	1	8.2%	3-6	2.0%
12 PM - 3 PM	40.8%	1-2	67.3%	2-3	38.8%	6-12	12.2%
3 PM - 5 PM	8.2%	> 2	14.3%	> 3	53.1%	>12	73.5%
5 PM - 7 PM	28.6%						
After 7 PM	6.1%						

Since nearly 62% of gym user respondents in the Fall were students and a total of 18% were staff and faculty members, most of them would prefer to use their lunch hour to exercise. Also, the second peak in visiting time (i.e., 5:00 PM to 7:00 PM) is when most of the students, faculty, and staff members finish work on campus. As mentioned earlier in section 3.1.3, the morning peak attendance rate occurring at 11:00 AM in the Fall had almost the same occupancy level as the evening peak rate at 4:00 PM, with nearly 250 ALC users (University of Manitoba, 2019). According to Table 23, approximately 67% of respondents visited the facility for one to two hours at a time and 53% visited it more than three times per week. The ease of access of the ALC on campus and the well-equipped sports facility could be the reason behind gym users' visiting routine. Around 73% had been using the ALC for more than a year. With respect to the staff, 85% of the staff had been working in the facility for more than a year, and 71% for more than 30 hours per week.

Table 24 summarizes respondents’ satisfaction, perception, and preference with different aspects of the ALC’s thermal conditions in the Fall of 2019. According to Table 24, the gym users’ mean satisfaction rate with air temperature (SAT_T), relative humidity (SAT_RH), and surface temperature (SAT_TSurf) were 0.46, 0.51, and 0.83, respectively. Therefore, the users rated their satisfaction with these three factors between “Neutral (0.0)” and “Slightly satisfied (+1.0)”.

Table 24 Descriptive statists on respondents’ thermal conditions perceptions, Fall 2019.

Respondents	Statistics	SAT_T	SAT_RH	SAT_AirFlow	SAT_TSurf	T_Sense	T_Pref	T_Perform
Gym users (n=49)	Min	-2.0	-2.0	-3.0	-2.0	-2.0	-3.0	-2.0
	Max	2.0	3.0	3.0	3.0	2.0	2.0	3.0
	Mean	0.46	0.51	0.04	0.83	0.48	-0.23	-0.10
	Std. Dev	1.40	1.47	1.82	0.31	1.09	0.99	1.08
Staff (n=7)	Min	-3.0	-1.0	-3.0	-1.0	-3.0	-1.0	-2.0
	Max	2.0	2.0	2.0	2.0	2.0	1.0	1.0
	Mean	-0.57	0.29	0.00	0.43	-0.43	0.14	-0.43
	Std. Dev	1.90	0.95	1.73	1.13	1.71	0.90	0.98

On the other hand, the mean satisfaction rate with airflow (SAT_AirFlow) was 0.04, which was very close to “Neutral (0.0)”. Therefore, gym users were most satisfied with surface temperature in the Fall of 2019. Their mean thermal sensation (T_Sense) was 0.48, which was between “Neutral (0.0)” and “Slightly warm (+1.0)”. Moreover, gym users’ mean temperature preference (T_Pref) was -0.23 and was thus between “No change (0.0)” and “Slightly cooler (-1.0)”. Lastly, they perceived that thermal conditions in the gym had a very marginal negative effect on their ability to exercise since the mean T_Perform was -0.10 (i.e., between -1.0 and 0.0).

Staff’s feedback summarized in Table 24 showed that their mean SAT_RH and SAT_TSurf were 0.29, and 0.43, respectively, both between “Neutral (0.0)” and “Slightly satisfied (+1.0)”. These two rates were lower than the gym users’ satisfaction rate with relative humidity and surface temperature, respectively. Nevertheless, their mean SAT_T was -0.57, which was in the range of “Slightly dissatisfied (-1.0)” to “Neutral (0.0)”, and their mean SAT_AirFlow was exactly “Neutral (0.0)”. Therefore, staff’s satisfaction with air temperature and airflow were also lower than gym users’ mean rate of SAT_T and SAT_AirFlow. Staff perceived air to somewhat cool as their T_Sense of -0.43 was between “Slightly cool (-1.0)” and “Neutral (0.0)”, as opposed to gym users’ mean rate of 0.48. Also, their mean T_Pref of 0.14 was very close to “No change (0.0)”, indicating they did not want the air to be cooler or warmer. It was in contrast with gym users’ preference for having lower temperatures. Staff’s temperature preference varied between “Slightly cooler” and “Slightly warmer” (i.e., -1.0 to 1.0), with no respondents choosing options outside of this range. The staff perceived that thermal conditions somewhat affected their physical performance negatively, as the mean T_Perform was -0.43 and thus between -1.0 and 0.0. Overall, gym users were more satisfied with thermal conditions in comparison with staff.

Table 25 summarizes respondents' feedback with respect to different aspects of IAQ including their level of satisfaction with IAQ (SAT_IAQ), whether the air was smelly (Air_Smell), stuffy (Air_Stuffy), and dusty (Air_Dusty), and the perceived effect of IAQ on their abilities (IAQ_Perform), in the Fall of 2019. On average, gym users rated their SAT_IAQ as 0.96, which almost means "Slightly satisfied (+1.0)". Also, they did not believe that the air was smelly or dusty since the average rates of Air_Smell and Air_Dusty were 0.79 (between "Neutral (0.0)" and "Slightly disagree (+1.0)"), and 1.17 (between "Slightly disagree (+1.0)" and "Disagree (+2.0)"), respectively. However, the mean rate of Air_Stuffy was 0.06 and was thus very close to "Neutral (0.0)". This means that gym users did not agree or disagree that the air was stuffy. As a result, although gym users were Slightly satisfied with IAQ, air stuffiness was their major concern compared to air smell and dustiness. It implies that they perceived the air as relatively stuffy rather than dusty or smelly. IAQ had almost no effect on the users' physical performance since IAQ_Perform was rated as 0.06 and was thus close to 0.0 or "No effect".

Table 25 Descriptive statists on respondents' IAQ perceptions, Fall 2019.

Respondents	Statistics	SAT_IAQ	Air_Smell	Air_Stuffy	Air_Dusty	IAQ_Perform
Gym users (n=49)	Min	-3.0	-3.0	-3.0	-3.0	-3.0
	Max	3.0	3.0	3.0	3.0	3.0
	Mean	0.96	0.79	0.06	1.17	0.06
	Std. Dev	1.57	1.77	1.84	1.67	1.28
Staff (n=7)	Min	0.0	0.0	-3.0	-1.0	-2.0
	Max	2.0	3.0	3.0	3.0	1.0
	Mean	1.29	1.14	1.29	1.57	0.0
	Std. Dev	0.95	1.46	2.13	1.62	1.00

The staff were more than "Slightly satisfied" with IAQ because their mean SAT_ IAQ was 1.29, and thus more satisfied with IAQ than gym users. Also, none of them chose rates of "Very dissatisfied (-3.0)” to “Slightly dissatisfied (-1.0)”. They did not believe the air was smelly, dusty, or stuffy as all of those three aspects were rated more than “Slightly disagree (+1.0)”. The mean IAQ_Perform was 0.0, implying that IAQ did not affect the staff’s physical performance, almost the same as gym users' perception.

Table 26 shows the distribution of respondents based on their level of satisfaction (i.e., “Dissatisfied”, “Satisfied”, or “Neutral”) with various parameters. Approximately 65% of gym users were satisfied with IAQ, whereas almost 47% were satisfied with T. Gym users were mostly dissatisfied with airflow (38%) and the lowest dissatisfaction rate was with surface temperature (8.2%).

Table 26 Distribution of respondents based on thermal conditions and IAQ perceptions, Fall 2019.

Respondents	Rating	SAT_T	SAT_RH	SAT_AirFlow	SAT_TSurf	SAT_IAQ
Gym users (n=49)	Dissatisfied	32.6%	28.5%	38.7%	8.2%	20.4%
	Satisfied	46.9%	40.8%	20.4%	49.0%	65.3%
	Neutral	18.4%	26.5%	38.5%	40.8%	12.2%
Staff (n=7)	Dissatisfied	71.4%	14.3%	28.6%	14.3%	0.0
	Satisfied	28.6%	28.6%	28.6%	28.6%	71.4%
	Neutral	0.0	57.1%	42.9%	57.1%	28.6%

Cianfanelli et al. (2016) studied two sports facilities in Italy between January and May 2015 and asked respondents to use a four-point scale of "Dissatisfied", "Not very satisfied", "Satisfied", "Very satisfied" to rate their level of satisfaction or dissatisfaction with various aspects of IEQ. The study found 55% were “Very satisfied” with air temperature, 41% were “Satisfied”, and no one was “Dissatisfied”. Moreover, 59% were “Satisfied” with air humidity and 23% “Not very satisfied”. Therefore, the nearly 33% of gym users dissatisfied with air temperature in the ALC is relatively high when compared with Cianfanelli et al.'s (2016) results. Nevertheless, the ALC’s data were collected in the Fall, while Cianfanelli et al. (2016) surveyed the participants between January and May. These seasonal differences as well as the buildings’ design may explain these differences in results.

The higher percentage of gym users satisfied with IAQ compared to thermal conditions indicates that air quality (with the mean rate of nearly “Slightly satisfied”) was more satisfactory to gym users than thermal conditions (with the mean rates in the range of “Neutral” to “Slightly satisfied”).

As per Table 26, approximately 32% of the users rated their SAT_T below “Neutral”. This percentage of dissatisfied respondents was less than the reported 40% in the CBE survey benchmark database (ASHRAE, 2013). However, the thermal conditions satisfaction rate established by ASHRAE (2013) needs to be more than “Neutral (0.0)” (i.e., between “Neutral (0.0)” to “Very satisfied (+3.0)”) to pass the satisfaction survey. This indicates that the studied gym provides less than satisfactory thermal conditions for some occupants, but was still relatively satisfactory on average (based on the obtained mean rates between “Neutral” to “Slightly satisfied”).

Although nearly 90% of the users explained they had never complained about the thermal conditions of the ALC’s gym, and the same percentage had never complained about its IAQ, around 50% answered “Yes” to the question asking whether they would like to change the facility’s temperature, and 55% answered “Yes” to another question asking whether they would like to change the airflow.

As per Table 26, around 71% of staff were “Satisfied” with IAQ, whereas the rest were “Neutral”. The reverse was observed with respect to air temperature and almost 71% were “Dissatisfied” with air temperature, and thus below the range of “Neutral (0.0)” to “Very satisfied (+3.0)”, established by ASHRAE (2013). Also, the percentages of staff who rated their satisfaction with relative humidity (SAT_RH), airflow (SAT_AirFlow), and surface temperature (SAT_TSurf) as “Neutral (0.0)” were nearly 57%, 43%, and 57%, respectively. Also, 43% explained they had complained about the thermal conditions of their offices, whilst 14% had complained about their offices’ IAQ in the Fall. Moreover, all staff respondents said they would have liked to be able to adjust their offices’ temperature by themselves, while 43% would have liked to be able to adjust the airflow themselves. These outcomes demonstrate that the staff would prefer to be able to adjust their indoor environmental conditions themselves, particularly air temperature. This finding is similar to other studies’ findings such as Kim et al., (2018) that revealed the preference of occupants to manually control their environment. Overall, the staff were more satisfied with IAQ than with thermal conditions. This is very similar to gym users’ feedback. However, they had more complaints about their offices’ IEQ compared to gym users.

Table 27 shows that around 45% of gym users believed the air was “Warm”. However, a smaller percentage of gym user respondents, nearly 33%, preferred it to be “Cooler”. According to Revel & Arnesano (2014b), 40% of one gym’s users in Italy preferred cooler air in April. This is higher than the 33% in the ALC in the Fall (i.e., October and September). Approximately, 43% of the staff perceived the air as “Cool”, and another 43% preferred a “Warmer” environment. Therefore, the number of staff respondents who perceived the air as “Cool” was equal to the number who wanted “Warmer” air. This exact match was not observed in gym users’ responses (i.e., thermal sensation of “Warm”: 45% compared to temperature preference of “Cool”: 33%).

Table 27 Distribution of respondents based on thermal sensations and preferences, Fall 2019.

Respondents	T_Sense		T_Pref	
Gym users (n=49)	Warm	44.80%	Cooler	32.60%
	Cool	18.30%	Warmer	20.40%
	Neutral	34.70%	Neutral	44.90%
Staff (n=7)	Warm	28.60%	Cooler	28.60%
	Cool	42.90%	Warmer	42.90%
	Neutral	28.60%	Neutral	28.60%

4.2.2.2 Inferential Statistics

This section presents the results of investigating relationships between different survey responses, in the Fall of 2019. The staff’s survey results are not evaluated in this section, because the staff’s feedback collected in the Summer (with nearly the same number of participants compared to the Fall) did not show consistent trends of correlations between different aspect (compared to the correlations found in as was found for gym users’ responses).

4.2.2.2.1 Demography

Since the demographic data of gym user respondents in the Summer, with almost twice the number of respondents in the Fall, did not correlate with other aspects, the possible correlations between demography and other aspects of the survey were not evaluated in the Fall. Overall, only the correlations assessed in the Summer were investigated in the Fall.

4.2.2.2.2 Thermal Comfort

According to Table 28, the Spearman rank-order correlation test showed that gym users' satisfaction with air temperature (SAT_T) had a statistically significant moderate positive correlation of 0.59 with their satisfaction with relative humidity (SAT_RH). Also, SAT_T was statistically significantly correlated with airflow (SAT_AirFlow), surface temperature (SAT_TSurf), and the perception of the effect of thermal conditions on the users' performance (T_Perform), all of which were moderate correlation coefficients of 0.43, 0.49, and 0.40, respectively. These correlations were expected because air temperature, relative humidity, air velocity, and mean radiant temperature (which is affected by surface temperature) are the physical factors that define thermal comfort. However, the users' SAT_T in the Fall was not statistically significantly correlated with their thermal preference (T_Pref).

Table 28 Correlations between different aspects of gym users' thermal conditions perceptions, Fall 2019.

Statistical parameters	SAT_T SAT_RH	SAT_T SAT_AirFlow	SAT_T SAT_TSurf	SAT_T T_Perform	SAT_T T_Pref
Correlation coefficient	0.59	0.43	0.49	0.40	Not correlated
P-value	<0.0005	<0.05	<0.0005	<0.0005	

As Table 29 shows, gym users' thermal sensation (T_Sense) as a measure of thermal comfort was only statistically significantly correlated with their temperature preferences (T_Pref), a moderate negative correlation of -0.47.

Table 29 Correlation between thermal sensation and other aspects of thermal conditions in the gym from gym users’ perspective, Fall 2019.

Statistical Parameters	T_Sense SAT_T	T_Sense SAT_RH	T_Sense SAT_AirFlow	T_Sense T_Pref	T_Sense T_Perform	T_Sense SAT_TSurf
Correlation coefficient	Not correlated	Not correlated	Not Correlated	-0.47	Not correlated	Not correlated
P-value				<0.05		

As Table 24 showed previously, the mean rate of gym users’ T_Sense was 0.48, between “Neutral” to “Slightly Warm” and their mean T_Pref was -0.23, between “No change” to “Slightly cooler”. Therefore, the correlation of -0.47 between these two aspects was expected. The thermal sensation was not correlated with other elements of satisfaction with air temperature (SAT_T), satisfaction with relative humidity (SAT_RH), satisfaction with airflow (SAT_AirFlow), satisfaction with surface temperature (SAT_TSurf), and the perception of the effect of thermal conditions on users’ performance (T_Perform).

In the next step, ordinal logistic regression was run to determine the effect of the users' satisfaction with relative humidity (SAT_RH), airflow (SAT_AirFlow), and surface temperatures (SAT_TSurf) on their satisfaction with air temperature (SAT_T). Multicollinearity was observed as the tolerance values were more than 0.10 for SAT_RH and SAT_AirFlow. Therefore, these two were removed from the test, and SAT_TSurf was kept. The assumption of proportional odds was not met, as assessed by a full likelihood ratio test comparing the fit of the proportional odds model to a model with varying location parameters, $\chi2(15) = 38.43$, $p < 0.05$, and multinomial logistic regression was run instead. Estimated parameters showed that none of the coefficients were statistically significant, and the comparison between different ratings was not possible.

4.2.2.2.3 Indoor Air Quality

According to Table 30, the Spearman rank-order correlation test showed that there was a statistically significant correlation between gym users' satisfaction with indoor air quality (SAT_IAQ) and their perception of air smell (Air_Smell), air stuffiness (Air_Stuffy), air dustiness (Air_Dusty), as well as the effect of IAQ on their performance (IAQ_Perform), moderate positive correlations of 0.57, 0.58, 0.50, and 0.50, respectively.

Table 30 Correlations of different aspects of gym users' IAQ perceptions, Fall 2019.

Statistical parameters	SAT_IAQ Air_Smell	SAT_IAQ Air_Stuffy	SAT_IAQ Air_Dusty	SAT_IAQ IAQ_Perform
Correlation coefficient	0.57	0.58	0.50	0.50
P-value	<0.0005	<0.0005	<0.0005	<0.0005

As per Table 25, the mean rate of SAT_IAQ was 0.96 (i.e., gym users were almost "Slightly satisfied" with IAQ). Also, the mean rates of Air_Smell and Air_Dusty were 0.79 (i.e., users were "Neutral" to "Slightly disagree" that air was smelly), and 1.17 (i.e., users were "Slightly disagree" to "Disagree" that air was dusty), respectively. Therefore, the correlations between SAT_IAQ and Air_Smell as well as between SAT_IAQ and Air_Dusty were expected. On the other hand, both mean rates of IAQ_Perform and Air_Stuffy were 0.06 (i.e., users' perceptions were almost "Neutral" with respect to the air stuffiness and believed IAQ had "No effect" on their performance). As a result, the unexpected moderate correlations between SAT_IAQ and

Air_Stuffy, and between SAT_IAQ and IAQ_Perform could be due to the distribution of responses.

Ordinal logistic regression test was used to assess the effect of gym users' ratings of air smell (Air_Smell), air stuffiness (Air_Stuffy), and air dustiness (Air_Dusty) on their satisfaction with indoor air quality. The test showed all tolerance values of Air_Smell were less than 0.10, and multicollinearity did exist. Therefore, this variable was removed, and the test was continued with Air_Stuffy and Air_Dusty. The assumption of proportional odds was not met, as assessed by a full likelihood ratio test comparing the fit of the proportional odds model to a model with varying location parameters, $\chi2(60) = 92.96$, $p < 0.05$, and multinomial logistic regression was run instead. Two and four outliers were observed in the dataset of Air_Stuffy versus SAT_IAQ and Air_Dusty versus Sat_IAQ, respectively, as assessed by an inspection of boxplots. However, those values were kept in the test because they were not due to an error in data entry and were allowed options to choose from in the survey. Pearson and Deviance Chi-Square values revealed the model did not fit the data well. Model Fitting Information showed that the full model did not statistically significantly predict the dependent variable better than the intercept-only model, $\chi^2(72) = 18.93$, $p > 0.05$. The Likelihood Ratio Tests showed that both Air_Dusty and Air_Stuffy were statistically significant in the model prediction, $\chi^2(36) = 393.10$, $p < 0.0005$, and $\chi^2(36) = 62.87$, $p < 0.05$, respectively. However, estimated parameters showed that none of the coefficients were statistically significant, and the comparison between different ratings was not possible.

4.2.2.2.3 Thermal Comfort and Indoor Air Quality

The Spearman rank-order correlation test revealed there was a statistically significant positive correlation between gym users' satisfaction with indoor air quality (SAT_IAQ) from one side and their satisfaction with air temperature (SAT_T), relative humidity (SAT_RH), and airflow (SAT_AirFlow) from the other side, as can be seen in Table 31. While the first correlation was weak (r=0.34), the other two were moderate (r=0.59 and r=0.55, respectively).

Table 31 Correlations of gym users' thermal conditions and IAQ perceptions, Fall 2019

Statistical parameters	SAT_IAQ SAT_T	SAT_IAQ SAT_RH	SAT_IAQ SAT_AirFlow	IAQ_Perform T_Perform
Correlation coefficient	0.34	0.59	0.55	0.49
P-value	<0.05	<0.0005	<0.0005	<0.0005

Since both mean rates of SAT_T and SAT_IAQ were between "Neutral" to "Slightly satisfied", the statistically significant correlation between these two was expected. However, the mean satisfaction rate with IAQ was higher than satisfaction with air temperature (0.96 vs 0.46, as shown in Table 24 and Table 25). Thus, the weak correlation between them was presumable. Similarly, the correlation between SAT_IAQ and SAT_RH was expected. Besides, there was a statistically significant moderate positive correlation between the perception of the effect of IAQ on their performance (IAQ_Perform) and the perception of the effect of thermal conditions on their performance (T_Perform), with the correlation coefficient of 0.49.

Overall, the inferential statistics show that gym users' satisfaction with air temperature was statistically significantly correlated to the other factors of thermal conditions (i.e., satisfaction with relative humidity, airflow, and surface temperature, as well as the perception of thermal condition effect on their performance). Moreover, their thermal sensation was statistically significantly correlated to their temperature preference. Also, gym users' satisfaction with indoor air quality was statistically significantly correlated to their perception of air stuffiness, air smell, air dustiness, and the effect of IAQ on their performance. Lastly, users' satisfaction with indoor air quality was statistically significantly correlated to their satisfaction with thermal conditions aspects.

4.2.3 Surveys Feedback Versus Actual Conditions

According to Table 32, 65.3% of gym users were satisfied with the gym's indoor air quality in the Fall of 2019, and the mean satisfaction rate was 0.96 (almost "Slightly satisfied (+1.0)"). On the other hand, the 15-minute recorded CO_2 levels did not exceed 902.0 ppm and the mean CO_2 concentration was 521.17 ppm.

Table 32 Gym users' satisfaction with IAQ linked to physical CO_2 levels, Fall 2019.

SAT_IAQ				**15-minute CO_2 (ppm)**			
Statistics on ratings		Gym users distribution (n=49)		Statistics on values	September	October	Fall
Min	-3.0	Dissatisfied	20.4%	Min	416.20	405.71	405.71
Max	3.0	Satisfied	65.3%	Max	901.75	723.04	901.75
Mean	0.96	Neutral	12.2%	Mean	539.96	502.97	521.17
Std. Dev	1.57			Std. Dev	102.09	77.82	92.435

As Figure 6(a) showed before, the maximum of mean 1-hour CO_2 levels in the Fall was 613.0 ppm and was observed at 6:00 PM. As mentioned previously, Alves et al. (2013) reported the minimum, maximum, and average CO_2 levels in a gymnasium as 397.0 ppm, 787.0 ppm, and 468.0 ppm, respectively. Ramos et al. (2014) found CO_2 levels to be between 1,116.0 ppm to 4,418.0 ppm.

Therefore, CO_2 concentrations in the ALC in the Fall were closer to the values reported by Alves et al. (2013) than the values measured by Ramos et al. (2014). As only 25.0% of the users were "Dissatisfied" with the IAQ of the gym and the mean 15-minute CO_2 level was nearly 540 ppm, the results of subjective assessments and physical measurements were consistent and indoor air quality in the ALC appeared to be relatively satisfactory in Fall 2019.

As shown in Table 33, only 28.5% of gym users were "Dissatisfied" with RH levels in the gym in the Fall of 2019, and the mean satisfaction rate was 0.51 (between "Neutral" and "Slightly satisfied"). Also, none of the users selected -3.0 ("Very dissatisfied") as their rating. On the other hand, the maximum 15-minute recorded RH level was 76.39% and was recorded in September, while the mean 15-minute RH level in the Fall was 43.46%.

Table 33 Gym users' satisfaction with RH linked to objective results, Fall 2019.

SAT_RH				**15-minute RH (%)**			
Statistics on ratings		Gym users distribution (n=49)		Statistics on values	September	October	Fall
Min	-2.0	Dissatisfied	28.5%	Min	26.27	19.58	19.58
Max	3.0	Satisfied	40.8%	Max	76.39	52.34	76.39
Mean	0.51	Neutral	26.5%	Mean	53.73	33.53	43.46
Std. Dev	-2.00			Std. Dev	26.27	19.58	19.58

As shown in Figure 6(b), the difference between the maximum and minimum of mean 1-hour RH levels in both September and October was less than 5%, with September being more humid. The mean 1-hour RH levels in the Fall varied between 41% to 45%, as per Figure 6(b). As mentioned previously, there are no acceptable RH levels established for gymnasiums. Almost 35% of the 15-minute recorded RH levels in the return air ducts of L300 were higher than 60% in September, whereas more than 99% of the RH records in October were less than 50%. The minimum RH values measured in other studies varied between 10.80% (Alves et al., 2013) and 49.60% (Revel and Arnesano, 2014), while the mean levels were in the range of 25.80% (Alves et al., 2013) and 58.00% (Cianfanelli et al., 2016), and the maximum levels between 37.30% (Alves et al., 2013) and 73.50% (C. A. Ramos et al., 2014). RH levels in the gym in Fall 2019 were only higher than the ones reported by Alves et al. (2013). Given gym users' mean satisfaction rate of 0.51 (between "Neutral to" "Slightly satisfied"), their total dissatisfaction rate of 28.50%, and mean RH levels of 43.46 %, the survey results and physical measurements appear to be consistent. The ALC seems to provide a slightly satisfactory rather than dissatisfactory environment from an RH perspective in the Fall of 2019.

Table 34 summarizes subjective and objective aspects related to air temperature in the gym in the Fall of 2019. Approximately 33% of the users were "Dissatisfied" with air temperatures in the gym, and the mean satisfaction rate was 0.46 (between "Neutral" and "Slightly satisfied"). Furthermore, participants' ratings ranged from "Dissatisfied (-2.0)" to "Satisfied (+2.0)", and none selected the rates of "Very Dissatisfied (-3.0)" or "Very satisfied (+3.0)" with air temperature. Nearly 45% of the users perceived the air to be "Warm" and almost 32% preferred the air to be "Cooler". On the other hand, the mean 1-hour temperatures for a representative 24-hour period in the Fall varied between 19.80 ℃ and 20.40 ℃, as depicted in Figure 6(c), and the overall mean temperature was 20.10 ℃. Temperatures were higher in September than in October.

Table 34 Gym users' satisfaction, perceptions, and preferences with respect to T, linked to objective results, Fall 2019.

SAT_T				**T_Sense**		**T_Pref**		**15-minute T(°C)**		
Statistics on ratings		Gym users distribution (n=49)		Gym users distribution (n=49)		Gym users distribution (n=49)		Statistics on values	September	October
Min	-2.0	Dissatisfied	32.6%	Warm	44.8%	Cooler	32.6%	Min	19.10	19.23
Max	2.0	Satisfied	46.9%	Cool	18.3%	Warmer	20.4%	Max	22.37	21.31
Mean	0.46	Neutral	18.4%	Neutral	34.7%	Neutral	44.9%	Mean	21.10	20.03

As explained before, there are no standards and guidelines for acceptable temperature levels in gyms. A review of the literature reveals that measured air temperatures in a gymnasium by Alves et al. (2013) were between 20.40 ℃ and 36.60 ℃, whereas Revel & Arnesano (2014b) reported temperatures between 15.40 ℃ and 22.00 ℃ in one gym, with the average being 19.90 ℃. Ramos et al. (2014) reported temperatures from 15.0 ℃ to 25.0 ℃ in 11 gyms in Portugal whereas Cianfanelli et al. (2016) measured a temperature of 16.5 ℃ in a gymnasium in Italy. Given gym users' mean satisfaction rate of 0.46 (between "Neutral to" "Slightly satisfied"), the higher percentage of "Satisfied" versus "Dissatisfied" individuals (i.e. 46.9 % vs 32.6 %, respectively), and the mean temperature of 20.10 ℃ in the gym in the Fall, the results seem consistent. The gym could be considered partly satisfactory rather than dissatisfactory.

The results show that gym users were satisfied with IAQ and the thermal conditions of the gym in Fall 2019. The results of the objective and subjective factors measured in the gym seemed consistent. However, offices were perceived to be less thermally comfortable than the gym.

4.3 Summer Versus Fall

This section provides a comparison between the Summer and Fall survey results to evaluate seasonal changes in the ALC's IEQ.

4.3.1 Physical Indoor Environmental Quality Data

This subsection provides seasonal differences in CO_2, RH, and T levels over the Summer and Fall of 2019.

4.3.1.1 Descriptive Results

Table 35 shows the descriptive statistics for the 15-minute recorded CO_2, RH, and T levels in the Active Living Centre (ALC), in the Summer versus the Fall of 2019.

Table 35 Descriptive statistics on T, RH, and CO_2 level in ALC, Summer vs Fall 2019.

Spaces	Statistics	**CO_2 (ppm)**		**RH (%)**		**T(°C)**	
		Summer	Fall	Summer	Fall	Summer	Fall
Gym	Min	401.26	405.71	24.37	19.58	19.01	19.10
	Max	799.49	901.75	79.72	76.39	21.14	22.37
	Mean	510.56	521.17	57.65	43.46	19.75	20.10
	Std. Dev	76.50	92.43	13.44	14.09	0.30	0.49
Offices	Min	420.47	429.76	18.49	18.62	20.11	20.55
	Max	695.34	789.44	76.48	73.27	21.69	22.22
	Mean	512.85	521.89	50.94	38.17	20.99	21.17
	Std. Dev	51.35	78.65	11.26	8.74	0.74	0.91

With respect to the gym, the maximum CO_2 concentration was almost 100 ppm lower in the Summer than in the Fall, and the minimum concentration was only 4.45 ppm lower in the Summer than in the Fall. The mean concentration in the Fall was 10.61 ppm higher than its value in the Summer. Figure 8 shows the mean 1-hour CO_2, RH, and T and in the gym for a representative day in the Summer and Fall of 2019. The difference in CO_2 trends between the Summer and Fall (Figure 8(a)) is notable from 7:00 AM to 5:00 PM as mean 1-hour concentrations were higher in the Fall within that period. This observation could be related to the higher number of gym users in the Fall, as shown in Figure 3. According to Figure 3, the difference between Fall and Summer attendance rates was greater from 7:00 AM to 5:00 PM compared to after 5:00 PM, and thus consistent with hourly CO_2 variation. CO_2 levels in the Fall and Summer had the same maximum concentration in the evening, at around 6:00 PM. However, the Fall trend shows that the first peak value around noon was higher than its corresponding value in the Summer, which could be due to the users' higher attendance rates in the Fall than in the Summer.

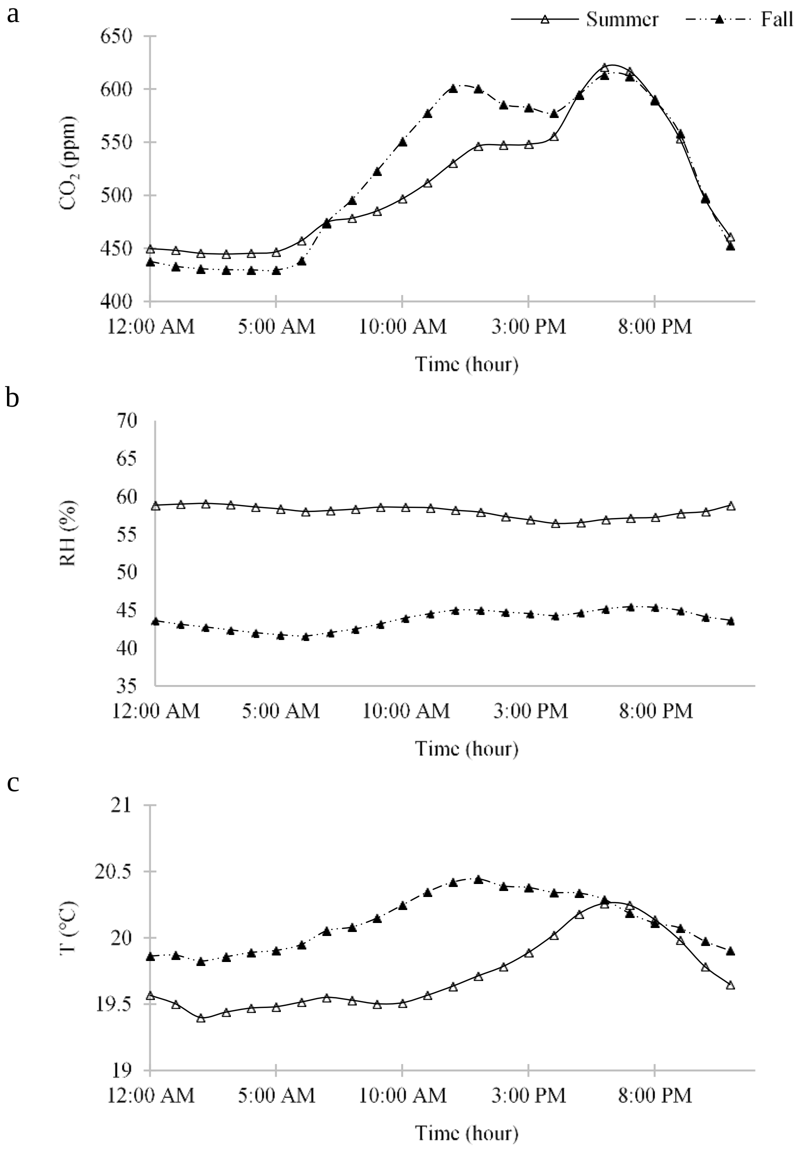

Figure 8 Variations of mean hourly a) CO_2, b) RH, and c) T levels in the gym, Summer vs Fall 2019.

On the other hand, there was no considerable difference between maximum 15-minute RH levels in the Summer and Fall, as can be seen in Table 35. However, the mean 15-minute RH level in the Summer was nearly 14% higher than its value in the Fall. Based on Figure 8(b), while mean 1-hour RH levels in the Fall varied between 41% to 45%, RH levels in the Summer were in the range of 56 % to 59%. Assessing outdoor weather data on Climate Data Canada (2020) revealed that the mean daily relative humidity levels in Winnipeg were higher in the Fall (i.e., September and October) than in the Summer (i.e., June and July) 2019. Figure 9 shows the outdoor mean daily (i.e., 30 days of a month) RH trends in the Summer and Fall of 2019. As can be seen in Figure 9, outdoor weather in the Fall was more humid than in the Summer. Therefore, the seasonal changes of indoor RH levels in the gym were in contrast with the seasonal changes of outdoor RH values in Winnipeg. As a result, higher indoor RH in the Summer would not be primarily related to outdoor RH levels. Air dehumidification requirements in the ALC could explain the high RH in the gym in the Summer compared to the Fall.

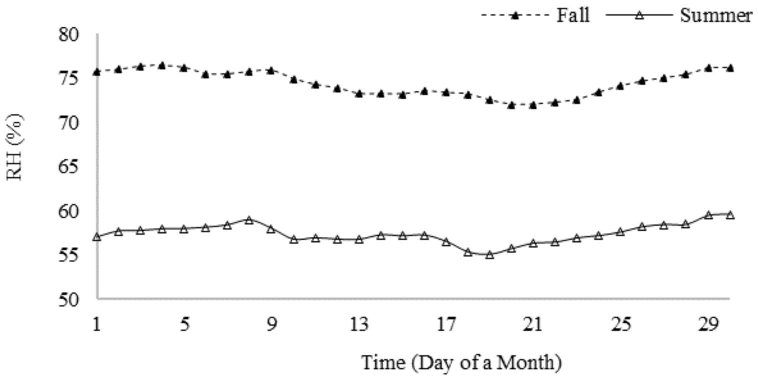

Figure 9 The outdoor mean daily relative humidity levels in Winnipeg, Summer vs Fall 2019 (Climate Data Canada, 2020).

According to T records in Table 35, the mean, maximum, and minimum air Ts in the Fall were 0.35 °C, 1.23 °C, and 0.09 °C higher, respectively, than their corresponding Summer levels. The mean 1-hour T levels shown in Figure 8(c) indicates that temperatures were higher in the Fall than in the Summer, except for the time between 6:00 PM and 8:00 PM when both seasons had the same mean temperatures. The maximum point in the Fall season was observed around noon, whereas the peak 1-hour temperature in the Summer was recorded in the evening, between 6:00 PM and 7:00 PM. Again, this observation was in line with the differences in occupancy patterns between the Fall and Summer seasons, as Figure 3 displayed. As per Figure 3, the total number of ALC users was higher in the Fall, and the occupancy graph had a morning maximum point of 250 users around noon and the evening maximum point with the same number of users at 4:00 PM. However, the Summer graph in Figure 3 showed that the peak occupancy rate of 190 users occurred at 4:00 PM.

As expected, Figure 10 shows the outdoor mean daily temperatures in Winnipeg were higher in the Summer (i.e., June and July) than in the Fall (i.e., September and October) (Climate Data Canada, 2020). Consequently, the seasonal changes of indoor T levels in the gym were not compatible with the seasonal changes of outdoor T levels in Winnipeg.

According to Figure 11, supply air temperatures in the gym were higher in the Fall than in the summer, except for between 1:00 PM and 4:00 PM in which slightly higher supply temperatures were applied in the Summer.

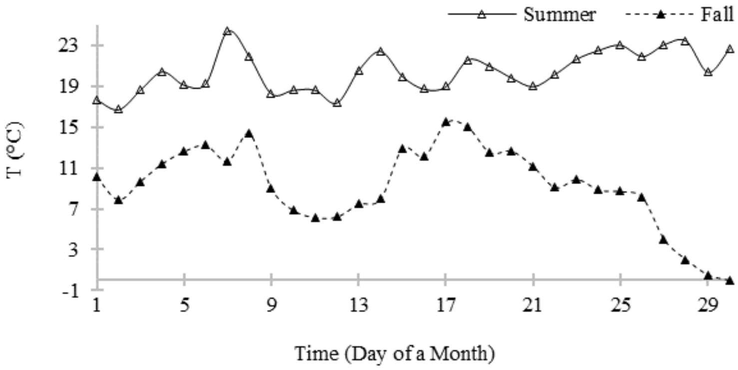

Figure 10 The outdoor mean daily temperature levels in Winnipeg, Summer vs Fall 2019 (Climate Data Canada, 2020).

The higher supply air temperatures in the Fall (probably to balance the low temperature of fresh air used by HVAC systems) as well as its higher attendance rates could explain the higher temperatures recorded by the gym's loggers in the Fall. As shown in Figure 4 and Figure 6, the hourly variations of CO_2 and T had almost the same trends in the gym. This implies that CO_2 and T were both affected by the occupancy rates, with higher levels recorded in the higher occupancy hours.

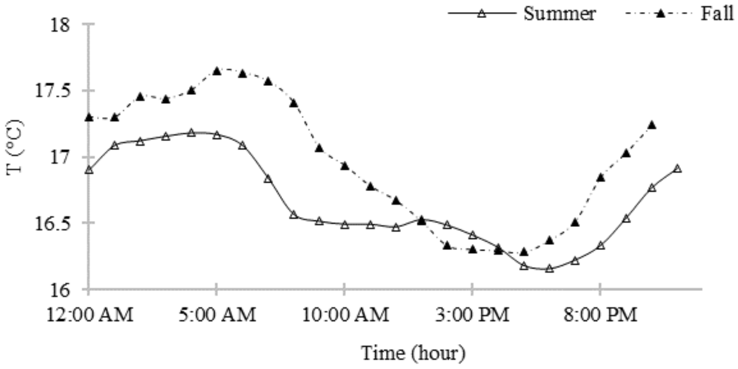

Figure 11 Supply air temperatures in the gym, Summer vs Fall 2019.

As per Table 35, CO_2, RH, and T levels in offices displayed the same pattern as those for the gym. Figure 12 shows the mean 1-hour CO_2, RH, and T levels in offices of the ALC for a 24-hour period in the Summer versus Fall of 2019. CO_2 and T levels were lower in the Summer, whereas RH levels were higher compared to the Fall. According to Figure 12(a), CO_2 levels in the Fall had small variations from noon to the evening, whereas they increased in the Summer in that period until reaching a peak point between 6:00 PM and 7:00 PM, which was similar to the Summer's CO_2 pattern in the gym noted in Figure 8(a).

Higher CO_2 concentrations in offices in the Fall could be also due to higher attendance rates in that season. Some of the surveyed staff were faculty members who were more available in their offices in the Fall than in the Summer. According to Figure 12(b), offices were more humid in the Summer than in the Fall, just like the gym. Figure 12(c) shows the mean 1-hour temperature levels in offices. Even though the two graphs for the Summer and Fall had almost the same variation patterns, temperatures were higher in the Fall, which could be due to higher supply air temperatures and attendance rates in the Fall.

Overall, both the gym and offices were more humid in the Summer, and had higher levels of CO_2 and T, in the Fall.

To evaluate the statistical significance of these seasonal differences, paired-samples t-tests were used, with the results presented in subsection 4.3.1.2.

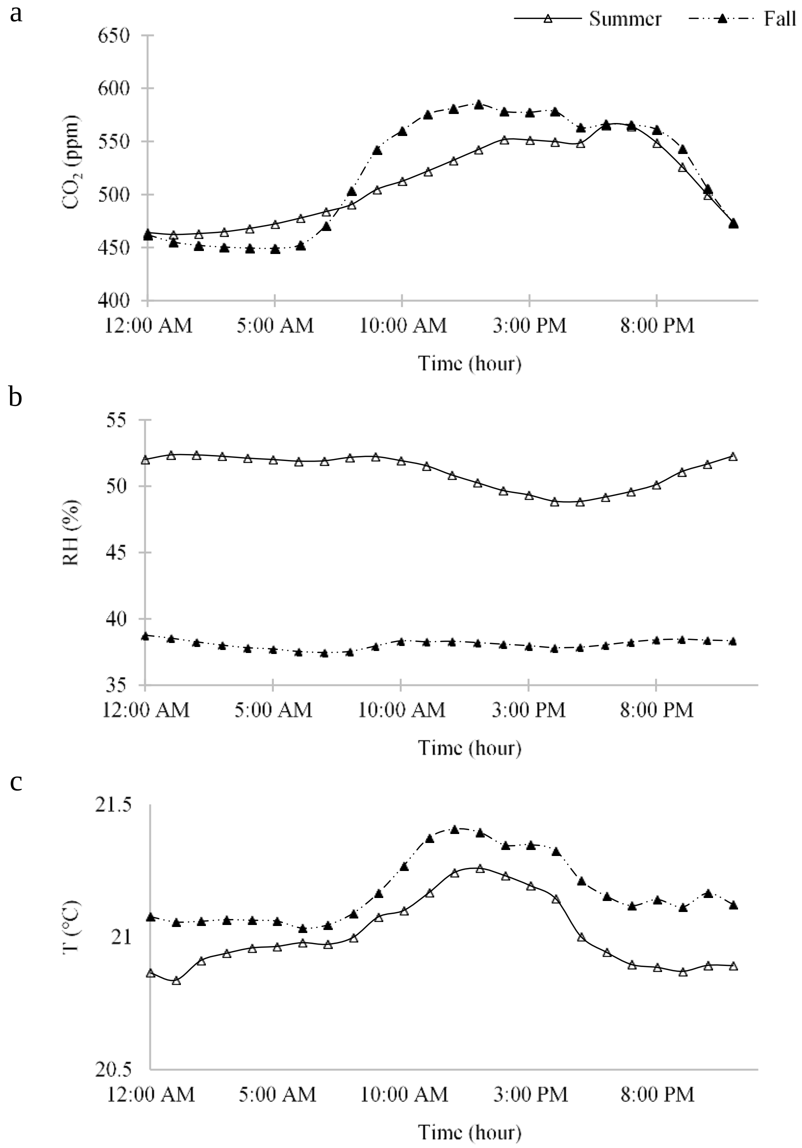

Figure 12 Variations of mean hourly a) CO_2, b) RH, and c) T levels in the offices, Summer vs Fall 2019.

4.3.1.2 Statistical Significance of Seasonal Differences

A paired-samples t-test was used to determine whether there was a statistically significant mean difference between CO_2 levels in the gym in the Summer and Fall of 2019. Although 32 outliers were detected, the inspection of their values revealed they were not due to an error in data entry, measurements, or unusual values. Since the outliers were observed because of differences between the Fall and Summer records, they were kept in the analysis. The assumption of normality was violated, as assessed by visual inspection of a Normal Q-Q Plot. However, the test was run regardless of this violation as the paired-samples t-test is robust to handle this violation (Leard Statistics, 2019). CO_2 levels were higher in the Fall (521.17 ppm ± 92.43 ppm) than the Summer (510.56 ppm ± 76.50 ppm), a statistically significant increase of 10.61 ppm (95% CI, 12.77 ppm to 8.45 ppm), t(5855) = 9.61, $p < 0.0005$, $d = 0.12$. This result supplements CO_2 trends shown in Figure 8(a). According to Figure 8(a), CO_2 levels between 7:00 AM to 5:00 PM were higher in the Fall than in the Summer and were almost the same in the remaining hours. The small effect size of 0.12 indicates that the practical importance of the calculated mean difference between CO_2 levels in the Summer and Fall was small. As explained before, the higher CO_2 levels in the Fall was in line with the higher occupancy rates in that season.

Next, another paired-samples t-test was used to determine whether there was a statistically significant mean difference between RH levels in return air ducts of the gym in the Summer versus Fall. No outliers were detected by visual inspection of a boxplot. The assumption of normality was violated, as assessed by Normal Q-Q Plot. However, the test was run regardless of this violation as the paired-samples t-test is robust to handle this violation (Leard Statistics, 2019). RH levels were lower in the Fall (43.46% ± 0.14.09 %) than in the Summer (57.65% ± 13.44%), a statistically significant decrease of 14.18% (95% CI, 13.57% to 14.80%) c, t(5855) = 45.43, $p < 0.0005$, $d =$ 0.59. As Figure 8(b) showed already, RH levels were consistently higher in the Summer than the

Fall. The calculated effect size of 0.59 indicates that the significance of the calculated mean difference between RH levels over the Summer and Fall was practically large.

The last paired-samples t-test in this section was used to determine whether there was a statistically significant mean difference between air temperatures in the gym in the Summer versus Fall. The number of detected outliers was 29. Since the inspection of their values revealed that the outliers were not due to an error in data entry, measurements, or unusual values, they were kept in the analysis. Although the assumption of normality was violated, as assessed by visual inspection of Normal Q-Q Plot, the test was run as it is robust to handle this violation (Leard Statistics, 2019). Temperatures were higher in the Fall (20.10 °C ± 0.49 °C) than the Summer (19.75 ± 0.30 °C), a statistically significant increase of 0.36 °C (95.00% CI, 0.34 °C to 0.37 °C) c, $t(4657) = 46.71$, $p < 0.0005$, $d = 0.68$. The calculated effect size of 0.68 denotes that the significance of the calculated mean difference between T levels in the Summer and Fall was practically large, although the difference was only 0.36 °C. Figure 8(c) showed that mean 1-hour temperatures in the Fall were higher than temperatures in the Summer, except for the time between 6:00 PM and 8:00 PM when both seasons had the same average temperatures. Return air temperatures (RAT) recorded in return air ducts also revealed that temperatures in the gym were higher in the Fall than in the Summer, as Table 36 shows. As described in subsection 3.2.1, the data for T logger 340/320 was missing in the Summer but not in the Fall. Therefore, it could be possible that the captured T trends (by wall-mount loggers) in the gym would not show the actual seasonal temperature changes. This could result in interpreting the trends in the gym falsely. Analyzing RAT in the ducts validated extracted temperature trends (i.e., temperatures in the gym were higher in the Fall than in the Summer).

Table 36 Descriptive statistics on return air temperatures in L300, Summer vs Fall 2019.

Statistics	RAT(°C)	
	Summer	Fall
Min	19.76	20.13
Max	23.32	24.57
Mean	20.71	21.11
Std. Dev	0.32	0.68

4.3.2 Surveys

This subsection provides a comparison of the Summer versus Fall survey responses.

4.3.2.1 Descriptive Results and Correlations

As per Table 37, the gym users' mean rates of satisfaction with air temperature (SAT_T) were -0.22 (between “Slightly dissatisfied” and “Neutral”) and 0.46 (between “Neutral” and “Slightly satisfied”) in the Summer and Fall, respectively. Similarly, the mean satisfaction rate with relative humidity (SAT_RH) was -0.22 (between “Slightly dissatisfied” and “Neutral”) in the Summer, but 0.51 (between “Neutral” and “Slightly satisfied”) in the Fall. This difference will be discussed in more detail in sub-section 4.3.2.2. On the other hand, the users’ mean satisfaction rate with airflow (SAT_AirFlow) was almost zero in the Fall, but -0.18 in the Summer. Satisfaction with surface temperature (SAT_TSurf) in both seasons was between “Neutral” and “Slightly satisfied”, with Fall respondents being more satisfied with it than Summer respondents (i.e., 0.83 vs 0.56). Hence, gym users were more satisfied with air temperature, relative humidity, airflow, and surface temperature in the Fall than in the Summer of 2019.

On average, both groups of Summer and Fall gym users rated their thermal sensation (T_Sense) between “Neutral” and “Slightly warm”. However, Summer respondents perceived the air to be warmer because their T_Sense was higher than Fall participants (i.e., 0.65 vs 0.48). Further evidence shows that Summer users wanted the air to be cooler than Fall users (i.e., -0.8 vs -0.23), although both of them rated their thermal preference (T_Pref) between “Slightly cooler (-1.0)” and “Neutral (0.0)”. Moreover, Summer respondents perceived thermal conditions to have a higher negative impact on their physical performance (T_Perform) than Fall respondents (i.e. -0.40 vs -0.10, respectively). These findings were in line with their lower satisfaction rate with thermal conditions in the Summer compared to the Fall.

Table 37 Mean rates of respondents’ thermal conditions perceptions, Summer vs Fall 2019.

Respondents	Season	SAT_T	SAT_RH	SAT_AirFlow	SAT_TSurf	T_Sense	T_Pref	T_Perform
Gym users	*S (n=104)	-0.22	-0.22	-0.18	0.56	0.65	-0.80	-0.40
	**F (n=49)	0.46	0.51	0.04	0.83	0.48	-0.23	-0.10
Staff	S (n=8)	0.25	0.63	0.13	0.25	-1.62	0.0	0.13
	F (n=7)	-0.57	0.29	0.0	0.43	-0.43	0.14	-0.43

*Summer; **Fall

According to Table 37, the mean rate of staff's satisfaction with air temperature (SAT_T) was 0.25 (between "Neutral" and "Slightly satisfied") in the Summer versus -0.57 (between "Slightly dissatisfied" and Neutral") in the Fall. Another remarkable difference between the two seasons' responses was with Summer staff perceiving the air (T_Sense) to be cooler than Fall staff, as the mean rates in the summer and Fall were -1.62 versus -0.43 (i.e, between "Cool" and "Slightly cool", and between "Slightly cool" and "Neutral", respectively). Also, the effect of thermal condition on staff's physical performance (T_Perform) was rated as -0.43 in the Fall but 0.13 in the Summer, indicating a worse perceived effect in the Fall. The higher dissatisfaction with air temperature in the Fall explains this difference. The mean rates of satisfaction with relative humidity (SAT_RH) and surface temperature (SAT_TSurf) were 0.63, and 0.25, respectively, in the Summer, and 0.29, and 0.43, respectively, in the Fall. These values were between "Neutral" and "Slightly satisfied", in both the Summer and Fall. Although the mean rate of staff's thermal sensation (T_Sense) was lower in the Summer compared to the Fall (-1.62 versus -0.43), staff preferred little higher temperatures in the Fall, as the mean rate of temperature preference (T_Pref) was 0.0 (i.e., "No change") in the Summer, but 0.14 (i.e., between "No change" and "Slightly Warm") in the Fall. This could be due to lower outdoor temperatures in the Fall affecting occupants' preferences. Overall, staff respondents were more satisfied with air temperature, relative humidity, and airflow in the Summer than in the Fall.

Table 38 shows the distribution of respondents based on their levels of satisfaction/dissatisfaction in the Summer and Fall. More gym users were "Dissatisfied" with air temperature, relative humidity, airflow, surface temperature, and IAQ in the Summer than in the Fall. It follows that more gym users were "Satisfied" with all of those aspects, except for airflow, in Fall.

Table 38 Distribution of respondents based on satisfaction/dissatisfaction, Summer vs Fall 2019.

Respondents	Rating	Season	SAT_T	SAT_RH	SAT_AirFlow	SAT_TSurf	SAT_IAQ
Gym users	Dissatisfied	S	48.1%	44.2%	46.2%	16.3%	29.8%
		F	32.6%	28.5%	38.7%	8.2%	20.4%
	Satisfied	S	31.7%	29.8%	35.6%	40.4%	58.7%
		F	46.9%	40.8%	20.4%	49.0%	65.3%
	Neutral	S	19.2%	25.0%	17.3%	42.3%	9.6%
		F	18.4%	26.5%	38.5%	40.8%	12.2%
Staff	Dissatisfied	S	37.5%	25.0%	25.0%	37.5%	12.5%
		F	71.4%	14.3%	28.6%	14.3%	0.0
	Satisfied	S	50.0%	50.0%	25.0%	37.5%	87.5
		F	28.6%	28.6%	28.6%	28.6%	71.4%
	Neutral	S	12.5%	25.0%	50.0%	25.0%	0.0
		F	0.0	57.1%	42.9%	57.1%	28.6%

These findings are confirmed by Table 39 as the percentage of the gym users who preferred the air to be “Cooler” was almost twice in the Summer than in the Fall. All of these statistics suggest that the ALC’s gym was more thermally comfortable in the Fall than in the Summer of 2019. Staff’s responses did not show the same pattern, as they were mostly “Dissatisfied” with air temperature in the Fall and preferred the air to be “Warmer” in that season, as Table 39 shows. Due to the lower metabolic rates and more sedentary activities in offices compared to the gym, staff’s thermal perception could be more affected by outdoor conditions.

Table 39 Distribution of respondents based on thermal sensations and preferences, Summer vs Fall 2019.

Respondents	T_Sense			T_Pref		
Gym users	Warm	S	53.8%	Cooler	S	61.5%
		F	44.8%		F	32.6%
	Cool	S	25.0%	Warmer	S	14.4%
		F	18.3%		F	20.4%
	Neutral	S	18.3%	Neutral	S	23.1%
		F	34.7%		F	44.9%
Staff	Warm	S	0.0	Cooler	S	50.0%
		F	28.6%		F	28.6%
	Cool	S	87.5%	Warmer	S	37.5%
		F	42.9%		F	42.9%
	Neutral	S	12.5%	Neutral	S	12.5%
		F	28.6%		F	28.6%

Overall, the correlations between different aspects of gym users' thermal perceptions were statistically significantly stronger in the Summer than in the Fall, as can be seen in Table 40. However, a stronger statistically significant correlation was observed between their satisfaction with air temperature (SAT_T) and their satisfaction with surface temperature (SAT_TSurf) in the Fall (r=0.49).

According to Table 40, there was no statistically significant correlation between their satisfaction with air temperature (SAT_T) and with thermal preference (T_Pref) in the Fall, although this correlation level was 0.36 (i.e., a statistically significant weak positive association) in the Summer.

Table 40 Correlations between different aspects of gym users' thermal conditions perceptions, Summer vs Fall 2019.

	Season	SAT_T SAT_RH	SAT_T SAT_AirFlow	SAT_T SAT_TSurf	SAT_T T_Perform	SAT_T T_Pref	T_Sense SAT_T	T_Sense T_Pref
Correlation coefficient	S (n=104)	0.63	0.59	0.40	0.64	0.36	-0.50	-0.56
	F (n=49)	0.59	0.43	0.49	0.40	Not correlated	Not correlated	-0.47

Likewise, there was no statistically significant correlation between satisfaction with air temperature (SAT_T) and thermal sensation (T_Sense) in the Fall, although this correlation level was -0.50 (i.e., a statistically significant moderate negative association) in the Summer. In both seasons, their thermal sensation (T_Sense) was statistically significantly moderately correlated with their temperature preferences (T_Pref), with the correlation stronger in the Summer than in the Fall. The reason for overall stronger correlations in the Summer than in the Fall could be due to the bigger number of respondents in the Summer.

As per Table 41, gym users were more satisfied with IAQ in the Fall than in the Summer as their mean rates were 0.96 (almost +1.0 or "Slightly satisfied") and 0.71 (between "Neutral" and "Slightly satisfied"), respectively. Also, the mean rates of the perception of the IAQ effect on their physical performance (IAQ_Perform) were approximately zero in both seasons, implying no effect perceived as positive or negative. A similar result of almost zero was observed for the users' ratings of air stuffiness.

Table 41 Mean rates of respondents' IAQ perceptions, Summer vs Fall 2019.

Respondents	Season	SAT_IAQ	Air_Smell	Air_Stuffy	Air_Dusty	IAQ_Perform
Gym users	S (n=104)	0.71	0.98	0.12	1.31	0.07
	F (n=49)	0.96	0.79	0.06	1.17	0.06
Staff	S (n=8)	1.75	1.75	1.00	1.63	0.13
	F (n=7)	1.29	1.14	1.29	1.57	0.00

Summer gym user respondents slightly disagreed that the air was smelly and gave this a mean rating of 0.98, while Fall respondents' mean rate was 0.79 (i.e., still between "Neutral" to "Slightly disagree"). Both groups of respondents in the Summer and Fall rated the term "air is dusty" between “Slightly disagree” and “Disagree” (1.31 in the Summer, and 1.17 in the Fall). Staff were also satisfied with IAQ in both seasons, with their mean rates of 1.75 in the Summer and 1.29 in the Fall, both being between “Slightly Satisfied” to “Satisfied”. They perceived the air to be less smelly and dusty but stuffier in the Summer. Like for users, IAQ had almost no effect on staff’s performance, as the mean rates of IAQ_Perform in the Summer and Fall were 0.13 and 0.0 (very close to “No effect”), respectively. Staff’s higher satisfaction with IAQ in the Summer compared to the Fall was consistent with the perceived slightly more positive effect of IAQ on their performance within the Summer.

Table 42 shows that all correlations between different aspects of IAQ in the Fall and Summer were statistically significantly moderate and positive. The only exception was the statistically significantly strong (r=0.63) association between gym users’ satisfaction with IAQ (SAT_IAQ) and their perception of air stuffiness (Air_Stuffy) in the Summer. The correlation between satisfaction with IAQ and IAQ_Perform was stronger in the Fall than in the Summer (0.50 vs 0.46, respectively). This could be a result of the higher satisfaction rate with IAQ in the Fall.

Table 42 Correlations of different aspects of gym users IAQ perceptions, Summer vs Fall 2019.

	Season	SAT_IAQ Air_Smell	SAT_IAQ Air_Stuffy	SAT_IAQ Air_Dusty	SAT_IAQ IAQ_Perform
Correlation coefficient	S (n=104)	0.47	0.63	0.56	0.46
	F (n=49)	0.57	0.58	0.50	0.50

As per Table 43, the statistically significant correlation between gym users’ SAT_IAQ and SAT_T was stronger in the Summer (r=0.58, moderate) than in the Fall (r=0.34, weak). Both sets of correlation coefficients between SAT_IAQ and SAT_RH, as well as SAT_IAQ and SAT_AirFlow in the Summer and Fall were statistically significantly moderate. The correlation was stronger in the Fall compared to the Summer, and between SAT_IAQ and SAT_RH (r=0.59 vs r=0.55).

Table 43 Correlations between gym users' thermal conditions and IAQ perceptions, Summer vs Fall 2019.

	Season	SAT_IAQ SAT_T	SAT_IAQ SAT_RH	SAT_IAQ SAT_AirFlow	IAQ_Perform T_Perform
Correlation coefficient	S (n=104)	0.58	0.55	0.49	0.69
	F (n=49)	0.34	0.59	0.55	0.49

According to Table 44, more than 91% of gym users in the Summer and Fall answered that they had never complained about the IAQ (Complain_IAQ). Nearly 90% in both seasons explained they had never complained about thermal conditions (Complain_T). However, around 60% of users in the Summer wanted to change air temperature (Adjust_T), and the same percentage wanted to change airflow (Adjust_AirFlow). In the Fall, approximately 52% and 56% of gym users wanted to adjust temperature and airflow, respectively. As per staff survey, nearly 87.5% and 100.0% of them wanted to adjust air temperature in the Summer and Fall, respectively. The similar results in the Summer and Fall indicate occupants' preference to control their indoor environment.

Table 44 Distribution of respondents based on the tendency to change conditions and the history of complaints, Summer vs Fall 2019.

Respondents	Answers	Season	Adjust_T	Adjust_AirFlow	Complain_T	Complain_IAQ
Gym users	Yes	S	59.2%	60.2%	9.0%	8.7%
		F	52.1%	56.3%	10.4%	6.4%
	No	S	40.8%	39.8%	91.0%	91.3%
		F	47.9%	43.8%	89.6%	93.6%
Staff	Yes	S	87.5%	50.0%	25.0%	0.00
		F	100.0%	42.9%	42.9%	14.3%
	No	S	12.5%	50.0%	75.0%	100.0%
		F	0.00	57.1%	57.1%	85.7%

4.3.2.2 Statistical Significance of Seasonal Differences

The Kruskal-Wallis H test showed that seasonal changes (i.e. Summer vs Fall), statistically significantly affected only three factors: satisfaction with air temperature (SAT_T), satisfaction with relative humidity (SAT_RH), and temperature preferences (T_Pref). Therefore, among all factors investigated in the survey, only the distributions of SAT_T, SAT_RH, and T_Pref were statistically significantly different ($p < 0.05$) between the Fall and Summer, as summarized in Table 45. These three distributions were not similar in the two seasons, as assessed by a visual inspection of boxplots.

Table 45 Statistically significantly different distributions of gym users' feedback, Summer vs Fall 2019.

Kruskal-Wallis H test results	SAT_T	SAT_RH	T_Pref
	H (1) = 5.55, p = 0.018	H (1) = 5.48, p = 0.019	H (1) = 9.77, p = 0.002

Figure 13 depicts gym users' distribution based on their satisfaction with T and RH, and their temperature preferences. As can be seen, "Satisfied" was the most chosen response for satisfaction with air temperature (SAT_T) in the Fall, whereas “Satisfied”, “Dissatisfied” and “Slightly dissatisfied” were selected almost equally in the Summer.

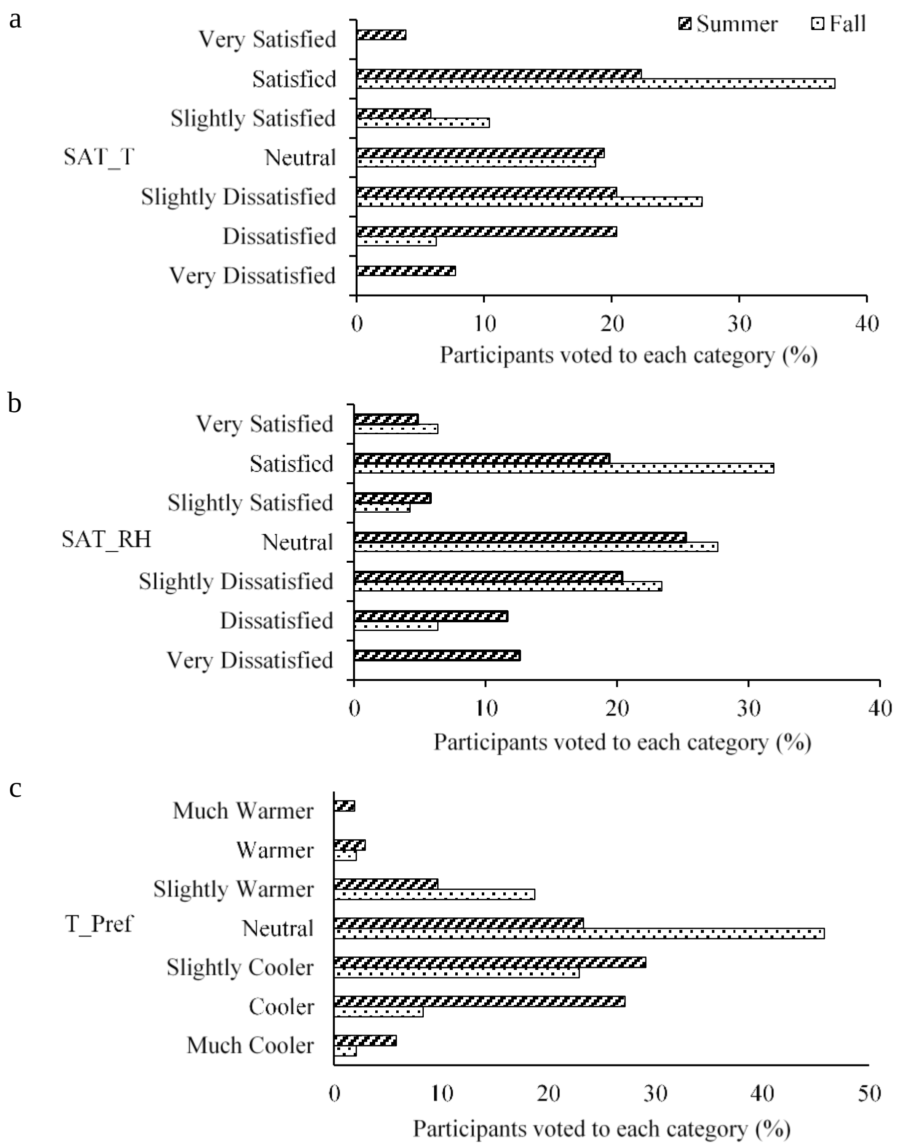

Figure 13 Gym users’ distribution based on their satisfaction with T (a) and RH (b), and temperature preferences (c), Summer vs Fall 2019.

No one was “Very dissatisfied” with relative humidity in the Fall whereas 12% chose that answer in the Summer. Besides, approximately 20% were “Satisfied” with relative humidity in the

Summer, whereas nearly 32% were "satisfied" with it in the Fall. The higher satisfaction rate with RH (SAT_RH) in the Fall could be a result of lower RH levels in that season. Lower RH levels could also explain the higher satisfaction rate with air temperature in the Fall, although T levels were slightly higher in the Fall than the Summer. This deduction is supported by the fact that "Slightly cooler" and "Cooler" were the two most selected responses for preferred temperatures in the Summer, whereas the ("Neutral") response indicating no change in temperatures was the most selected one in the Fall.

Seasonal differences of other factors (e.g., SAT_IAQ) were analyzed only based on descriptive results, as discussed earlier in this subsection because they did not statistically significantly vary between the Summer and Fall.

4.3.3 Surveys Feedback Versus Actual Conditions

As shown in Table 45, of all user responses, only the distributions of satisfaction with air temperature and relative humidity, as well as preferred air temperatures were statistically significantly different ($p < 0.05$) between the Fall and Summer of 2019.

According to Table 37, gym users were more "Satisfied" with air temperature and relative humidity in the Fall than in the Summer of 2019. In addition, Table 39 showed that the percentage of gym users who preferred the air to be "Cooler "was almost twice in the Summer than in the Fall. On the other hand, the paired-samples t-tests that was run to analyze the seasonal differences of RH and air T between the Summer and Fall proved that T levels were statistically significantly higher in the Fall, whereas RH levels were statistically significantly higher in the Summer.

Therefore, unlike the survey results that showed the gym was more thermally comfortable in the Fall, temperatures were higher in the Fall. These seasonal differences are summarized in Table 46.

Table 46 Subjective measures corresponding to objective physical measures to reflect seasonal IEQ differences in ALC's gym.

Subjective and objective measures	Seasonal trends
SAT_T & T	Higher percentage of dissatisfied respondents in the Summer (48.1% vs 32.6%). Lower mean satisfaction rate in the Summer (-0.22 vs 0.46). Lower temperatures in the Summer (19.75 °C vs 20.10 °C).
SAT_RH & RH	Higher percentage of dissatisfied respondents in the Summer (44.2% vs 28.5%). Lower mean satisfaction rate in the Summer (-0.22 vs 0.51). Higher relative humidity levels in the Summer (57.65% vs 43.46%).

Although the objective and subjective results may seem inconsistent, the lower satisfaction rate with air temperature in the Summer could be due to higher RH levels. Thermal comfort is a function of six parameters including air temperature and RH (ASHRAE, 2013). Therefore, gym users in the current research probably perceived air to be warmer in the Summer due to the gym's higher RH levels in that season (despite its lower temperature). The observed correlations of 0.63 and 0.59 between SAT_T and SAT_RH in the Summer and Fall, respectively, supports this explanation. Moreover, gym users who took part in the survey may have answered the questions based on what they remembered from their most recent visits, instead of thinking about the whole seasons (i.e., two months for the Summer and two months for the Fall), despite the questions asking about the latter. As surveys were conducted in July and October to represent the Summer and Fall seasons, respectively, comparing these two months' T and RH levels instead of the whole seasons can show a better picture. As per Table 47, a comparison of these two months shows that the mean RH in July was almost twice its level in October, while June and September had almost the same mean RH levels. Therefore, the higher dissatisfaction rates with air temperature and RH in the Summer (as per the feedback received in July) compared to the Fall are in line with the higher RH levels in July. The mean temperature in September was the highest among all, but gym users were more satisfied with air temperature in the Fall.

Table 47 Mean 15-minute T and RH levels in L300 in four studied months of 2019.

15-min RH (%)				**15-min T(°C)**			
June	September	July	October	June	September	July	October
52.19	53.73	65.85	33.53	19.64	21.1	19.80	20.03

Since the ALC has been certified as a LEED Silver building, it would be useful to refer to the literature on the IEQ assessment of green buildings. One of the most comprehensive studies in the field: Newsham et al. (2013) studied 12 pairs of green and "conventional" buildings with similar features in Canada and the Northern United States. The authors measured indoor environmental parameters using a mobile sensor platform and gathered data on occupants' feedback through an online survey. The study found green buildings provided superior indoor environmental performance including thermal conditions and IAQ satisfaction to conventional buildings. However, some of the studied green buildings had high PM_{10} concentrations and experienced higher work absenteeism rates, indicating that green certification did not necessarily lead to higher indoor environmental quality. The current research revealed that occupants' feedback was affected by seasonal changes. Occupants were less satisfied with the thermal conditions of the ALC in the Summer. This was surprising as it was expected that the facility as a green building would provide satisfactory indoor conditions steadily. This being the case, this research was focused on a sports facility whereas Newsham et al. (2013) investigated offices. Also, the bigger sample of gym users surveyed in comparison with staff members led to a more robust analysis of IEQ in the gym than in the offices.

CHAPTER 5: CONCLUSION

The research aimed to investigate thermal conditions and indoor air quality in a sports facility, the Active Living Centre (ALC), located at the Fort Garry campus of the University of Manitoba, Canada. The facility was certified as LEED Silver green building, in 2017. The research comprised two main methods: the objective assessment of indoor environmental parameters and the subjective assessment of building occupants' perception. It involved for the first method using trend logs of T, RH, and CO_2 recorded and archived by the Building Automation Systems (BASs) as the objective data. It involved for the second method surveying the users who exercised in the main fitness area (i.e., the gym) located on the third floor and the staff who worked in the offices, to receive their feedback about IEQ. The gym users and staff were surveyed twice: in July 2019, as the Summer dated collection phase, and in October 2019, as the Fall data collection phase. Respondents were asked to answer the questions based on their perception of the whole season (i.e., Summer or Fall). For the purpose of this research, June and July represented the Summer season, whereas September and October represented the Fall season. The objective data were collected for June, July, September, and October 2019, accordingly.

This chapter summarizes the results derived from implementing these tools. It also includes a summary of the research's contributions, limitations, and future research recommendations.

5.1 Summary of Results

The analysis of the data collected from the BASs showed the mean 1-hour temperatures in a 24-hour period were higher in the Fall, except for between 7:00 PM to 8:00 PM in which the average temperatures in both seasons were equal. In addition, the maximum temperature points were different in the Summer and Fall, as the maximum temperature in the Summer was observed around 7:00 PM whereas the maximum one in the Fall occurred around noon. These differences were in line with the differences in occupancy rates in the Fall and Summer, demonstrating the effect of occupancy on the indoor environment. Between 7:00 AM and 5:00 PM, CO_2 levels were higher in the Fall, whereas they were the same in the Summer and Fall outside of those hours. During the average 24-hour period, mean RH levels were 14% higher in the Summer than in the Fall.

The research revealed that ALC users exercising in the facility's gym were less satisfied with air temperature, relative humidity, and airflow in the Summer than in the Fall. As an example, approximately 48% of gym users were "Strongly dissatisfied", "Dissatisfied", and "Slightly dissatisfied" with air temperature in the Summer, versus 32% in the Fall. On the other hand, nearly 31% were "Strongly satisfied", "Satisfied", and "Slightly satisfied" with temperature in the Summer versus 47% in the Fall. The gym users' mean rate of satisfaction with air temperature was -0.22 (i.e., between "Slightly dissatisfied" and "Neutral") in the Summer versus 0.46 (i.e., between "Neutral" "Slightly satisfied") in the Fall. Also, their mean thermal sensation was higher (i.e., they felt warmer), and their mean temperature preference was lower (i.e., they wanted lower temperatures) in the Summer than in the Fall. More than 61% of gym users preferred to exercise in “Cooler” air in the Summer, but this percentage was almost half in the Fall. Lastly, gym users perceived the effect of thermal conditions on their physical performance worse in the Summer than in the Fall. All these results imply that the facility was less thermally comfortable in the Summer.

Since the levels of satisfaction with T and RH, and temperature preferences were statistically significantly different over the two seasons, T and RH trends were assessed in relation to survey responses. Higher RH levels in the Summer were in line with the lower satisfaction rates with RH in the same season. Even though the mean temperature was lower in the Summer, the rate of satisfaction with air temperature was lower and more gym users wanted “Cooler” air in the Summer as opposed to the Fall. This inconsistency could be due to higher humidity levels in the Summer, which affected occupants' thermal perceptions considerably. Therefore, providing acceptable levels of all thermal comfort parameters is needed to ensure thermally comfortable and satisfactory environment year-round.

Akin to thermal conditions, gym users were more satisfied with indoor air quality (IAQ) in the Fall than in the Summer, although both mean rates were between “Neutral” to “Slightly satisfied”. Gym users’ perceptions of IAQ were not statistically significantly different between the Summer and Fall. Around 58% of the users were “Strongly satisfied”, “Satisfied”, or “Slightly satisfied” with IAQ in the Summer, versus 65% in the Fall. Among the three factors of air smell, dustiness, and stuffiness, the users’ perception with air stuffiness was almost “Neutral”, while they did not find air to be smelly or dusty in the Summer and Fall. Overall, they perceived the effect of IAQ on their physical performance mostly as neutral. Based on these outcomes, IAQ was relatively satisfactory in the facility.

In the absence of specific standards and guidelines for acceptable levels of thermal comfort and IAQ in sports facilities, this research involved comparing its results to those of other relevant studies. CO_2 levels in the ALC were closer to the range of 397.0 ppm to 787.0 ppm reported by Alves et al. (2013) in a University sports facility in Spain, and less than the values of 1,116.0 ppm to 4,418.0 ppm reported by Ramos et al. (2014) for another research conducted in Portugal. Also, RH levels in the Summer were higher than measured values in the study conducted by Alves et al. (2013) in Spain, and closer to another study by Revel & Arnesano (2014b) in Italy. T levels were higher than a study's findings in Italy (Cianfanelli et al., 2016) that reported T as 16.50 °C, and closer to reported T levels as between 22.0 ℃ and 19.9 ℃, by Revel and Arnesano (2014b). This emphasized the need to enact relevant standards and guidelines for acceptable indoor environmental quality in sports facilities. The current research showed that RH levels of 60% (compared to lower RH levels such as 45%) would make the gym less thermally comfortable, even if its temperature and other factors would be within acceptable ranges. These outcomes can be helpful to facility managers and be used as a baseline for the development of acceptable levels of thermal comfort and IAQ in gyms.

The Active Living Centre (ALC), which was the subject of the current study, is a relatively new green building (i.e., built in 2015). However, the results of the research demonstrated the facility did not always provide stable satisfactory indoor conditions as gym users were less satisfied with thermal conditions in the Summer than the Fall, and thus the need to improve its indoor conditions, specifically its RH levels in the Summer. The research revealed deficiencies in the BASs' data logging. Deficiencies were found in three groups of loggers: 1) loggers that seemed to work flawlessly but showed some missing data, 2) loggers that were functional but were set up to start trending only after August 2019, and 3) loggers that were totally dysfunctional and did not record any data despite being detected in the systems. These observations reinforce the need for periodic inspections of existing loggers and for troubleshooting defective ones to ensure continued effective evaluation and benchmarking of building performance.

5.2 Contribution to the Knowledge and Implications of the Findings

This research has contributed to the IEQ literature an adapted tool in the form of an IEQ satisfaction survey to be used in sports facilities in particular, and a new integrated method for the long-term IEQ assessment of these facilities. This survey was developed by adapting questions from existing questionnaires used to evaluate the IEQ of offices, schools, and residential buildings so that they fit the context of sports facilities and gyms in particular. The existing questionnaires used in the literature to evaluate the IEQ of sports facilities were very short and mostly covered some aspects of thermal comfort such as satisfaction with air temperature and temperature preferences. The survey focused on evaluating gym users' satisfaction with thermal conditions and IAQ in particular and is comprehensive enough to be used to evaluate these two aspects in other types of sports facilities.

The research has contributed to the IEQ literature a method that can be used to assess the objective long-term IEQ of sports facilities using BASs. This involved collecting, refining, and analyzing BASs' data. Data were extracted from an online platform of BASs, based on the mechanical zoning and loggers installed in each zone, and was refined into a specific useable format. This enabled the assessment of long-term IEQ without the need to bring in expensive equipment to physically measure it. This method should be of interest to researchers looking to apply it and acquire physical IEQ trends over different periods. This can help building managers explain occupants' IEQ dissatisfaction and take required actions to improve IEQ in different types of buildings. The research has revealed that loggers can still be defective in green and new buildings even though they are expected to be functional and capture buildings' performance continuously. This reinforces the need for building operators and managers to not presume that BASs (loggers in particular) are completely functional and to detect and fix the systems' malfunctions. Fixing these would help avoid capturing incorrect building's performance due to the missing trending of data.

Surveying occupants in this research has shown that RH levels in sports facilities could affect occupants' dissatisfaction with thermal conditions more than other parameter such as T, and that RH levels around 60% would result in partial dissatisfaction with thermal conditions. The obtained outcomes can enrich the analysis and interpretation conducted by future studies. Also, these results can be used in developing acceptable levels of thermal comfort parameters in sports facilities. These findings strengthen the evidence that green certification of buildings does not always guarantee satisfactory indoor environmental conditions, which reinforces the need to review that certification every few years based on buildings' performance as it relates to indoor environmental quality in particular. Overall, the research also enabled the long-term IEQ assessment of sports facilities, in particular: 1) seasonal variations of IEQ parameters; 2) seasonal variations of occupants' satisfaction; and 3) the link between occupants' responses and the actual physical IEQ.

5.3 Limitations of the Study and Recommendations for Future Work

One limitation of the research was the number of survey respondents. Ideally, a total of 383 and 384 respondents were required, in the Summer and Fall, respectively, to ensure that the results can be generalized to the whole population of gym users. The majority of gym users were the University of Manitoba students who probably wanted to make the best use of their exercising time. Therefore, it was not easy to get them to spend their time filling out the survey while they were there. On the other hand, surveying occupants in the gym showed that the number of respondents per day decreased as time went on over the data collection period. Therefore, extending the data collection period by one or more days, or repeating the whole data collection in another time period in the Summer and Fall would not have led to achieving the sample size required. Although the ALC's administration supported the research by helping advertise and promote it within the ALC, no incentives were provided to those who completed the survey. Future research should therefore consider providing incentives such as gift cards to raise the number of survey respondents and thus the validity of the results.

Another limitation of the research was the data collection timeline. For the summer data, the physical IEQ data collected in June and July were assessed against the survey data collected on one week of July. For the fall data, the physical IEQ data collected in September and October were assessed in relation to the survey data collected on one week of October. Ideally, occupants should have been surveyed repeatedly over the two months for both the fall and summer data in order to ensure consistency in the timelines of the physical IEQ and survey data. Not surprisingly, this was not practical nor realistic given the decreasing number of respondents answering the survey each time. Therefore, future research should consider providing financial incentives to survey respondents to ensure satisfactory response rates every time the survey is repeated.

The next limitation of the research was the number of studied buildings. Initially, the research involved assessing more than one sports facility in the University of Manitoba's campus to compare those facilities' performance. The two candidate buildings were the Frank Kennedy Centre (FKC) and the ALC, both of which provided gym spaces. However, the initial evaluations showed that the two buildings were different inherently. The FKC encompassed a swimming pool, different courts for volleyball, basketball, and badminton, separate training studios, and an ice rink. These spaces were used on a random basis based on FKC users' preferences. On the other hand, the ALC contained a large gym on its third floor. The gym was continuously occupied from 6:00 AM to 10:00 PM, year-round. Besides, reviewing recorded data on enteliWEB (the BASs application) showed that almost no data were available as the physical IEQ data for FKC. Therefore, the FKC was removed from the research. Future studies should therefore evaluate at least one more building with similar characteristics and data to enhance the robustness and comprehensiveness of the research.

Another limitation was the fact that the gym's objective physical IEQ parameters used in this study were not measured according to existing measurement protocols. According to one of these protocols, ASHRAE (2013), measurements should be done at specific locations and at specific heights above the floor, where the occupants are present or are expected to spend their time. Measurements in this research were limited to where the BASs loggers were installed. Therefore, the gym's RH and CO_2 levels were measured in the return air ducts of the air handling units where the loggers were installed, rather than in the space surrounding occupants. Also, the gym's T levels were measured only at one height. ASHRAE (2013) requires measuring air temperatures at three different heights of 0.1 m, 0.6 m, and 1.1 m for seated occupants, and 0.1 m, 1.1 m, and 1.7 m for standing occupants. Similarly, T and CO_2 levels in the offices were measured at one height whereas RH levels were monitored in the air handling units. Moreover, EPA (2003) specifies that for each potential study area of 5.0 m × 5.0 m, four and five locations of continuous and snapshot monitoring are needed, respectively. Considering the gym's dimensions (i.e., approximately 82.0 m × 45.0 m), the number of existing and functional T loggers in L300 (i.e., three and four in the Summer and Fall, respectively) was not sufficient. Furthermore, some air handling units served more than one level or zone, decreasing the accuracy of the data collected for the third floor. All these factors decreased the accuracy of the analysis. To reduce the gap between the amount of physical data required by measurement protocols from one hand and the existing available data recorded by BASs' loggers on the other hand, smaller spaces should be selected as the study areas.

The research did not also involve measuring ventilation rates and indoor air pollutants such as PM as part of its evaluation of IAQ. This is because enteliWEB, the automation systems platform of the ALC, did not measure and provide long-term trending of these parameters. Assessing these parameters over the long-term would ensure a more comprehensive evaluation of IAQ, and thus long-term IEQ.

Although the Physical Plant Department of the University of Manitoba provided access to the ALC' BASs, deficiencies in the systems restricted the physical IEQ data collection of this research. Of all seven T loggers in the gym area, only three in the Summer and four in the Fall were functional. Faulty loggers caused missing data and thus reduced the comprehensiveness and accuracy of extracted trends. Existing loggers in the offices were more functional as their needed dataset was available for the considered period of Summer and Fall 2019. Since the objective data collection conducted by this research’s relied on loggers, future studies should ensure that all loggers are functional and collecting the required data.

Lastly, as the world deals with the COVID-19 pandemic, there will be a need to measure biological contaminants such as the SARS-CoV-2 virus transmission as part of future IEQ assessments. ASHRAE has suggested effective ventilation and filtration provided by heating, ventilating, and air-conditioning systems to control the transmission of SARS-CoV-2 virus through the air (ASHRAE, 2020). ASHRAE also argues that disabling heating, ventilating, and air-conditioning systems to prevent the transmission of the virus is not a proper solution as it can result in thermal stress in buildings and thus lower resistance of occupants to the infection. This denotes the importance of considering factors affecting biological contaminants in the built environment in general and in sports facilities specifically given that occupants have higher metabolic and inhalation rates in these facilities.

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Appendix A

Gym Users’ Informed Consent

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Civil Engineering

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Winnipeg, MB, R3T 5V6

Tel (204) 474-8212
Fax (204) 474-7513

Informed Consent

Research Project Title:
Investigating Long-term Thermal Comfort and Indoor Air Quality in University of Manitoba’s Sports Facilities.

Principal Investigator and Contact Information:
Ms. Mahboubeh Zamani, MSc Student, Department of Civil Engineering, University of Manitoba. EITC E1-386, 15 Gillson Street, Winnipeg MB R3T 5V6, Email: Zamanim@myumanitoba.ca

Advisor and contact information:
Dr. Mohamed. H Issa, Associate Professor, Department of Civil Engineering, University of Manitoba, SP 426, 15 Gillson Street, Winnipeg MB R3T 5V6, Email: Mohamed.Issa@umanitoba.ca

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

The purpose of the research
People spend approximately 90% of their time in indoor environments and are thus affected by Indoor Environmental Quality (IEQ) conditions that can influence their comfort and well-being. Although these conditions are mainly categorized as thermal comfort, indoor air quality, acoustics comfort, and visual comfort, the first two are the most assessed aspects in the literature. Among studies investigated IEQ, there appear to be fewer studies focused on sports facilities in comparison with offices, residential buildings, and schools. In addition, the studies are focused on the IEQ of sports facilities in Europe, with none assessing them in North America or Canada in particular. This study aims to address these knowledge gaps through conducting a long-term thermal comfort

and indoor air quality investigation in one of University of Manitoba's sports facilities, the Active Living Centre.

For this purpose, we will assess some of the parameters such as temperature and relative humidity that are recorded by the facility's automation system, and survey occupants' perception and preference for thermal comfort and indoor air quality in the facility, during Summer 2019 to Fall 2019.

Participation procedure

The target participants of this survey are adults (18 or older) who exercise/play sports in the Active Living Centre, Fort Garry Campus of University of Manitoba.

You can participate in this survey voluntary by filling in the paper-based questionnaire, which will take you approximately 10 minutes to answer all questions categorized in four modules. The whole questionnaire has four modules and questions are mostly about habits and motivations of the facility's occupants for using the sports facility, and satisfaction/dissatisfaction with the sports facility's indoor environmental items such as temperature, and air quality. We will also ask about occupants' personal preference for those conditions.

All responses to the questionnaire, as well as the information you provide on the consent form, will be held in the strictest of confidence. If you decide to participate in this research, please sign this consent form and fill in the questionnaire in the next step. Ms. Mahboubeh Zamani will show two separate boxes devoted to consent forms and questionnaires. Please put each of them in the devoted box. Ms. Mahboubeh Zamani will take the boxes and store them safely for the next steps of the research.

Benefits and Risks

There will be no direct benefit for you by participating in this research. However, your indirect benefit would be helping to improve the indoor environmental quality of sports facilities, and increase participants' comfort and satisfaction. There is a minimum risk or harm for you to participate in this survey as would be in daily life. You will answer questions by your tendency and have this option to not to answer the questions if you prefer so.

Privacy and confidentiality

We will ask no direct personal identifier and contact information such as name, phone number, email address and home address. All collected information will be strictly confidential. Only the principal investigator, Ms. Mahboubeh Zamani, will have access to filled questionnaires and consent forms. The filled questionnaires and consent forms will be stored in a safe locker, and extracted data will be stored on a safe PC system protected by a password, in the University of Manitoba. At the end of the research, (expected as for April 2020) the consent forms and filled questionnaires will be destroyed permanently by a shredder.

Withdrawal

If you sign this consent form, it means that you agree to participate in the survey voluntary. You have the right to withdraw from the research without any consequences. If you decide to withdraw during the survey, simply just do not return your filled questionnaire. However, if you decide to withdraw after submitting your answers, there will be no way to remove your answers since the survey does not include your name and contact information, and we will not be able to recognize your copy.

Providing a summary of the results for participants

If you are interested in having a summary of results, please provide your preferred contact way in the following that can be either your mailing address to receive a hard copy or email address to receive the electronic version. The principal investigator will send you the summary by the end of research expected as April 2020.

Email address: ……………………………………………………………………

Mailing address: …………………………………………………………………..

Results Disseminated

Results will be published in the form of scientific journal and conference papers as well as Ms. Mahboubeh Zamani's MSc thesis. The thesis is expected to be published in April 2020. There will be no direct refer to participants in results dissemination, and results will be presented through statistical measures.

Your signature on this form indicates that you have understood to your satisfaction the information regarding participation in the research project and agree to participate as a subject. In no way does this waive your legal rights nor release the researchers, sponsors, or involved institutions from their legal and professional responsibilities. You are free to withdraw from the study at any time, and /or refrain from answering any questions you prefer to omit, without prejudice or consequence. Your continued participation should be as informed as your initial consent, so you should feel free to ask for clarification or new information throughout your participation.

The University of Manitoba may look at your research records to see that the research is being done in a safe and proper way.

This research has been approved by the [Education/Nursing Research Ethics Board]. If you have any concerns or complaints about this project you may contact any of the above-named persons or the Human Ethics Coordinator at 204-474-7122 or humanethics@umanitoba.ca. A copy of this consent form has been given to you to keep for your records and reference.

Notice Regarding Collection, Use, and Disclosure of Personal Information by the University

Your personal information is being collected under the authority of The University of Manitoba Act. The information you provide will be used by the University for the purpose of this research project, and to send you a copy of the summary of the results (if applicable). Your personal information will not be used or disclosed for other purposes, unless permitted by The Freedom of Information and Protection of Privacy Act (FIPPA). If you have any questions about the collection of your personal information, contact the Access

& Privacy Office (tel. 204-474-9462), 233 Elizabeth Dafoe Library, University of Manitoba, Winnipeg, MB, R3T 2N2.

Participant’s Signature ________________________ Date ____________

Researcher and/or Delegate’s Signature ___________________ Date ____

Staff’s Informed Consent

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People spend approximately 90% of their time in indoor environments, and are thus affected by Indoor Environmental Quality (IEQ) conditions that can influence their comfort and well-being. Although these conditions are mainly categorized as thermal comfort, indoor air quality, acoustics comfort, and visual comfort, the first two are the most assessed aspects in the literature. Among studies investigated IEQ, there appear to be fewer studies focused on sports facilities in comparison with offices, residential buildings, and schools. In addition, the studies are focused on the IEQ of sports facilities in Europe, with none assessing them in North America or Canada in particular. This study aims to address these knowledge gaps through conducting a long-term thermal comfort

and indoor air quality investigation in one of University of Manitoba's sports facilities, the Active Living Centre.
For this purpose, we will assess some of the parameters such as temperature and relative humidity that are recorded by the facility's automation system, and survey the perception and preference of the facility's staffs regarding thermal comfort and indoor air quality in the facility, during Summer 2019 to Fall 2019.

Participation procedure

The target participants of this survey are adults (18 or older) who work in the Active Living Centre, University of Manitoba.
You can participate in this survey voluntary to fill in the paper-based questionnaire, which will take you approximately 10 minutes to answer all questions categorized in three modules. The whole questionnaire has three modules and questions are mostly about the staffs' satisfaction/dissatisfaction with their office's indoor environmental items such as temperature, and air quality. We will also ask about occupant' personal preference for those conditions.
All responses to the questionnaire, as well as the information you provide on the consent form, will be held in the strictest of confidence. If you decide to participate in this research, please sign this consent form and fill in the questionnaire in the next step. Ms. Mahboubeh Zamani will show two separate boxes devoted to consent forms and questionnaires. Please put each of them in the devoted box. Ms. Mahboubeh Zamani will take the boxes, and store them safely for the next steps of the research.

Benefits and Risks

There will be no direct benefit for you by participating in this research. However, your indirect benefit would be helping to improve the indoor environmental quality of sports facilities, and increase participants' comfort and satisfaction. There is a minimum risk or harm for you to participate in this survey as would be in daily life. You will answer questions by your tendency and have this option to not to answer the questions if you prefer so.

Privacy and confidentiality

We will ask no direct personal identifier and contact information such as name, phone number, email address and home address. Meanwhile, one important question will be the room/office's number to correlate two groups of data: occupants' satisfaction with the indoor environmental quality of your room/office (first), and parameters such as temperature and relative humidity in the room/office (second). However, room numbers will be anonymized during the data analysis and publishing the results. All collected information will be strictly confidential. Only the principal investigator, Ms. Mahboubeh Zamani, will have access to filled questionnaires and consent forms. The filled questionnaires and consent forms will be stored in a safe locker, and extracted data will be stored on a safe PC system protected by a password, in the University of Manitoba. At the end of the research, (expected as for April 2020) the consent forms and filled questionnaires will be destroyed permanently by a shredder.

Withdrawal

If you sign this consent form, it means that you agree to participate in the survey voluntary. You have the right to withdraw from the research without any consequences. If you decide to withdraw during the survey, simply just do not return your filled questionnaire. However, if you decide to withdraw after submitting your answers, there will be no way to remove your answers since the survey does not include your name and contact information, and we will not be able to recognize your copy.

Providing a summary of the results for participants

If you are interested in having a summary of results, please provide your preferred contact way in the following that can be either your mailing address to receive a hard copy or email address to receive the electronic version. The principal investigator will send you the summary by the end of research expected as April 2020.

Email address: …………………………………………………………………

Mailing address: ………………………………………………………………..

Results Disseminated

Results will be published in the form of scientific journal and conference papers as well as Ms. Mahboubeh Zamani's MSc thesis. The thesis is expected to be published in April 2020. There will be no direct refer to participants in results dissemination, and results will be presented through statistical measures.

Your signature on this form indicates that you have understood to your satisfaction the information regarding participation in the research project and agree to participate as a subject. In no way does this waive your legal rights nor release the researchers, sponsors, or involved institutions from their legal and professional responsibilities. You are free to withdraw from the study at any time, and /or refrain from answering any questions you prefer to omit, without prejudice or consequence. Your continued participation should be as informed as your initial consent, so you should feel free to ask for clarification or new information throughout your participation.

The University of Manitoba may look at your research records to see that the research is being done in a safe and proper way.

This research has been approved by the [Education/Nursing Research Ethics Board]. If you have any concerns or complaints about this project you may contact any of the above-named persons or the Human Ethics Coordinator at 204-474-7122 or humanethics@umanitoba.ca. A copy of this consent form has been given to you to keep for your records and reference.

Notice Regarding Collection, Use, and Disclosure of Personal Information by the University

Your personal information is being collected under the authority of The University of Manitoba Act. The information you provide will be used by the University for the purpose of this research project, and to send you a copy of the summary of the results (if

applicable). Your personal information will not be used or disclosed for other purposes, unless permitted by The Freedom of Information and Protection of Privacy Act (FIPPA). If you have any questions about the collection of your personal information, contact the Access & Privacy Office (tel. 204-474-9462), 233 Elizabeth Dafoe Library, University of Manitoba, Winnipeg, MB, R3T 2N2.

Participant's Signature ________________________ Date ____________

Researcher and/or Delegate's Signature ___________________ Date _______

Appendix B

Gym Users' Questionnaire

Module 1: Demographics and General Questions

Date: …………………	Time: ……………………	Location: Level ……………	
1.	Age:	○ 18-20 ○ 21-30 ○ 31-40	○ 41-50 ○ More than 50
2.	Gender:	○ Female ○ Other	○ Male ○ Prefer not to answer
3.	U of M affiliation:	○ Alumni ○ Staff ○ Not affiliated with U of M	○ Faculty ○ Student ○ Other ……………….
4.	Personal perception of body shape:	○ Underweight ○ Overweight	○ Average weight ○ Prefer not to answer
5.	Tobacco smoking status:	○ Never ○ Rarely ○ Regularly	○ Formerly ○ Occasionally
6.	Subjected to tobacco smoke at home:	○ Never ○ Rarely ○ Regularly	○ Formerly ○ Occasionally
7.	Asthmatic status:	○ Asthmatic	○ Non-Asthmatic
8.	In current season, I normally:	○ Get 7-8 hours of sleep	○ Get less/more than 7-8 hours of sleep.
9.	Average number of visits per week in current season/term, to exercise/play sports in this facility:	○ Less than once a week ○ 2-3 times a week	○ Once a week ○ More than 3 times a week
10.	Average duration of each visit in current season/term, to exercise/play sports in this facility:	○ Less than half an hour ○ 1-2 hours	○ half an hour to 1 hour ○ More than 2 hours
11.	I have been using this facility since:	○ Less than 3 months ago ○ 6 months to 1 year ago	○ 3 - 6 months ago ○ More than 1 year ago
12.	In current season, I normally start my sessions:	○ Before 9:00 ○ 12:00-15:00 ○ 17:00-19:00	○ 9:00-12:00 ○ 15:00-17:00 ○ After 19:00
13.	I exercise/play sports:	○ Recreationally ○ None	○ Professionally (paid) ○ Other…………………….

Module 2: Indoor Air Quality

1. In current season, I rate my satisfaction/dissatisfaction with indoor air quality in this facility as:

Very dissatisfied	Dissatisfied	Slightly dissatisfied	Neutral	Slightly satisfied	Satisfied	Very satisfied
-3	- 2	-1	0	+1	+2	+3
○	○	○	○	○	○	○

2. In current season, I rate following indoor air quality items in this facility as:

	Strongly agree	Agree	Slightly agree	Neutral	Slightly disagree	Disagree	Strongly disagree
	-3	- 2	-1	0	+1	+2	+3
Air smells bad	○	○	○	○	○	○	○
Air is stuffy/stale (not enough fresh air)	○	○	○	○	○	○	○
Air is dusty	○	○	○	○	○	○	○

3. (*Answer only if you have rated at least one of issues in Question 2 as either -3, -2, or -1.*)
In current season, I think air quality problems in this facility come from *(Please check all that apply)*:

○ Surfaces (walls, ceilings, floors, windows)
○ Chemical substances used in the facility (e.g. cleaners)
○ Materials used during exercising/playing sports (e.g. bulk chalk for climbing wall)
○ Outdoor pollution entering the facility
○ Sprays/perfumes/cosmetics used by people
○ Other ……………………………………

4. (*Answer only if you have rated at least one of issues in Question 2 as either -3, -2, or -1.*)
In current season, I think air quality issues in this facility are found in *(Please check all that apply)*:

○ Washrooms/showers
○ Stairways/elevators/hallways
○ Other …………………………
○ Locker rooms
○ Areas used for exercising/playing sports

5. In current season, I normally experience following health symptoms *(Please check all that apply)*:

○ None
○ Runny/itchy/sneezing/stuffy/blocked nose
○ Eczema, dry/itchy skin
○ Wheezing in the chest/difficulty breathing
○ Having a cold/influenza/fever
○ Malaise/fatigue
○ Swollen/red/burning/itchy/dry/teary eyes
○ Dry cough/dry throat
○ Feeling like getting a cold
○ A headache
○ Other: ………………………………

6. In current season, I … to a manager/supervisor/staff about indoor air quality in this facility.

○ have complained ○ never have complained

7. In current season, I … a moldy/earthy/cellar-like odour inside this facility.

○ have noticed ○ never have noticed

8. In current season, I … the visible signs of moisture damage in ceiling/walls/floors in this facility.

○ have noticed ○ never have noticed

9. In current season, I rate the effect of indoor air quality on my abilities to exercise/play sports in this facility as:

It interferes with my abilities			It has no effect on my abilities			It enhances my abilities
-3	- 2	-1	0	+1	+2	+3
○	○	○	○	○	○	○

Comments (optional: ……………………………………………………………………………………………

Module 3: Thermal Comfort

1. In current season, I mostly feel as follow while exercising/playing sports in this facility:

Cold	Cool	Slightly cool	Neutral	Slightly warm	Warm	Hot
-3	-2	-1	0	+1	+2	+ 3
○	○	○	○	○	○	○

2. In current season, I rate my satisfaction/dissatisfaction with following thermal comfort items in this facility as:

	Very dissatisfied	Dissatisfied	Slightly dissatisfied	Neutral	Slightly satisfied	Satisfied	Very satisfied
	-3	-2	-1	0	+1	+2	+3
Air Temperature	○	○	○	○	○	○	○
Air humidity	○	○	○	○	○	○	○
Air movement	○	○	○	○	○	○	○
Temperature of surfaces (e.g. floor/ equipment)	○	○	○	○	○	○	○

3. In current season, I rate following thermal comfort problems in this facility as:

	Strongly disagree	Disagree	Slightly disagree	Neutral	Slightly agree	Agree	Strongly agree
	-3	-2	-1	0	+1	+2	+3
Air is too humid	○	○	○	○	○	○	○
Air is too dry	○	○	○	○	○	○	○
Air movement is too high	○	○	○	○	○	○	○
Air movement is too low	○	○	○	○	○	○	○
Air is too hot	○	○	○	○	○	○	○
Air is too cold	○	○	○	○	○	○	○
Floor surfaces are too hot	○	○	○	○	○	○	○
Floor surfaces are too cold	○	○	○	○	○	○	○
Wall surfaces are too hot	○	○	○	○	○	○	○
Wall surfaces are too cold	○	○	○	○	○	○	○

4. In current season, I prefer indoor environment in this facility to be:

Much cooler	Cooler	Slightly cooler	Neither warmer nor cooler	Slightly warmer	Warmer	Much warmer
-3	-2	-1	0	+1	+ 2	+3
○	○	○	○	○	○	○

5. In current season, I typically wear the following sports clothing ensemble (*Please select the one that best matches):*

○ a ○ b ○ c ○ d ○ e ○ f ○ g ○ h ○ i

a) Athletic clothing (e.g. sweat pant; long-sleeve sweatshirt)

Module 3: Thermal Comfort

b) Basketball uniform 1 (e.g. basketball mesh jersey (tucked in); basketball mesh shorts; footie socks; athletic shoes)
c) Basketball uniform 2 (e.g. sleeveless T-shirt (tucked in); basketball mesh jersey (tucked in); basketball compression shorts; basketball mesh shorts; ankle-length socks; athletic shoes)
d) Casual running ensemble (e.g. short-sleeve; crew neck T-shirt; loose-fitting shorts; ankle-length socks; athletic shoes)
e) Cycling ensemble 1 (e.g. helmet; short-sleeve zip-up jersey; gloves; compression shorts; ankle-length socks; athletic shoes)
f) Cycling ensemble 2 (e.g. helmet; short-sleeve T-shirt; short-sleeve zip-up jersey (half zipped); gloves; loose-fitting shorts; ankle-length socks; athletic shoes)
g) Men's tennis ensemble (e.g. tennis cap; button-down sports shirt (tucked in); tennis shorts; ankle-length socks; athletic shoes)
h) Women's tennis ensemble (e.g. tank top (tucked in); women's tennis briefs; tennis skirt; footie socks; athletic shoes)
i) Women's running/aerobic ensemble (e.g. sports bra; above-the-knee length knit tight shorts; footie socks; athletic shoes)

Please specify if you are wearing more/other items: ……………………………………………………………………

6. I have spent the past hour on the following activities *(Please check all that apply):*

Activity	Time spent on activity (minutes)	Activity	Time spent on activity (minutes)
○ Aerobic	…………….	○ Swimming	…………….
○ Basketball	…………….	○ Tennis	…………….
○ Climbing	…………….	○ Weight training	…………….
○ Cycling	…………….	○ Wrestling	…………….
○ Dancing	…………….	○ Walking quickly	…………….
○ Light exercising	…………….	○ Yoga	…………….
○ Running	…………….	○ Other…………..	....

7. In current season, I … to a manager/supervisor/staff about thermal condition in this facility.

○ have complained ○ never have complained

8. In current season, if I could, I would change/adjust temperature in this facility. ○ Yes ○ No

9. In current season, if I could, I would change/adjust airflow in this facility. ○ Yes ○ No

10. In current season, I rate the effect of thermal condition on my abilities to exercise/play in this facility as:

It interferes with my abilities			It has no effect on my abilities			It enhances my abilities
-3	- 2	-1	0	+1	+2	+3
○	○	○	○	○	○	○

Comments (optional): ……………………………………………………………………………………………………

Module 4: Motivation and Well-being

1. In current season, I visit this facility because of its *(please check all that apply):*

○ Easy access
○ Pleasant/ healthy/comfortable atmosphere
○ Affordable fees
○ I'm not sure
○ Membership discounts
○ Other ……………

2. In current season, I visit this facility *(please check all that apply):*

○ To have fun
○ To influence/motivate others
○ To relax and relieve stress
○ To gain recognition of achievements
○ I'm not sure
○ To be/stay healthy
○ To improve my self-esteem
○ To devote time to myself
○ To compete against others/be a good player
○ Other ………………..
○ To make friends
○ Because I like this facility
○ To improve my physical skills/ fitness
○ To improve my sense of belongingness/connectedness with the community

3. In current season, I rate following items as (*here the effect is considered as a negative effect*):

	Strongly agree	Agree	Slightly agree	Neutral	Slightly disagree	Disagree	Strongly disagree
	-3	-2	-1	0	+1	+2	+3
Temperature levels in this facility affect my abilities to exercise/play sports here.	○	○	○	○	○	○	○
Air Humidity in this facility affects my abilities to exercise/play sports here.	○	○	○	○	○	○	○
Airflow in this facility affects my abilities to exercise/play sports here.	○	○	○	○	○	○	○
Indoor air quality in this facility affects my abilities to exercise/play sports here.	○	○	○	○	○	○	○

4. In current season, I rate following items as:

	Strongly disagree	Disagree	Slightly disagree	Neutral	Slightly agree	Agree	Strongly Agree
	-3	-2	-1	0	+1	+2	+3
I feel safe and secure in this facility	○	○	○	○	○	○	○
I feel comfortable in this facility	○	○	○	○	○	○	○
This is a healthy environment to exercise/play sports	○	○	○	○	○	○	○
I feel I am connected to the community	○	○	○	○	○	○	○
I feel connected with people in this facility	○	○	○	○	○	○	○
I feel good about my body	○	○	○	○	○	○	○
I have lots of energy and can get through the day without being overly tired	○	○	○	○	○	○	○

Module 4: Motivation and Well-being

Comments (optional): …………………………………………………………………………………………………….

Staff's Questionnaire

Module 1: Demographics

Date: …………………	Time: ……………………	Location: Level ……………/Room………………
1. Age:	○ 18-20 ○ 21-30 ○ 31-40	○ 41-50 ○ More than 50
2. Gender:	○ Female ○ Other	○ Male ○ Prefer not to answer
3. Personal perception of body shape:	○ Underweight ○ Overweight	○ Average weight ○ Prefer not to answer
4. Tobacco smoking status:	○ Never ○ Rarely ○ Regularly	○ Formerly ○ Occasionally
5. Subjected to tobacco smoke at home:	○ Never ○ Rarely ○ Regularly	○ Formerly ○ Occasionally
6. Asthmatic status:	○ Asthmatic	○ Non-Asthmatic
7. In current season, I normally:	○ get 7-8 hours of sleep	○ get less/more than 7-8 hours of sleep.
8. Number of hours a week I spend working in this facility, in current season:	○ Less than 15 hours ○ More than 30 hours	○ 15-30 hours
9. I have been working in this facility since:	○ Less than 3 months ago ○ 6 months to 1 year ago	○ 3 - 6 months ago ○ More than 1 year ago

Module 2: Indoor Air Quality

1. In current season, I rate my satisfaction/dissatisfaction with indoor air quality in my office as:

Very dissatisfied	Dissatisfied	Slightly dissatisfied	Neutral	Slightly satisfied	Satisfied	Very satisfied
-3	- 2	-1	0	+1	+2	+3
○	○	○	○	○	○	○

2. In current season, I rate following indoor air quality items in my office as:

	Strongly agree	Agree	Slightly agree	Neutral	Slightly disagree	Disagree	Strongly disagree
	-3	- 2	-1	0	+1	+2	+3
Air smells bad	○	○	○	○	○	○	○
Air is stuffy/stale (not enough fresh air)	○	○	○	○	○	○	○
Air is dusty	○	○	○	○	○	○	○

3. (*Answer only if you have rated at least one of issues in Question 2 as either -3, -2, or -1.*)
In current season, I think air quality problems in my office come from *(Please check all that apply)*:

○ Surfaces (walls, ceilings, floors, windows)
○ Chemical substances used in the facility (e.g. cleaners)
○ Other ……………………………………
○ Outdoor pollution entering the facility
○ Sprays/perfumes/cosmetics used by people

4. In current season, I normally experience following health symptoms *(Please check all that apply)*:

○ None
○ Runny/itchy/sneezing/stuffy/blocked nose
○ Eczema, dry/itchy skin
○ Wheezing in the chest/difficulty breathing
○ Having a cold/influenza/fever
○ Malaise/fatigue
○ Swollen/red/burning/itchy/dry/teary eyes
○ Dry cough/dry throat
○ Feeling like getting a cold
○ A headache
○ Other: ………………………………

5. In current season, I … to a manager/supervisor/staff about indoor air quality in my office.

○ have complained   ○ never have complained

6. In current season, I … a moldy/earthy/ cellar-like odour in my office.

○ have noticed   ○ never have noticed

7. In current season, I … the visible signs of moisture damage in ceiling/walls/floors in my office.

○ have noticed   ○ never have noticed

8. In current season, I rate the effect of indoor air quality of my office on my abilities to do my job as:

It interferes with my abilities		It has no effect on my abilities			It enhances my abilities	
-3	- 2	-1	0	+1	+2	+3
○	○	○	○	○	○	○

Comments (optional: ……………………………………………………………………………………………

Module 3: Thermal Comfort

1. In current season, I mostly feel as follow in my office:

Cold	Cool	Slightly cool	Neutral	Slightly warm	Warm	Hot
-3	-2	-1	0	+1	+2	+ 3
○	○	○	○	○	○	○

2. In current season, I rate my satisfaction/dissatisfaction with following thermal comfort items in my office as:

	Very dissatisfied	Dissatisfied	Slightly dissatisfied	Neutral	Slightly satisfied	Satisfied	Very satisfied
	-3	-2	-1	0	+1	+2	+3
Air temperature	○	○	○	○	○	○	○
Air humidity	○	○	○	○	○	○	○
Air movement	○	○	○	○	○	○	○
Temperature of surfaces (e.g. floor/ equipment)	○	○	○	○	○	○	○

3. In current season, I rate following thermal comfort problems in my office as:

	Strongly disagree	Disagree	Slightly disagree	Neutral	Slightly agree	Agree	Strongly agree
	-3	-2	-1	0	+1	+2	+3
Air is too humid	○	○	○	○	○	○	○
Air is too dry	○	○	○	○	○	○	○
Air movement is too high	○	○	○	○	○	○	○
Air movement is too low	○	○	○	○	○	○	○
Air is too hot	○	○	○	○	○	○	○
Air is too cold	○	○	○	○	○	○	○
Floor surfaces are too hot	○	○	○	○	○	○	○
Floor surfaces are too cold	○	○	○	○	○	○	○
Wall surfaces are too hot	○	○	○	○	○	○	○
Wall surfaces are too cold	○	○	○	○	○	○	○

4. In current season, I prefer the indoor environment of my office to be:

Much cooler	Cooler	Slightly cooler	Neither warmer nor cooler	Slightly warmer	Warmer	Much warmer
-3	-2	-1	0	+1	+ 2	+3
○	○	○	○	○	○	○

5. In current season, I typically wear the following clothing ensemble (*Please select the one that best matches):*

○ a ○ b ○ c ○ d ○ e ○ f ○ g ○ h ○ i ○ j ○ k

Module 3: Thermal Comfort

a) Shorts or knee-length skirt, short-sleeve shirt b) Shorts or knee-length skirt, short-sleeve shirt, sweater or jacket
c) Shorts or knee-length skirt, long-sleeve top d) Shorts or knee-length skirt, long-sleeve shirt, long-sleeve sweater or jacket
e) Trousers or ankle-length skirt, short-sleeve shirt f) Trousers or ankle-length skirt, short-sleeve shirt, sweater
g) Trousers or ankle-length skirt, long-sleeve shirt h) Trousers or ankle-length skirt, long-sleeve shirt, sweater
i) Trousers or ankle-length skirt, long-sleeve shirt, suit jacket
j) Trousers or ankle-length skirt, long-sleeve shirt, suit jacket, vest or T-shirt
k) Trousers or ankle-length skirt, long-sleeve shirt, suit jacket, sweater, vest or T-shirt

Please specify if you are wearing more/other items: ……………………………………………………………………

6. In current season, I … to a manager/supervisor/staff about thermal condition in my office.

○ have complained ○ never have complained

7. In current season, if I could, I would change/adjust temperature in my office. ○ Yes ○ No

8. In current season, if I could, I would change/adjust airflow in my office. ○ Yes ○ No

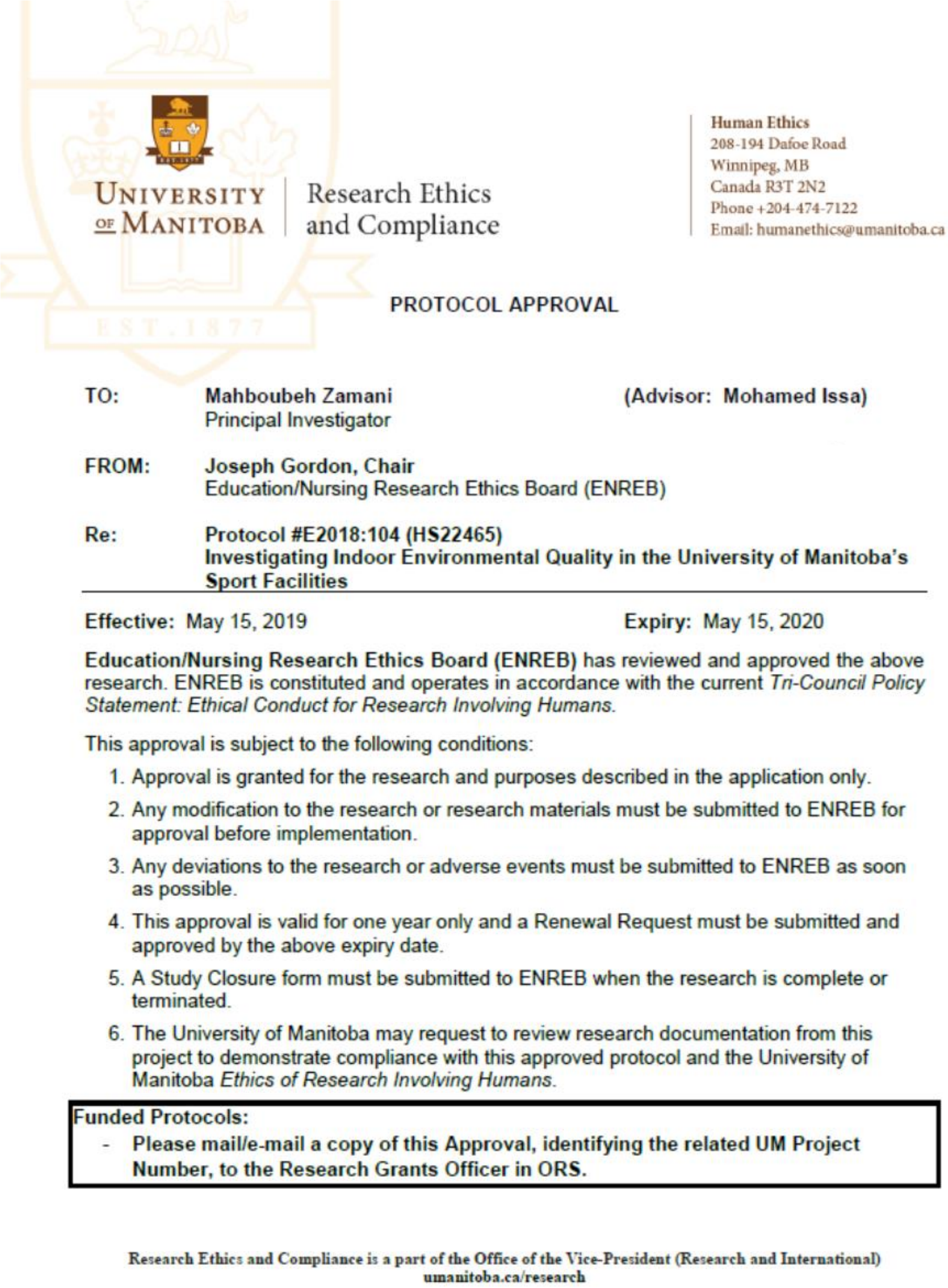
9. In current season, I rate the effect of thermal condition of my office on my abilities to do my job as:

It interferes with my abilities			It has no effect on my abilities			It enhances my abilities
-3	- 2	-1	0	+1	+2	+3
○	○	○	○	○	○	○

Comments (optional): ……

Appendix C

Education/Nursing Research Ethics Board Approval



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PROTOCOL APPROVAL

TO: **Mahboubeh Zamani** **(Advisor: Mohamed Issa)**
Principal Investigator

FROM: **Joseph Gordon, Chair**
Education/Nursing Research Ethics Board (ENREB)

Re: **Protocol #E2018:104 (HS22465)**
Investigating Indoor Environmental Quality in the University of Manitoba's Sport Facilities

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Effective: May 15, 2019 **Expiry:** May 15, 2020

Education/Nursing Research Ethics Board (ENREB) has reviewed and approved the above research. ENREB is constituted and operates in accordance with the current *Tri-Council Policy Statement: Ethical Conduct for Research Involving Humans.*

This approval is subject to the following conditions:

1. Approval is granted for the research and purposes described in the application only.
2. Any modification to the research or research materials must be submitted to ENREB for approval before implementation.
3. Any deviations to the research or adverse events must be submitted to ENREB as soon as possible.
4. This approval is valid for one year only and a Renewal Request must be submitted and approved by the above expiry date.
5. A Study Closure form must be submitted to ENREB when the research is complete or terminated.
6. The University of Manitoba may request to review research documentation from this project to demonstrate compliance with this approved protocol and the University of Manitoba *Ethics of Research Involving Humans.*

Funded Protocols:

- **Please mail/e-mail a copy of this Approval, identifying the related UM Project Number, to the Research Grants Officer in ORS.**

Research Ethics and Compliance is a part of the Office of the Vice-President (Research and International)
umanitoba.ca/research