COMPARING APARTMENT BALCONY OPTIONS IN TORONTO FOR USEABILITY, HEALTHY LIGHTING AND DAYLIGHT AVAILABILITY

By

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Abstract

This major research project (MRP) summarizes findings of a simulation-based study that explored the possibilities of balconies as functional spaces and examined the impacts of balcony designs on daylight and healthy daylighting. This study analyzed and compared open air and glass-enclosed inset balconies for two typical unit sizes in multi-unit residential buildings (MURB) in Toronto, Canada. The simulation results were compared against the Daylight Credit in Leadership in Energy and Environmental Design (LEED) standard and Feature 54 of the WELL Building Standard. Findings included recommendations for design options that enable balcony uses as dining, living and garden spaces, and relating to the impacts of balcony designs on building performance. Daylight availability and healthy lighting were evaluated both for the unit, and on the balcony. Future work should compare simulation findings to occupant satisfaction in field studies.

Acknowledgements

I would like to express my deepest appreciation to my supervisor, Dr. Terri Peters for her continued support and encouragement throughout this research process. This endeavor would not have been possible without her positive encouragement and countless hours of dedication.

I would also like to thank Dr. Mark Gorgolewski as a second reader for this MRP and I am gratefully indebted to his valuable suggestions and comments on this MRP.

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List of Acronyms

ALFA: Adaptive Lighting for Alertness

ASE: Annual Sunlight Exposure

CBDM: Climate-Based Daylight Modelling

CCT: Correlated Colour Temperature

DA: Daylight Autonomy

EML: Equivalent Melanopic Lux

IpRGCs: Intrinsically Photosensitive Retinal Ganglion Cells

LEED: Leadership in Energy and Environmental Design

MRP: Major Research Project

MURB: Multi-Unit Residential Buildings

sDA: Spatial Daylight Autonomy

1.0 Introduction

Toronto, as Canada's most populous city, is expected to have over 3.9 million people living in the city by 2041 (Government of Ontario, 2021). As the city continues to densify, most new housing projects in Toronto and across all urban centers in Canada, will be multi-unit residential buildings (MURB) (CMCH, 2022). To meet the increased demand in housing, smaller units including studio and one-bedroom apartment layouts have become more prevalent. As more MURB projects take place, the need to understand how the quality of living can be addressed in small and limited living spaces becomes increasingly important. Furthermore, with the ongoing global pandemic, the amount of time people spend indoors has increased. Due to the COVID-19 outbreak, 30 percent of the workers worked from home in 2021 in contrast to only 4 percent in 2016 (Statistics Canada, 2021). As a typical component of new high density apartment buildings in Toronto, balconies can provide access to the outdoors, adequate fresh air and daylight. Significantly, balconies can be utilized to extend the indoor programs to the outside to enhance and improve the living quality of the occupants in the limited space available in apartment units. To date, research on balconies has focused on the energy efficiency and resilience in balcony designs as they impact the apartment units, and little has been studied about the qualities of the balconies as spaces of their own, such as the relationship between size, location and functionality in various balcony options. This MRP therefore compared different functional possibilities of balcony designs and the associated impacts on daylight availability and human centric lighting.

All balconies impact daylighting in buildings, since they either protrude from the building facade and shade the unit below, or if they are inset, they effectively lengthen the unit floorplate (Peters et al., 2019). Therefore, this study examined lighting when comparing various inset balcony options. The availability of natural daylight in housing is crucial since it has been related to occupant well-being. Much research has proven the positive influence of daylight exposure to human health. The most notable benefit of daylight exposure is that natural daylight can improve vision and visual performance (Veitch, 2005). Furthermore, daylight has a positive impact on visual comfort in addition to being linked to numerous health benefits. This emphasizes the value of sufficient daylight in living areas, particularly in MURB apartments. However, even though daylight has a significant influence in occupant health, poor daylighting continues to be one of the biggest challenges when it comes to the indoor environment comfort in apartment buildings (Peters et al., 2019).

Recent publications have highlighted the importance of full spectrum lighting, also known as circadian or healthy lighting, to human well-being. Light has the ability to disrupt or promote human circadian photoentrainment (Altenberg Vaz & Inanici, 2021; Veitch, 2005). This is especially important when building occupants spend much of their time indoors where there is often insufficient daylighting. Currently, the use of artificial light sources as circadian stimuli is the main focus of effort in the field of circadian lighting design. This is due to the widespread use of LED technology and its potential in changing the circadian rhythm as an alternative source of daylight (Figueiro et al., 2019). However, little study has been done on the use of daylight to provide circadian stimulus and in urban apartment housing. The work by Nareshkumar and Peters has started to explore this area of research(Nareshkumar & Peters, 2022). Therefore, this

MRP extended this work to gain further understanding of how balcony designs influence healthy daylighting from daylight in apartment housing.

1.1 Objectives

The objective of this MRP was to understand how different balcony layouts in MURB could be used to provide functional spaces and promote occupant well-being. The different balcony designs were tested for their ability to extend indoor programs such as the living and dining space into the outdoors and to create all-season, winter gardens on balconies. With early-stage design simulation tools, Adaptive Lighting for Alertness (ALFA) for healthy lighting and ClimateStudio for daylighting, the research aimed to answer the following questions:

1. How do open-air and glass enclosed balcony designs compare in terms of daylight availability and healthy daylighting for the units and balconies?
2. When enlarging the balcony to accommodate a living and dining space, how do daylight availability and healthy daylighting change for the units and balconies?
3. How does incorporating different amounts of plants affect daylighting for the units and balconies?

2.0 Literature Review and Background

2.1 Lighting in Apartment Housing

Incorporating balconies in high density urban MURB can be important for inhabitant well-being since balconies provide direct access to outer space. Balconies have the potential to act as an extension of the interior space and enhance the living quality of residents in small apartment units. However, there are important considerations that must be considered when designing balconies. According to a recent study, some important design decisions include the balcony's geometry and orientation to the sun as it can affect the thermal and visual comfort of the interior space (Kisnarini et al., 2018). Daylight availability is a key factor in balcony designs, because the design of the balcony impacts potential energy use, quality of life, and health and well-being. A recent study of urban balconies addressed the impacts of balcony design on daylight (Peters & Kesik, 2020). In their study, design parameters including geometry and size of balcony, location of the balcony in relation to the unit and the material of the balcony railings were considered significant. The findings revealed that all balconies negatively affect the daylight in the unit and have various effects on daylight penetration (Peters & Kesik, 2020). In a study by Ribeiro et al. (2019), different types of balconies and their impacts on daylight availability were analyzed. Protruding balconies, shaded balconies and glazed balconies were studied respectively on their impacts of lighting comfort. Ribeiro et al.'s research concluded that balconies help to block undesirable penetration of sunlight while shaded balconies filter and control the passage of light to reduce glare discomfort. However, the authors found that glazed balconies contributed to the light barrier effect where the amount of daylight is reduced when passing through an additional glazing layer (Ribeiro et al., 2019). Another investigation focused on the impact of glazed balconies on lighting comfort, and glazed balconies were found to contribute to an undesirable barrier effect that decreased daylight penetration in the living spaces (Wilson et al., 2000). The study showed that an open balcony with 1.5 meters of depth and 2.5 meters of height can decrease daylight penetration by 30-35 percent and up to 60 percent when glass is added to enclose the balcony (Wilson et al., 2000). Given the aforementioned studies, it is evident that balcony designs can contribute negatively to daylight availability in apartment units if not designed properly and should therefore be carefully considered when designing.

LEED is the world's most well-known green building rating system that promotes a holistic approach to sustainability. The rating system is focused on resource efficiency, with points allocated to various credit categories. The daylight credit in the LEED v4 focuses on daylight analysis using simulations to estimate daylight quality and levels (U.S. Green Building Council, 2022). The goal of the daylight design metric is to connect occupants with the outdoors, and to allow daylight penetration to interior space to reduce the use of electric lighting. For LEED compliance spatial daylight autonomy (sDA) and annual sunlight exposure (ASE) must be evaluated. The sDA metric requires a percentage of the floor area to meet minimum daylight illuminance levels for a specified period of working hours per year (IES, 2022). For the LEED v4.1 daylighting credit, at least 55 percent of space must receive 300 lux of daylight for at least 55 percent of the working hours per year. On the other hand, ASE is a metric that measures visual discomfort and glare. To meet LEED v4.1 daylighting credits, no more than 10 percent of a space should have daylight more than 1000 lux for a maximum period of 250 hours per year (U.S. Green Building Council, 2022). Table 1 outlines the achievable points for daylight regulation.

Table 1: Daylight points in LEED v4.1

Daylight Regulation	Points Achieved
The average sDA300, 50% value for the regularly occupied floor area is at least 40%	1 point
The average sDA300, 50% value for the regularly occupied floor area is at least 55%	2 points
The average sDA300, 50% value for the regularly occupied floor area is at least 75%	3 points

Discussed later in Section 3.3, ClimateStudio was used to calculate daylight availability and compliance with LEED daylighting credit through sDA and ASE measurements. ClimateStudio is a climate-based daylight modeling (CBDM) software that allows evaluation of luminous quantity (illuminance and or luminance) using realistic sun and sky conditions taken from climate data (Solemma, 2022). Typically, CBDM evaluates a full year and a time step of an hour or less to capture the daily and seasonal dynamics of natural daylight (Brembilla & Mardaljevic, 2019).

The introduction of CBDM progressed the practice of daylight simulation forward, but much more study is needed to understand daylighting in MURB. As indicated by Peters et al. (2020), MURB has been understudied in the field of daylighting as opposed to other typologies like office buildings. The study of office buildings contributes to a big portion of current daylight research, but the need to study MURB typology is just as important. According to Klepeis et al. (2001) people spend about 87 percent of their time indoors. Significantly, as MURBs have become a prevalent housing type, it proves that the study of MURB is needed in daylight research.

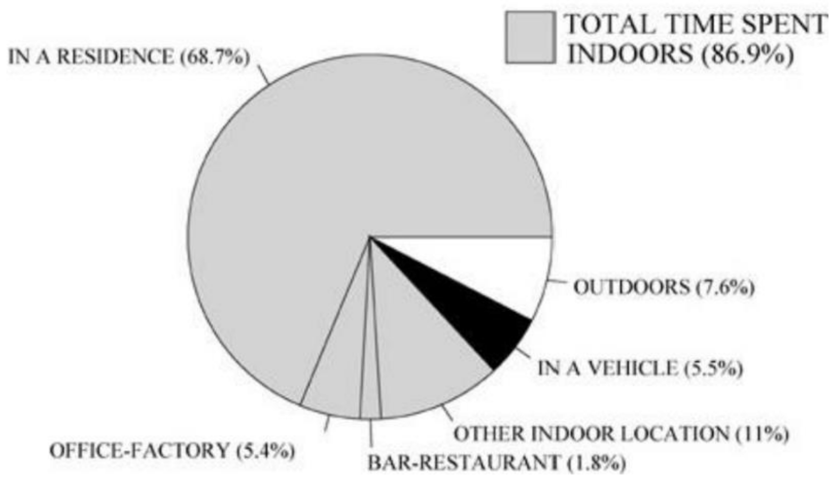

Figure 1:Percentage of time spent by location (Klepeis et al., 2001)

2.2 Healthy Lighting

Light is a significant factor in regulating the daily human physiology and providing information to control daily circadian rhythms (Dijk & Lockley, 2002). The synthesis of certain hormones, temperature regulation, sleep-wake cycles, alertness and performance patterns, and many other elements of physiology, metabolism, and behavior are all influenced by the circadian rhythm(Czeisler & Gooley, 2007). Lucas et al. (2014) found that these biological and behavioral effects of lights are caused by a distinct photoreceptor in the eye, known as melanopsin-containing intrinsically photosensitive retinal ganglion cells (ipRGCs), in addition to conventional rods and cones. These types of light responses are non-visual effects as they are separate from other aspects of vision. Non-visual effects of light are important because they can affect the occupants' mood, behavior and decision-making process (Lucas et al., 2014). Furthermore, adequate daylighting can provide better alertness, sleep and mood, while ineffective lighting can lead to fatigue, dullness, and low productivity (Iringova, 2019).Thus, it is evident that access to daylight can significantly influence human health and wellness.

The WELL Building Standard is the first performance-based rating system that measures, certifies, and keeps monitoring of built-environment elements that have an influence on people's health and wellness (IWBI, 2022). The standard aims to combine best practices in design and construction with measures for improving health and wellness that are supported by research. The WELL Building Standard evaluates seven performance concepts which consist of air, water, light, and the increase in occupant nutrition, fitness, mood, and comfort (IBWI 2022). There are many features in the WELL Standard about lighting, and this MRP focused specifically on Feature 54 Circadian Lighting Design in v1 (IWBI 2022). To meet the requirements of this feature, at least one of the two requirements outlined in the standard must be met:

1. At least 75 percent or more of the workstation area, at least 200 EML must be available. This is measured on a vertical plane facing forward at 1.2 meters above the floor finish. The 200 EML may be daylight and must be present for at least hours between 9AM and 1PM for every day of the year (IWBI, 2022).
2. Electric lights must provide maintained illuminance for all workstations on the vertical plane facing forward (at occupant eye level) of 150 EML or greater (IWBI, 2022)

For this MRP, given that the building type studied was apartment housing, it was determined that the focus would be natural light, as it is difficult to make assumptions about what kinds of lighting people will select in their home. For this MRP, only the first WELL Feature 54 requirement was considered as the second requirement is not applicable to daylight. The WELL Standard has a particular focus on when the light is in the space because the timing of the light is crucial to circadian lighting. According to a phase response curve, exposure to light in the late evening (18:00–6:00) will cause the circadian pacemaker to advance, while early morning light will delay it (18:00–6:00 h) (Khalsa et al., 2003; Rüger et al., 2013). Evening light exposure may cause the brain to alert at the wrong time and interrupt sleep (Münch et al., 2006), whereas morning light exposure may be helpful in reducing sleep inertia, or the grogginess experienced when waking (Sletten et al., 2009). Therefore, the WELL Building Standard only evaluates daylight from hours between 9AM to 1PM.

2.3 Useability

There are currently few balcony guidelines and occupant preference and satisfaction studies of balconies. The "Growing Up Vertical Guidelines" is a Toronto city-wide guideline designed to integrate family suitable design into MURB development (City of Toronto 2020). The goal of the guideline was to provide support to new vertical high-density communities to meet the needs of diverse households including those with children. The Growing Up Vertical Guidelines state that balconies should be a minimum of 2.4 meters deep and 2.7 meters wide to maximize daylight access, safety, flexibility and adaptability. The balcony should be designed so that it can be used for family dining and socializing, extend the interior space and provide access to fresh air. Significantly, the guidelines recommend that an ideal balcony should provide space for seating, play and landscape planters (City of Toronto, 2020).

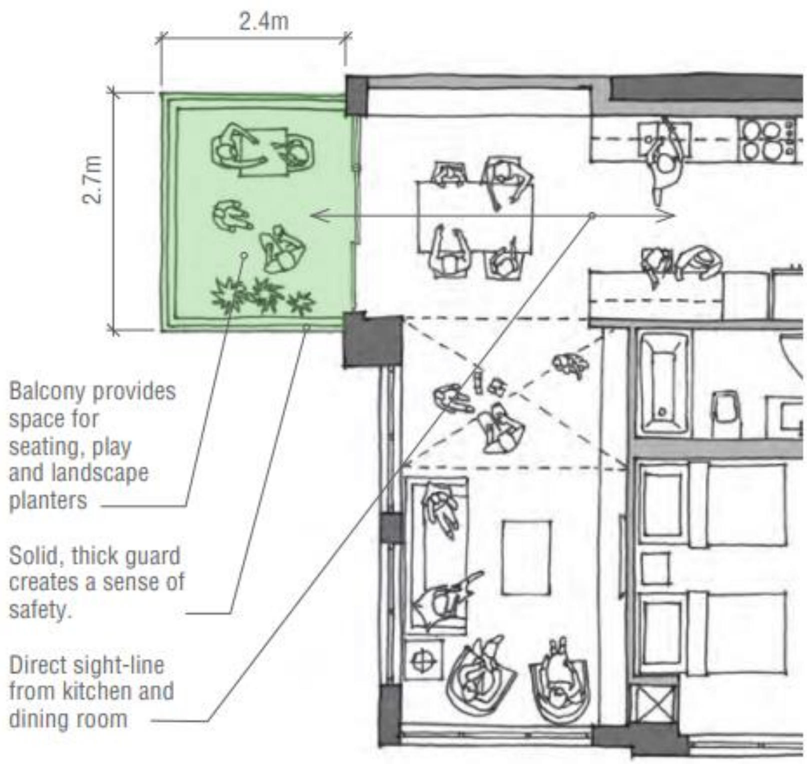

Figure 2: Plan diagram of an ideal balcony (City of Toronto, 2020)

Another City of Toronto document is relevant to this study. The "Design Consideration in Developing Alternative Housing Guide" suggests that balconies should aim to provide adequate space for various activities (City of Toronto 2017). It states that residents prefer additional balcony space to be used as living and gardening space. The importance of this space increases as the area of the housing unit decreases (City of Toronto, 2017). However, no existing literature and research were identified that describe what an appropriate size a balcony should be, based on different uses. Many studies have pointed out the importance of balcony as a place where private life can be open up to the well-being of the occupants such as fresh air, daylight and social interactions, especially in the recent emergence of public space disposition during the COVID-19 pandemic (Grigoriadou, 2021; Rosa-Jimenez & Jaime-Segura, 2021). Therefore, the ability for housing to accommodate different needs and programs should be considered when designing new MURB. Rosa-Jimenez and Jaime-Segura, (2021) highlighted three housing needs that should be addressed in the post pandemic era. These needs include the need to consider the orientation of housing to improve the quality of indoor and outdoor space, the need for housing to facilitate remote working and the need to provide rooms that overlook green areas (Rosa-Jimenez and Jaime-Segura, 2021) . A recent study found that a balcony is the most sought-after place by home users during the lockdown period of COVID-19 as it allows numerous social activities and practices, such as gardening, leisure, recreation and exercise (Bettaieb & Alsabban, 2020). However, the study found that balconies should be at least 6 square meters per apartment to allow for those functions (Bettaieb & Alsabban, 2020).

There seems to be increased interest in balcony gardening as there is increasing evidence proving the mental and physical health benefits from exposure to plants and green space (Thomson, 2018). Many studies have revealed the benefits of observing nature or images of nature on mood and mental health (Kaplan, 1973; Ulrich, 1984). However, as mentioned earlier, there are no guidelines on what makes a balcony appropriate for balcony gardening and the impacts of balcony plants on daylight qualities. The measurement and quantification of plants have often been neglected due to difficulties in daylight simulation practices. Currently, trees in daylight simulation are simplified to geometric shapes such as cones, spheres or cylinders with a predicted reflectance of 20 percent. In research that looks at the measurement of light through trees by Balakrishnan and Jakubiec (2016), an average leaf reflectance is found to be 14 percent as opposed to the 20 percent used in most daylight simulation practice. Balakrishnan and Jakubiek employed HDR photography and automated image processing to measure the gap and transmittance percentage of trees. The gap percentage was defined as the gap sizes in the tree crown. Similarly, the transmittance percentage is the luminance level of the gap pixels. The higher the gap and transmittance percentage was, the higher the light transmittance will be (Balakrishnan & J. Alstan Jakubiec, 2016). Although this study was limited to larger trees and not home plants, the average leaf reflectance found in this study is used to compare with the reflectance values identified in healthy lighting simulations using ALFA software for this MRP. Further research needs to be undertaken to develop a database of different types of trees with various shapes, gap and transmittance percentages. In another research study by Villaba et al. (2014), three simplification systems in daylight simulation of trees were tested. The three simplification systems tested included diffusion (textile curtain), retroreflection (louvers system with high reflection), and sectorized blocking (screen panel). Their methodology was based on hemispherical images and ray-tracing simulation (Villalba et al., 2014). The simulation results were compared with measurements in situ of vertical illuminance values and their study found that the louver system is the most beneficial as it showed a high degree of adjustment (9% error) with respect to the measured data (Villalba et al., 2014). The main limitation of this study is that only one type of tree (mulberry tree) was examined and they had to really simplify their forms. Given the limited data on other tree types, especially smaller household plants, this simulation approach could not be directly used in this MRP. However, it was important to identify this type of simplification method in daylight simulation of trees.

3.0 Methods

This MRP analyzed daylight availability, healthy daylighting, and scenarios for potential balcony use for a number of apartment units and balcony designs in Toronto. In particular, the project focused on comparing glass enclosed and open-air designs for their ability to meet performance targets for: 1) daylight availability according to the LEED Daylight Credit; 2) healthy lighting according to the WELL v1 standard Circadian Lighting Credit; and 3) usability and size of the balcony including greenery and winter garden potential. To meet these objectives, the project used environmental simulation to predict performance. The research considered two common apartment unit types and explored the possibilities of balconies as functional spaces. Specifically, this research project aimed to examine the impacts of balcony designs on daylight and human centric lighting.

The research work had five phases: (1) Three-dimensional modeling of a number of apartment unit floor plans in Rhino; (2) Studies about balcony functionality and winter garden potential (3) Daylight availability simulations with ClimateStudio; (4) Healthy lighting simulation with ALFA; (5) Evaluation against design metrics including the LEED and WELL Building Standards. All these steps were followed for both unit types, enclosed and open air, in four orientations. The term 'building orientation' is the positing of a building in relation to the sun. The four orientations used in this study include south, east, north, and west. In step 2, certain parameters were tested to explore design options that enable balcony design options to be used as dining, living and garden spaces. A workflow of the research is illustrated in Figure 3 below.

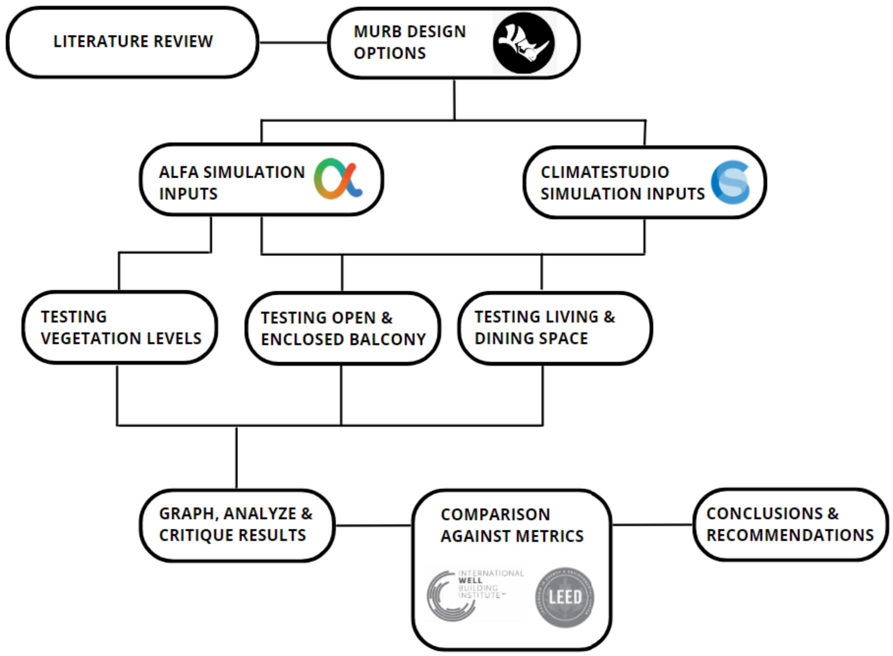

Figure 3: Project Workflow

3.1 Simulation as a Methodology

These simulation-based studies were identified as the most appropriate method for this research as they allow options to be rapidly tested using a number of different balcony design parameters. ClimateStudio (Solemma, 2022) uses Climate-based daylight modeling (CBDM) to evaluate options accurately using Radiance. ClimateStudio is capable of tracing multiple paths at a time which makes it an ideal choice for parametric studies. ALFA is a fully spectral circadian lighting design software that predicts and controls the non-visual effects of natural and artificial light (Solemma, 2022). It is a plug-in for Rhinoceros 3D. This software is capable of creating simulations in 81 colour channels by conducting spectral ray-tracing through a Radiance lighting engine (Solemma, 2022) Both ClimateStudio and ALFA are early design tools that have the capability to easily calculate the Daylight Credit in LEED (U.S. Green Building Council, 2022)and the Circadian

Lighting Credit in WELL (IWBI, 2022). The workflow of ClimateStudio and ALFA is explained in later sections.

3.2 Design Options Tested and Compared

Typical Toronto floor plans were identified from publications including Hans Ibelings and the Partisans' *Rise and Sprawl* (Ilbelings & Spunt, 2016) . Numerous studies have shown that as Toronto continues to densify, the housing trends are shifting towards smaller units and higher density. Therefore, the need to investigate human centric lighting and access to daylight in smaller units was considered highly relevant and a focus for this MRP.

In this study, the two floor plan types studied were studios and one bedroom apartment units. The studio units studied were small with little distinction between sleeping, living and eating areas. Bathrooms in this unit type were a similar size as bathrooms in other unit types and are therefore proportionally very large. Balconies tended to be quite small. Enclosed balcony designs in this type of apartment unit have the potential to be an important additional living space. In this study, the G24 unit layout from the Dundas Square Garden was chosen as a typical studio apartment unit.

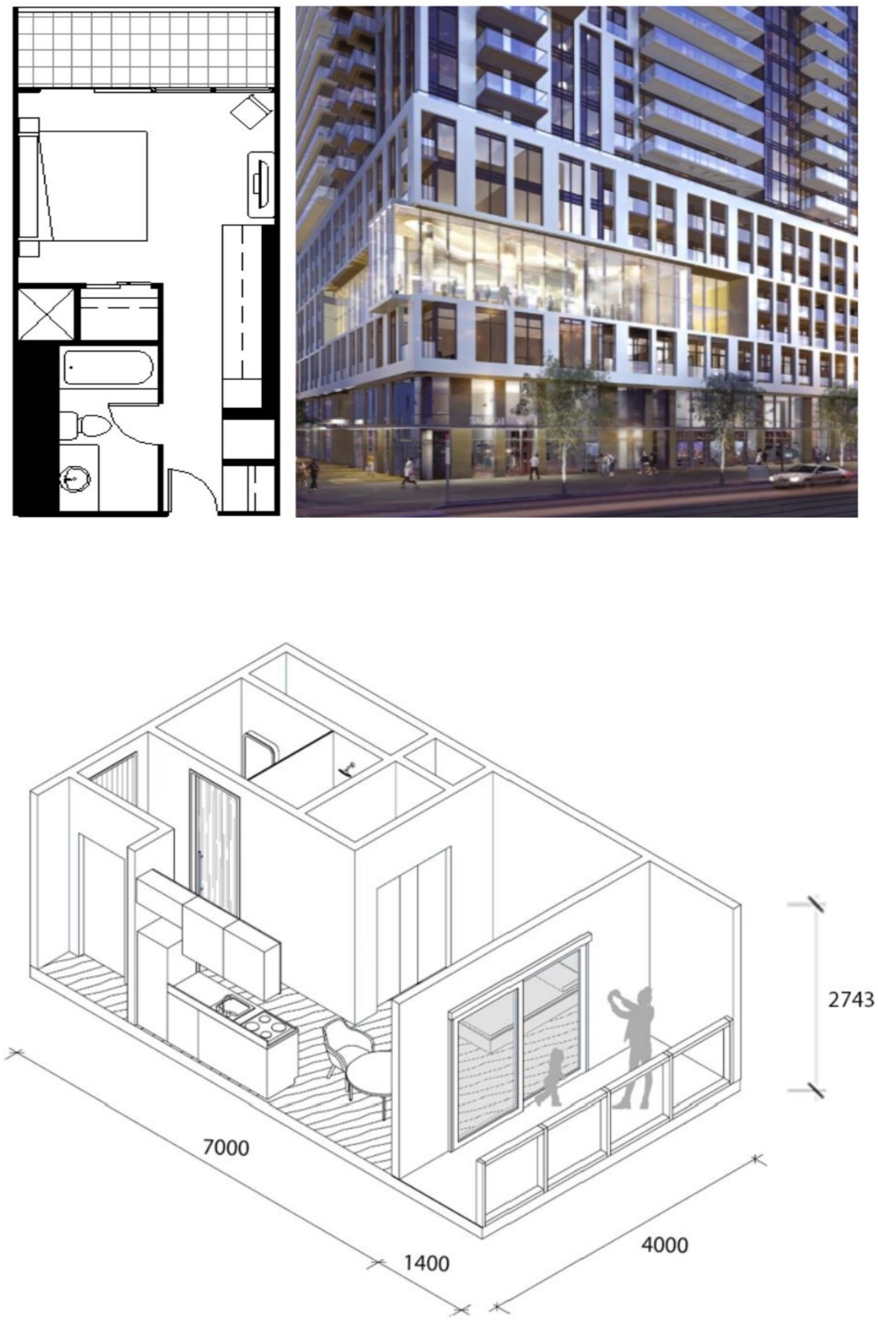

Figure 4: Plan, section and exterior view of the Dundas Square Gardens

Name: Dundas Square Gardens
Unit Type: G24
Architect: IBI Group
Year: 2019
Location: 200 Dundas St E, Toronto, Ontario, M5A 4R6
Unit Aspect Ratio: 1:1.8

One bedroom, one bay units are common unit layouts in the Toronto housing market. The designs normally have light from only one side and orientation, and sliding glass doors or interior windows to provide some daylight for the inboard bedroom. This type of unit is worth studying as they seem poorly lit, over lit on the exterior and underlit in the sleeping area. In this study, the Collins unit layout from the Residence of 488 University Avenue was selected.

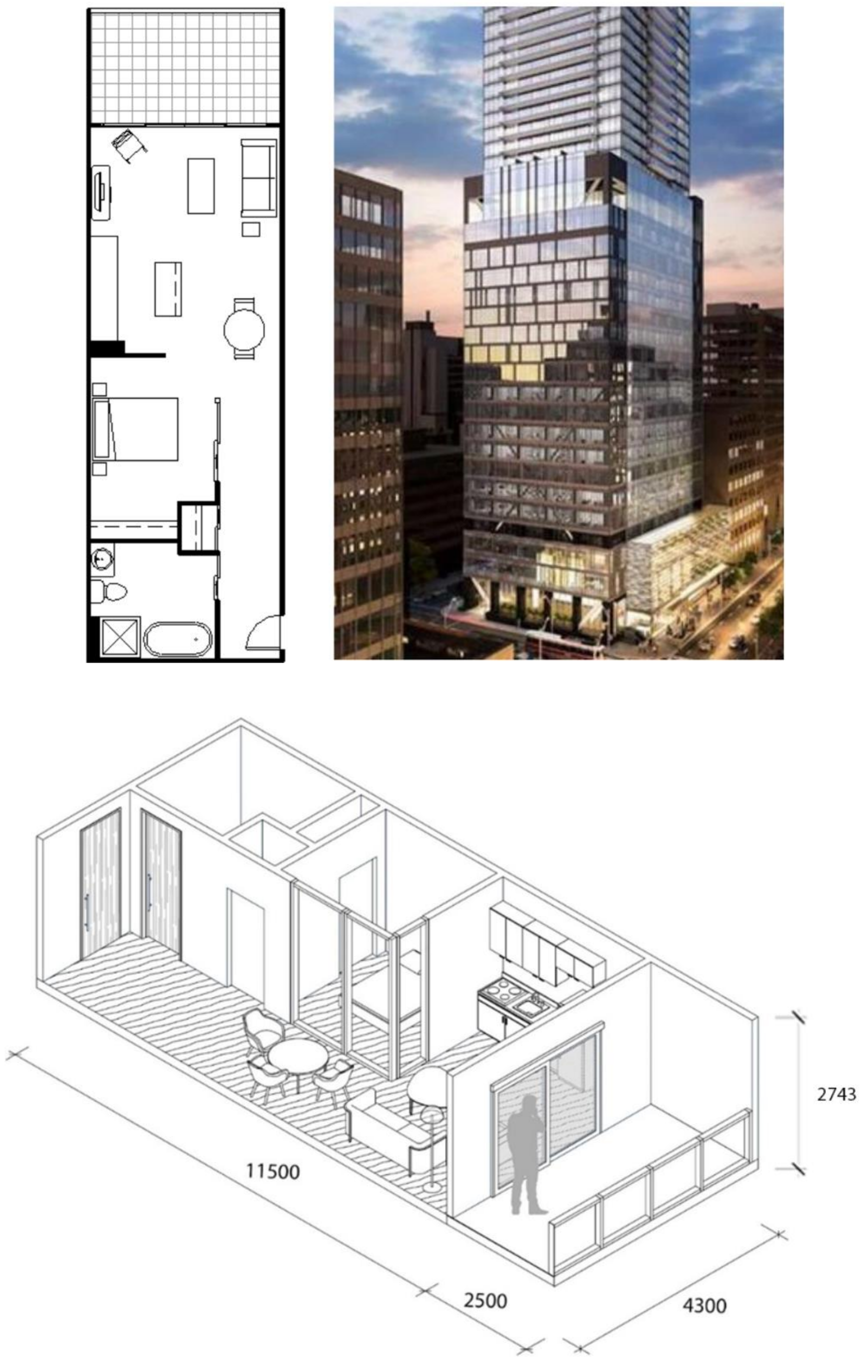

Figure 5:Plan, section and exterior view of the Residence of 488 University Avenue

Name: The Residence of 488 University Avenue
Unit Type: Collins
Architect: WZMH Architects
Year: 2017
Location: 488 University Ave, Toronto, ON M5G 0C1
Unit Aspect Ratio: 1:2.6

Similarly, there are no minimum standards for balcony designs in Toronto. The "Growing Up Vertical Guidelines" is a relevant document published by the City of Toronto that does mention balconies and was described in section 2. The document specified that balconies should be "a minimum of 2.4 meters deep and 2.7 meters wide and be designed to maximize sunlight access, safety, flexibility and adaptability and be free of uncomfortable wind conditions. Where possible, provide inset balconies to provide comfortable space, reducing building bulk and limit overlook" (City of Toronto, 2020, 47), but the document does not specify what an appropriate balcony size should be compared to indoor space, or mention the influence of balconies on daylight or recommend a level of enclosure for the balcony. There are only a few studies that report on resident satisfaction with balconies. A study by Nejati et al. (2016) reported that rooms with physical access to a balcony were given the highest level of satisfaction and restorative qualities. Therefore, the useability of the balcony becomes significant to offer opportunities for city dwellers to access the balcony. To address the functionalities of balconies in both floor plant types, both open-air and glass enclosed balconies were studied in this MRP. The impacts of glazed balconies to daylight availability and healthy daylighting were discusses in relation to both the balcony and unit space. An example of the studio apartment illustrating the difference between open-air and glass enclosed balcony can be found in Figure 6 below.

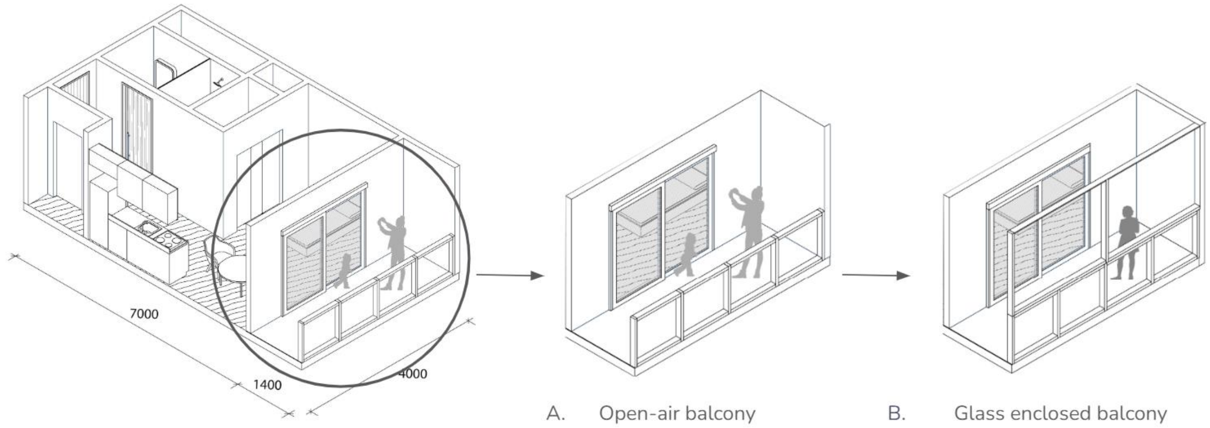

Figure 6: Open-air and glass enclosed balcony for the studio apartment

To explore the idea of an ideal balcony size, in this MRP the current one-bedroom balcony and also new options were tested, to try to extend indoor programs including the living and dining space into the outdoors. Typical apartment furniture was used to determine the modified balcony size. The modified balconies and their updated dimensions can be seen in Figure 7 below.

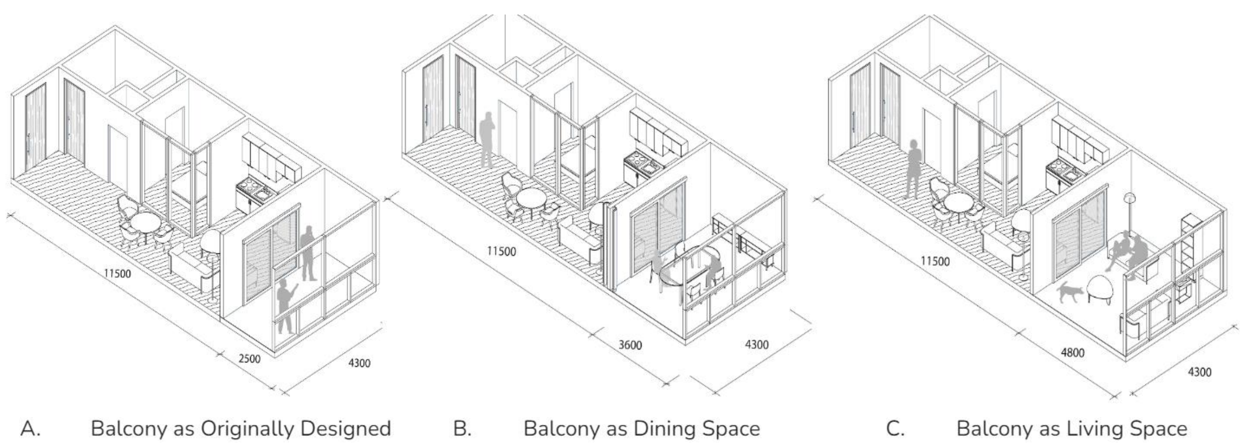

Figure 7: Existing (left) and updated plan (right) when the balcony size is modified to accommodate a living and dining space

3.3 Daylight Simulation Modeling Parameters

The two MURB units were modeled to represent the actual floor plans of the actual floor plans identified in Section 3.2. These units are single aspect, side lit, mid-level units with a floor to ceiling height of 8’ (2.4 meters). The surrounding buildings' massing context was not modeled because this MRP isn’t site-specific research. In addition, the interior partition walls and furniture were not modeled for two reasons: (1) this research is not specific to a certain apartment in Toronto and (2) how the space is used is unpredictable. In keeping with typical modeling of daylight availability in MURB (Peters et al., 2020), the units were modeled as simple shoebox models without detail floor window frame and mullions, to investigate the maximum amount of daylight availability in the space. Therefore, the models were modeled as one open space because the aim of this research is to understand the impacts of different balcony design options on healthy daylight. The two simulation software used in this research included ClimateStudio and ALFA and they required certain assumptions to be made about occupancy, materials, orientation and climate. These assumptions are discussed in the next two sections below.

3.3.1 Daylight Availability Analysis using ClimateStudio

For this research, ClimateStudio was used to calculate daylight availability and compliance with LEED Daylighting Credit through sDA and ASE measurements (U.S. Green Building Council, 2022). To simulate daylight availability, “LEED v4.1 Option 1” was selected within the Daylight Availability tab of the ClimateStudio software. This evaluates the annual daylight needed to achieve the LEED daylight credit. The Toronto weather file and materials selected from ClimateStudio radiance library were used. A summary of the material selection used in the daylight availability simulation is found in Table 2. The materials selected in ClimateStudio were consistent with the materials selected for the ALFA simulation.

Table 2: Summary of materials selected in ClimateStudio

Selected Materials from Radiance Library	Type	Surface	Roughness	Rvis (tot)	Rvis (diff)	Rvis (spec)	Tvis (tot)	Tvis (diff)	Tvis (spec)
Light gray floor tile nonslip	Glossy	Floor	0.3	41.8%	41.6%	0.2%	0%	0%	0%
Ceiling LM83	Matte	Ceiling	0	70%	70%	0%	0%	0%	0%
White painted walls	Glossy	Wall	0.2	84%	83.6%	0.3%	0%	0%	0%
Aluminum gray ext. cladding	Glossy	Exterior	0.2	47.6%	45.2%	2.4%	0%	0%	0%

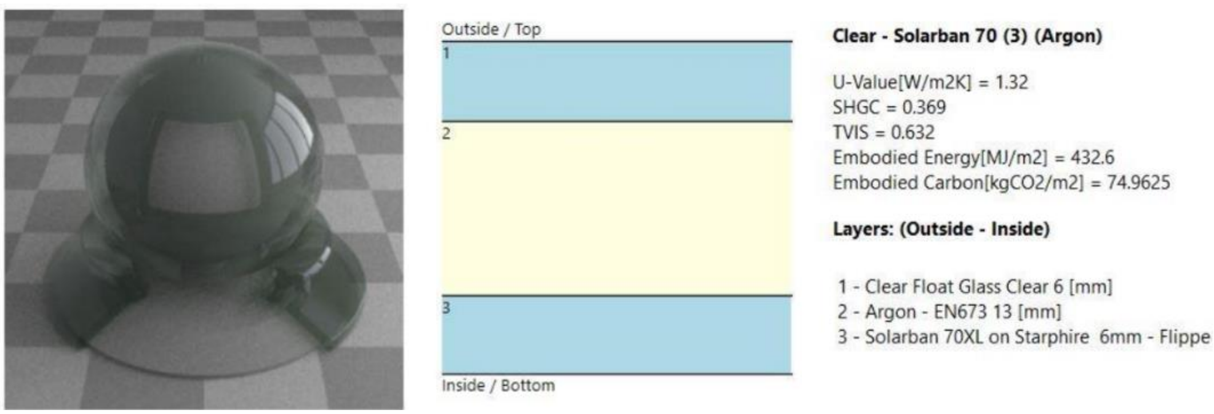

Figure 8: Detailed description of the double pane insulated glazing unit (IGU) used for the windows and glass enclosed balconies of the models

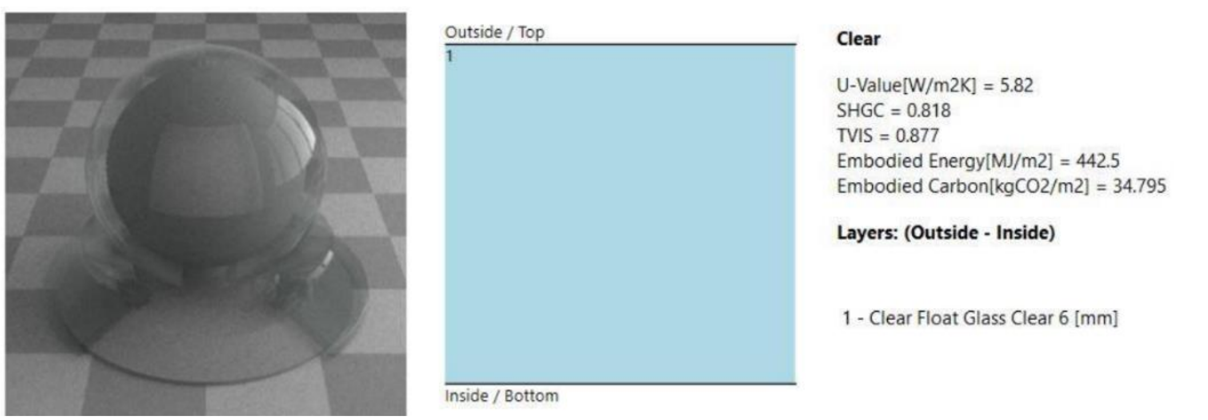

Figure 9: Detailed description of the single pane glass used for the balustrade glazing of the models

In the simulation, sensor grids were positioned 600 millimeters apart and 760 millimeters across the regularly occupied floor area to evaluate daylight availability of both the balcony and the unit (U.S. Green Building Council, 2022). Furthermore, an occupancy schedule of 8AM to 6PM was selected as these were the guidelines required by LEED to achieve the LEED Daylighting Credit. However, whether or not these guidelines are appropriate in residential settings is something that should be investigated further.

Table 3: Summarized table of ClimateStudio simulation set-up details

Grid Setup			Occupancy schedule	Orientation	Weather File	LEED Version
Sensor Spacing: 609.6	Sensor inset (target): 457.2	Sensor inset (min): 304.8	8AM - 6PM DST	N, S, W, E	Toronto	LEED V4.1

3.4 Healthy Lighting Analysis using ALFA

ALFA can predict the amount of light absorbed by an observer's non-visual photoreceptors. The quantity of these non-visual photoreceptors is referred to as equivalent melanopic lux (EML) as they absorb light using pigment melanopsin. This research evaluated healthy lighting using EML as a measurement without making assumptions about artificial lighting. Therefore, even though WELL Circadian Lighting Credit can be achieved by using both natural and artificial lighting, due to the uncertainties of how people use electric lighting at home, this study focused on daylight as the sole lighting source for meeting the WELL Circadian Lighting credit.

Tables 4 & 5 summarize the properties of the selected materials chosen from the Radiance material library and also used in the ClimateStudio simulations. In ALFA, the materials are assigned with different characteristics including specularity, reflectance range of photopic which is the eyes response to light, melanopic which is the non-visual response to light and the M/P ratio between the two. Moreover, glazing materials have additional properties including transmittance values in the photopic and melanopic range.

Table 4:Properties of the selected materials chosen from the Radiance material library in Climate Studio

MATERIALS PROPERTIES					
LAYERS	MATERIALS FROM LIBRARY	SPECTACULARITY	R(P)	R(M)	M/P
Interior Walls	White Painted Room Walls	0.40%	81.20%	76.80%	0.95
Floor	Light Gray Floor Tiles Non-Slip	0.20%	41.80%	37.60%	0.9
Ceiling	White Painted Room Ceiling	0.40%	82.20%	77.40%	0.94
Exterior Cladding	Aluminum Gray Exterior Cladding	2.40%	47.60%	46.60%	0.98

Table 5:. Properties of the selected glazing materials chosen from the Radiance material library in Climate Studio

MATERIALS PROPERTIES FOR GLAZING								
LAYERS	MATERIALS FROM LIBRARY	Rf (pho)	Rf (mel)	Rb (pho)	Rb (mel)	T (pho)	T (mel)	M/P
Glazing for Windows and Glass enclosed balconies	Double IGU Clear Tvis 63%	10.80%	10.90%	11.20%	11.10%	63.30%	61.70%	0.98
Glazing for Balustrade	Single Pane Clear Tvis 88%	8%	8.20%	8%	8.20%	88.30%	89.09%	1.01%

As with the ClimateStudio simulations, a Toronto weather file was used. In ALFA, rather than an annual measurement, for WELL the simulations are point-in-time analyses. The dates for simulations were March 21st (spring equinox), June 21st (summer solstice), September 21st (fall equinox) and December 21st (winter solstice). To run the simulations, the time between 9AM and 1PM was selected. This was selected because this time period is specifically identified in the WELL Building Standard and significant for circadian entrainment (Dijk & Lockley, 2002).

Unlike LEED, which measures lighting on the horizontal plane, WELL evaluates lighting on the vertical plane, at a person's eye level sitting. For this research, the sensor grid was positioned vertically above the floor by 1.2m, which is typically the eye level when one is sitting as shown in Figure 10. The surface was measured at an angle of 180 degrees in the horizontal direction, representing the angle where light strikes the cornea in the directional view of an occupant. The grid spacing of the sensors were 860 millimeters apart with eight directions to represent the different cardinal and ordinal directions. Lastly, the radius of the sensors was set to 250 millimeters. A summary of the simulation set-up can be seen in Table 6.

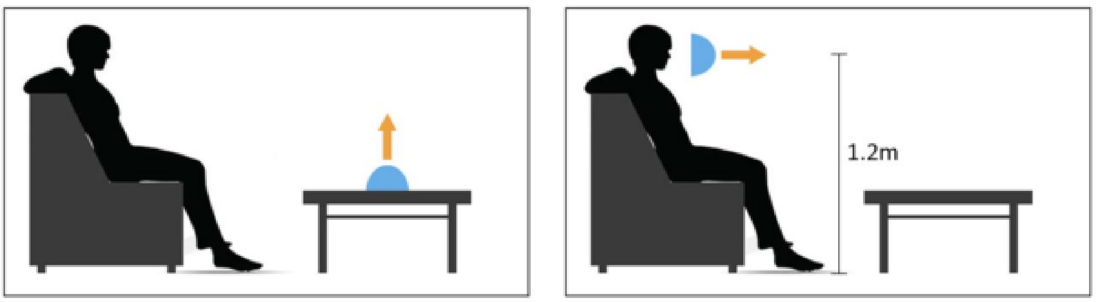

Figure 10: Sensor grid in relation to eye level

Table 6: Summarized table of ALFA simulation set-up details

Grid Setup						Dates	Time	Orientation	Location	Sky Conditions
Spacing: 1,227 mm	Directions: 8	Rotation: 0.0	Radius: 250 mm	Viewplane offset: 1,200 mm	Workplane offset: 400 mm	March 21st June 21st September 21st December 21st	9:00 AM 1:00 PM	N,S,W,E	Toronto, ON, Canada	Clear sky conditions

3.5 Testing Options for Greenery and Winter Garden

A question about balconies that this MRP addressed is: how big does a balcony need to be to be usable? and can it be a year-round green space? Greenery was estimated for different scenarios and evaluated for both the enclosed and open-air balcony types. Trees and plants are important in terms of experiencing daylight as they temper, scatter and transmit light. The influence and effects of trees for daylight simulation is normally neglected due to difficulties in daylight modeling as mentioned in Section 2. Trees are complex objects to model given their variability in shape, colour, crown density, reflectivity and transmissivity. For this MRP, common household plants were modeled in Rhinoceros 3D and daylight simulation was conducted with ALFA. The chosen plants include dracaena trifasciata (snake plant), pachira aquatica (money tree) and hedera helix (English Ivy). These plants were selected because of their ease in maintenance and commonality among other household plants. Information regarding the plants' types and sun requirements can be found in Table 7.

Table 7: Summarized table showing chosen plants for simulation

Name	Family	Plant Type	Mature Size	Sun Exposure	Photo
Dracaena Trifasciata	Asparagaceae	Evergreen, Perennial	6 inches to 6 feet tall	Shade to partial sun	
Pachira Aquatica	Malvaceae	Tree	Maximum height of 8' indoors	Full sun, partial shade	
Hedera Helix	Araliaceae	Perennial, Evergreen Climbing Vine	Climbs and spreads as much as possible	Full sun, partial shade	

Given the difficulties of modeling and simulating plants accurately in early-stage design tools, plants were simplified to geometric shapes in Rhinoceros 3D and material properties were chosen given the values identified in the literature review and choices provided by ALFA.

Materials of the plants were categorized into 3 groups including plants, planting boxes and soil as summarized in Table 8.

Table 8: Properties of the selected plants materials chosen from the Radiance material library for ALFA simulations

MATERIALS PROPERTIES FOR PLANTS					
LAYERS	MATERIALS FROM LIBRARY	SPECTACULARITY	R(P)	R(M)	M/P
Plants	Tree Leaf	0.00%	8.50%	4.40%	0.52
Planting boxes and pots	Wooden Planks	0.20%	10.70%	6.40%	0.6
Soil	Soil	0.00%	3.20%	2.40%	0.77

To evaluate the impacts of plants on healthy lighting in the one-bedroom apartment, three scenarios or levels of vegetation were assessed: no plants, small and large vegetation.

Figure 11: Different levels of vegetation used in ALFA simulation

No vegetation refers to a balcony with no plants. Whereas in the little vegetation scenario, one snake plant and one money tree were modeled on the balcony. In the large vegetation scenario, two snake plants and two money trees were placed on the balcony and four English ivy plants were hung on the walls of the balcony. As mentioned earlier, indoor plants were used in the simulation because of their ease in maintenance and commonality among other household plants.

4.0 Results

The results presented in this section are discussed in relation to the effects of open-air and glass-enclosed balconies, using the balcony as a living and dining space, and different levels of vegetation on balconies on daylight availability and healthy daylighting. The apartment units include studio and one-bedroom apartments. The results were divided into balcony and unit space as the simulations looked at the balcony and unit spaces separately.

4.1 Testing Enclosed and Open Balconies for Daylight Availability

To test for daylight availability, both the studio and one-bedroom apartments were evaluated under open-air and glass-enclosed conditions in four orientations for both the balcony and unit space. All numerical data can be seen in the Appendix 8.1. Summary tables are created based on the average of all simulation results. Table 9 shows the impact on the balcony, while Table 10 shows the impact on the unit space.

4.1.1 Simulation Summary for Balcony Space

Table 9 showed that the effects of enclosing the balcony for both apartment types are minor. The sDA levels and LEED credit for the balcony in all orientations of the building remained the same with three credits earned. However, the changes to the ASE level were insignificant as only the studio apartment indicated some changes.

Table 9: Simulation results showed the changes to sDA, ASE, and LEED credit in the balcony space when the balconies were enclosed

Comparison of Results for Studio and One Bedroom Apartment’s Balcony				
APARTMENT TYPE	**BALCONY DIMENSIONS (m)**	**sDA**	**ASE**	**LEED CREDIT**
Enclosed Studio	1.4 x 4	No changes	ASE changed minimally in the east orientation*	No changes
Enclosed One Bedroom	2.5 x 4.3	No changes	No changes	No changes

4.1.2 Simulation Summary for Unit Space

A summary table of the impact on unit space is shown in Table 10 below. For the unit, it was found that enclosing the balcony reduced the sDA by an average of 14% and increased the ASE by an average of 2.5% in the studio apartment. The one-bedroom apartment had less changes as the sDA was only reduced by 9% and the ASE had no changes except in the east orientation where it was reduced by 1.5%.

Table 10: Simulation results showing the changes to sDA, ASE, and LEED credit in the unit space when the balconies are enclosed

Comparison of Results for Studio and One Bedroom Apartment's Unit Space				
APARTMENT TYPE	**UNIT DIMENSIONS (m)**	**sDA**	**ASE**	**LEED CREDIT**
Enclosed Studio	7 x 4	sDA reduced by 14%	ASE increased minimally *	LEED credit dropped to 0
Enclosed One Bedroom	11.5 x 4.3	sDA reduced by 9%	ASE remains the same, except in the east orientation reduced by 1.5%	No changes in LEED Credit

4.2 Testing Enclosed and Open Balconies for Healthy Daylighting

This part of research evaluated the effects of both open-air and glass-enclosed balconies on healthy daylighting. The results are discussed in two separate parts; unit space and balcony space. To test for healthy daylighting, both the studio and one-bedroom apartments were tested under open air and glass enclosed conditions in four orientations for both the balcony and unit space. All simulation data can be seen in the Appendix 8.1.4.

4.2.1 Simulation Summary for Unit Space

Table 11 below showed that the studio balcony and one bedroom apartment have a 12.4% and 11.6% reduction on average in the percentage of floor area to meet 200 EML minimum at 9 am respectively. At 1 pm, the studio balcony and one bedroom apartment had a 18.8% and 13.4% reduction in the percentage of floor area to meet the 200 EML minimum. In comparison, the one-bedroom apartment had less impact on healthy daylighting than the studio apartment when the balcony is enclosed. However, the addition of glass layer to the balcony did reduce the percentage of floor area to meet 200 EML for both units.

Table 11: Simulation results showing the changes to healthy daylighting levels in the unit space when the balconies are enclosed

Comparison of Results for Studio and One Bedroom Apartment's Unit Space			
APARTMENT TYPE	**UNIT DIMENSIONS (m)**	**% OF FLOOR AREA TO MEET 200 EML AT 9AM**	**% OF FLOOR AREA TO MEET 200 EML AT 1PM**
Enclosed Studio	7 x 4	12.4% reduction	18.8% reduction
Enclosed One Bedroom	11.5 x 4.3	11.6% reduction	13.4% reduction

To understand how healthy daylight was affected in different orientations, the simulation results were shown in the four orientations tested in Table 12 & 13 below. The reduction values referred to the reduction in the percentage of floor area to meet 200 EML minimum when balconies were enclosed compared to when they are open.

Table 12: Summarized results for different orientations at 9 am

Comparison of Results for Studio and One Bedroom Apartment's Unit Space at 9 am					
APARTMENT TYPE	**UNIT DIMENSIONS (m)**	**SOUTH**	**EAST**	**NORTH**	**WEST**
Enclosed Studio	7 x 4	8.3% reduction	5% reduction	18% reduction	18.3% reduction
Enclosed One Bedroom	11.5 x 4.3	10.8% reduction	2.8% reduction	15.3% reduction	15.5% reduction

Table 13: Summarized results for different orientations at 1 pm

Comparison of Results for Studio and One Bedroom Apartment's Unit Space at 1 pm					
APARTMENT TYPE	**UNIT DIMENSIONS (m)**	**SOUTH**	**EAST**	**NORTH**	**WEST**
Enclosed Studio	7 x 4	8.3% reduction	20.8% reduction	21% reduction	25.3% reduction
Enclosed One Bedroom	11.5 x 4.3	15.3% reduction	6% reduction	18% reduction	14.5% reduction

It can be seen that at 9 am, the east orientation had the least reduction when the balconies (both apartment types) were enclosed compared to all other orientations. At 1pm, the east orientation had less impact in the one-bedroom apartment than the studio apartment. Overall, the south and east orientation were less affected by the glass layer, while the north and west were more affected by it in both apartment types.

A summary of the results is presented in Table 14 & 15, which identifies the orientations that passed or failed the Feature 54 Precondition in the WELL Standard. These results here were solely for the March equinox. As for the other June solstice, September equinox and December solstice, refer to the Appendix 8.1.5 for reference.

Table 14: Summary of orientations that passed or failed the ALFA simulations on March 21st at 9 am

MARCH 21 AT 9AM				
MODEL TYPE	SOUTH	EAST	NORTH	WEST
Studio Apartment with Open Balcony	PASS	PASS	FAIL	FAIL
Studio Apartment with Enclosed Balcony	FAIL	PASS	FAIL	FAIL
One Bedroom Apartment with Open Balcony	FAIL	FAIL	FAIL	FAIL
One Bedroom Apartment with Enclosed Balcony	FAIL	FAIL	FAIL	FAIL

Table 15: Summary of orientations that passed or failed the ALFA simulations on March 21st at 1 pm

MARCH 21 AT 1PM				
MODEL TYPE	SOUTH	EAST	NORTH	WEST
Studio Apartment with Open Balcony	PASS	FAIL	FAIL	PASS
Studio Apartment with Enclosed Balcony	PASS	FAIL	FAIL	FAIL
One Bedroom Apartment with Open Balcony	FAIL	FAIL	FAIL	FAIL
One Bedroom Apartment with Enclosed Balcony	FAIL	FAIL	FAIL	FAIL

The one-bedroom apartment, regardless of open or enclosed balcony, failed to meet the WELL Standard Feature 54 requirements. The studio apartment, on the other hand, met the WELL requirements in some conditions. At 9 am, the studio apartment with an open balcony passed the WELL Standard at the south and east orientation. For the enclosed studio apartment, the WELL Standard was met at the east orientation. At 1 pm, the studio apartment with open balcony fulfilled the requirements at the south and west orientation. For the enclosed studio apartment, the WELL Standard was achieved at the south orientation.

4.2.2 Simulation Results for Balcony

Through simulations, it was found that the June solstice was the best performing date. Therefore, it was chosen in conducting the ALFA simulations of the balcony space. A simulation summary could be seen in Table 16 and 17 below.

Table 16: ALFA simulation results testing open and enclosed balcony on June 21st at 9 am

JUNE 21 AT 9AM				
MODEL TYPE	SOUTH	EAST	NORTH	WEST
Studio Apartment with Open Balcony	97 %	100 %	94 %	94 %
Studio Apartment with Enclosed Balcony	100 %	100 %	100 %	97 %
One Bedroom Apartment with Open Balcony	100 %	100 %	100 %	100 %
One Bedroom Apartment with Enclosed Balcony	98 %	88 %	100 %	100 %

Table 17: ALFA simulation results testing open and enclosed balcony on June 21st at 1 pm

JUNE 21 AT 1PM				
MODEL TYPE	SOUTH	EAST	NORTH	WEST
Studio Apartment with Open Balcony	100 %	98 %	100 %	100 %
Studio Apartment with Enclosed Balcony	100 %	100 %	100 %	100 %
One Bedroom Apartment with Open Balcony	92 %	100 %	100 %	100 %
One Bedroom Apartment with Enclosed Balcony	100 %	83 %	100 %	100 %

Table 18 shows the reduction of floor area to reach 200 EML. It can be seen that the percentage of floor area to meet 200 EML was not affected when glass is added to enclose the balcony. The changes were minor and negligible.

Table 18: Comparison of results for studio and one-bedroom apartment's balcony space

Comparison of Results for Studio and One Bedroom Apartment's Balcony Space			
APARTMENT TYPE	BALCONY DIMENSIONS (m)	% OF FLOOR AREA TO MEET 200 EML AT 9AM	% OF FLOOR AREA TO MEET 200 EML AT 1PM
Enclosed Studio	1.4 x 4	3 % increase *	0.5 % increase *
Enclosed One Bedroom	2.5 x 4.3	4 % reduction	2 % reduction

Overall, the healthy daylighting levels of the balconies were adequate. Both balconies, regardless of open or enclosed were able to meet the Feature 54 Precondition in the WELL Standard as shown in Table 19 and 20 below.

Table 19: Summary of orientations that passed or failed the ALFA simulations on June 21st at 9 am

JUNE 21 AT 9AM				
MODEL TYPE	SOUTH	EAST	NORTH	WEST
Studio Apartment with Open Balcony	PASS	PASS	PASS	PASS
Studio Apartment with Enclosed Balcony	PASS	PASS	PASS	PASS
One Bedroom Apartment with Open Balcony	PASS	PASS	PASS	PASS
One Bedroom Apartment with Enclosed Balcony	PASS	PASS	PASS	PASS

Table 20: Summary of orientations that passed or failed the ALFA simulations on June 21st at 1 pm

JUNE 21 AT 1PM				
MODEL TYPE	SOUTH	EAST	NORTH	WEST
Studio Apartment with Open Balcony	PASS	PASS	PASS	PASS
Studio Apartment with Enclosed Balcony	PASS	PASS	PASS	PASS
One Bedroom Apartment with Open Balcony	PASS	PASS	PASS	PASS
One Bedroom Apartment with Enclosed Balcony	PASS	PASS	PASS	PASS

4.3 Testing Balconies as Dining and Living Space for Usability

As discussed in the methods section, the glass enclosed balcony of the one-bedroom apartment has been modified and redesigned to accommodate two types of functional spaces: (1) dining space (2) living space. This section of the research aimed to see which of these functional spaces have better daylight qualities in regards to daylight availability and healthy daylighting. As mentioned in the previous sections, the results were divided into balcony and unit space as the simulations looked at the balcony and unit spaces separately.

Sectional drawings of the original balcony as designed by the WZMH Architects and modified balcony as a living and dining space can be seen in Figures 12-14 below.

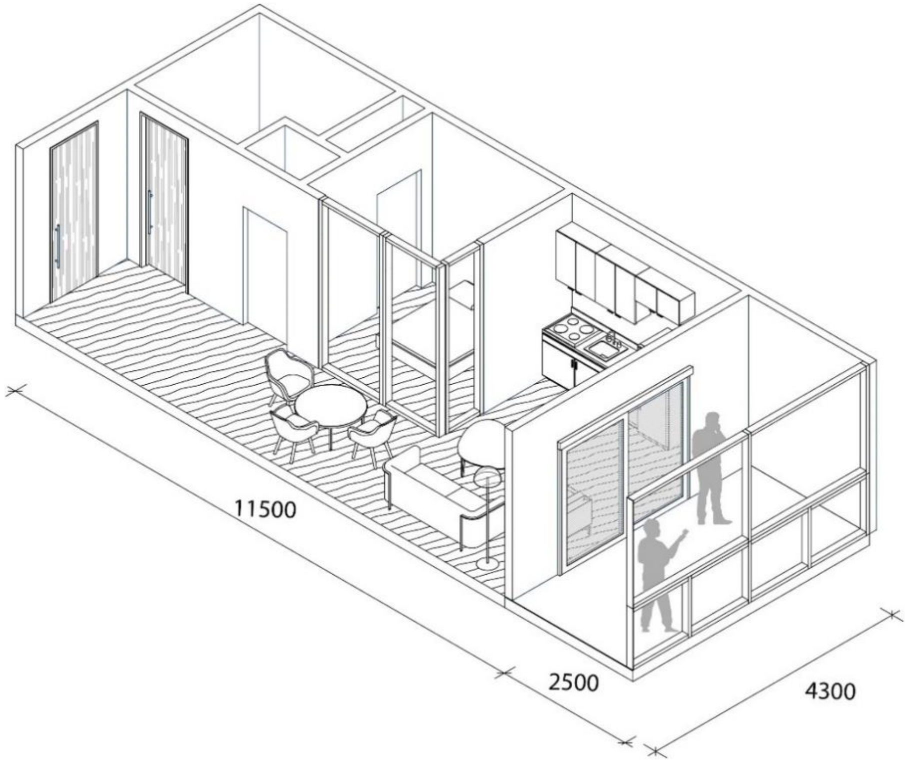

Figure 12: Axonometric section of existing balcony

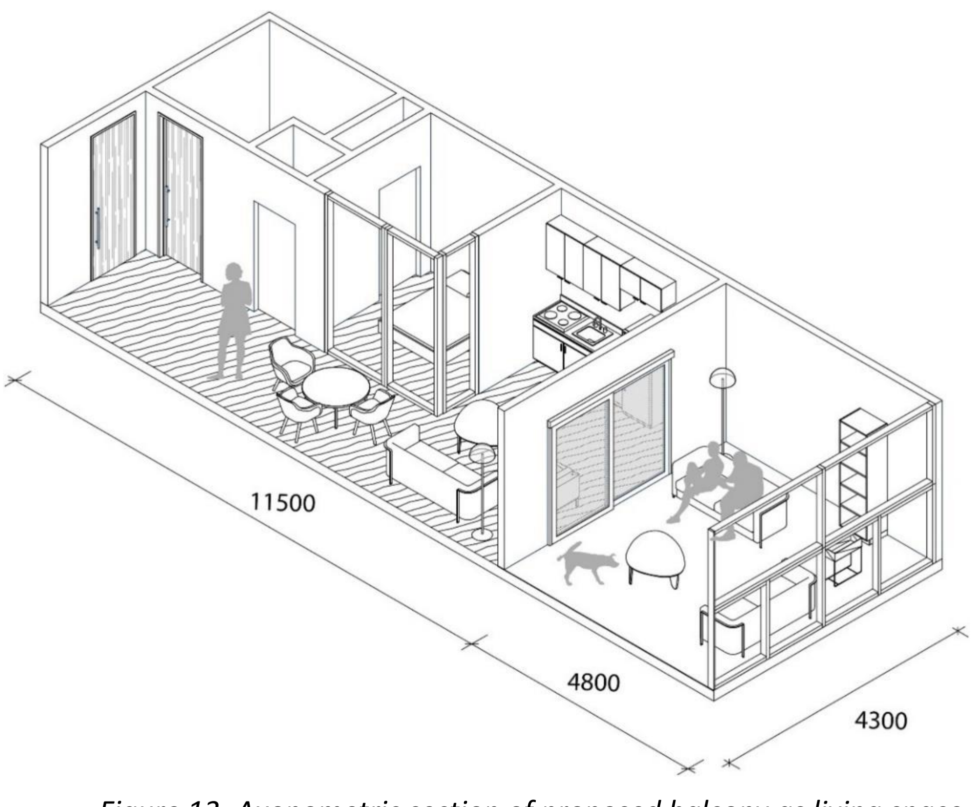

Figure 13: Axonometric section of proposed balcony as living space, this would require enlarging the balcony space

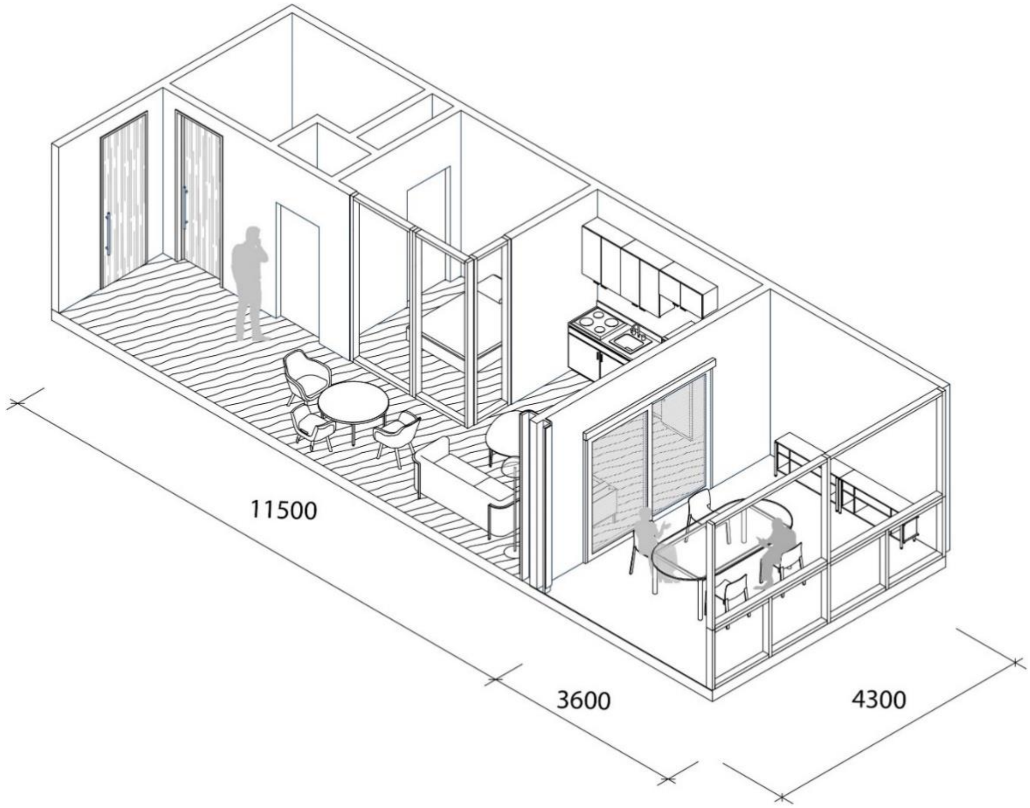

Figure 14: Axonometric section of proposed balcony as dining space, this would require enlarging the balcony space

4.3.1 Simulation Results for Daylight Availability

The simulation results included the original open-air balcony designed by the WZMH Architects and modified balcony as dining space and living space. The results for the daylight availability in the balcony are summarized in Table 21 below.

Table 21: Daylight availability comparison chart for original, outside and living balcony

COMPARISON CHART FOR ORIGINAL, OUTSIDE DINING AND LIVING BALCONY			
	Original Enclosed Balcony as Designed by WZMH	Modified Enclosed Balcony as Dining Space	Modified Enclosed Balcony as Living Space
sDA	N: 100% E: 100% S: 100% W: 100%	N: 100% E: 100% S: 100% W: 100%	N: 91.8% E: 100 % S: 100% W: 100%
ASE	N: 0% E: 89.3% S: 100% W: 78.6%	N: 0% E: 64.3% S: 78.6% W: 47.6%	N: 0% E: 49.6% S: 57.1% W: 34.7%
LEED CREDIT	N: 3 E: 3 S: 3 W: 3	N: 3 E: 3 S: 3 W: 3	N: 3 E: 3 S: 3 W: 3

From Table 21 above, it was concluded that the daylight qualities for all three balconies were adequate as seen from the LEED credits. The sDA percentage for the original balcony design and the two modified balcony designs remained almost unchanged except in the north orientation of the living space balcony where it was reduced to 91.8%. Generally, the ASE percentage decreased as the depth of the balcony increases, because the additional depth helped to block some excessive daylight. In the context, the depth of the dining space balcony was deeper than that of the original balcony and the living space balcony was deeper than the dining space balcony. Evidently, the ASE percentage was the highest in the original balcony, the second highest in the dining space balcony and the lowest in the living space balcony. In terms of daylight availability, the balcony conditions of all three balcony types were adequate in all orientations. Therefore, the daylight availability of the unit space must also be taken into account when looking at the daylight qualities of each program space.

The table below summarized the ClimateStudio simulation results for the daylight conditions in the one-bedroom apartment. The sDA percentage of the one-bedroom apartment is low and the increase in depth of the balcony to make it into a dining and living space made it significantly lower. When the balcony was enlarged to accommodate a living space, the sDA for the unit space became inadequate as it was reduced to 0% in all orientations. The ASE percentage was insignificant because there was not enough daylight to cause glaring or over lighting.

Table 22: Daylight availability comparison chart for the unit space of original, outside and living balcony

COMPARISON CHART OF ORIGINAL, DINING AND LIVING SPACE BALCONY FOR UNIT SPACE			
	Original Enclosed Balcony as Designed by WZMH	**Modified Enclosed Balcony as Dining Space**	**Modified Enclosed Balcony as Living Space**
sDA	N: 5.3% E: 9.8% S: 14.3% W: 9.8%	N: 0% E: 0% S: 3.8% W: 0%	N: 0% E: 0% S: 0% W: 0%
ASE	N: 0% E: 0% S: 0% W: 0%	N: 0% E: 0% S: 0% W: 0%	N: 0% E: 0 % S: 0% W: 0%
LEED CREDIT	N: 0 E: 0 S: 0 W: 0	N: 0 E: 0 S: 0 W: 0	N: 0 E: 0 S: 0 W: 0

4.3.2 Simulation Results for Healthy Daylighting

The ALFA simulations are summarized in the tables below. The tables are organized by the simulation dates consisting of March equinox, June solstice, September equinox and December solstice. The simulation looks at the balcony and the unit space separately. The unit space simulation results were summarized in Table 23-26 below.

Table 23 : Healthy daylighting comparison chart for the unit space of original, outside and living balcony on March 21

MARCH 21 UNIT SPACE SIMULATION RESULTS				
MODEL TYPE	SOUTH	EAST	NORTH	WEST
One Bedroom Apartment with Enclosed Balcony	9 am： 48 % 1 pm: 63 %	9 am：63 % 1 pm: 37 %	9 am：25 % 1 pm: 32 %	9 am：24% 1 pm: 36 %
One Bedroom Apartment with Enclosed Balcony as a Dining Space	9 am：28 % 1 pm: 45 %	9 am：58 % 1 pm: 30 %	9 am：20 % 1 pm: 26 %	9 am：24 % 1 pm: 38 %
One Bedroom Apartment with Enclosed Balcony as a Living Space	9 am：29 % 1 pm: 51 %	9 am：44 % 1 pm: 17 %	9 am：13 % 1 pm: 20 %	9 am：16 % 1 pm: 29 %

Table 24: Healthy daylighting comparison chart for the unit space of original, outside and living balcony on June 21

JUNE 21 UNIT SPACE SIMULATION RESULTS				
MODEL TYPE	SOUTH	EAST	NORTH	WEST
One Bedroom Apartment with Enclosed Balcony	9 am： 42 % 1 pm: 53 %	9 am：13 % 1 pm: 35 %	9 am：34 % 1 pm: 37 %	9 am：32 % 1 pm: 40 %
One Bedroom Apartment with Enclosed Balcony as a Dining Space	9 am：26 % 1 pm: 34 %	9 am：55 % 1 pm: 33 %	9 am：25 % 1 pm: 27 %	9 am：33 % 1 pm: 38 %
One Bedroom Apartment with Enclosed Balcony as a Living Space	9 am：30 % 1 pm: 36 %	9 am：41 % 1 pm: 25 %	9 am：20 % 1 pm: 24 %	9 am：18 % 1 pm: 26 %

Table 25: Healthy daylighting comparison chart for the unit space of original, outside and living balcony on September 21

SEPTEMBER 21 UNIT SPACE SIMULATION RESULTS				
MODEL TYPE	SOUTH	EAST	NORTH	WEST
One Bedroom Apartment with Enclosed Balcony	9 am： 49 % 1 pm: 63 %	9 am：62 % 1 pm: 33 %	9 am：27 % 1 pm: 31 %	9 am：29 % 1 pm: 41 %
One Bedroom Apartment with Enclosed Balcony as a Dining Space	9 am：31 % 1 pm: 45 %	9 am：58 % 1 pm: 33 %	9 am：20 % 1 pm: 25 %	9 am：27 % 1 pm: 35 %
One Bedroom Apartment with Enclosed Balcony as a Living Space	9 am：33 % 1 pm: 48 %	9 am：43 % 1 pm: 22 %	9 am：14 % 1 pm: 20 %	9 am：16 % 1 pm: 28 %

Table 26: Healthy daylighting comparison chart for the unit space of original, outside and living balcony on December 21

DECEMBER 21 UNIT SPACE SIMULATION RESULTS				
MODEL TYPE	**SOUTH**	**EAST**	**NORTH**	**WEST**
One Bedroom Apartment with Enclosed Balcony	9 am：36 % 1 pm: 53 %	9 am：33 % 1 pm: 35 %	9 am：10 % 1 pm: 37 %	9 am：12 % 1 pm: 40 %
One Bedroom Apartment with Enclosed Balcony as a Dining Space	9 am：21 % 1 pm: 34 %	9 am：25 % 1 pm: 33 %	9 am：6 % 1 pm: 27 %	9 am：8 % 1 pm: 38 %
One Bedroom Apartment with Enclosed Balcony as a Living Space	9 am：19 % 1 pm: 36 %	9 am：17 % 1 pm: 25 %	9 am：4 % 1 pm: 24 %	9 am：5 % 1 pm: 26 %

It can be seen that the east orientation is the best orientation for circadian stimulus at 9 am and the south orientation is the best orientation for circadian stimulus at 1 pm. Similar to daylight availability, the percentage of floor area to meet EML requirements decreases as the depth of the balcony increases. This was indicated by the decrease in the percentage of floor area to meet the EML requirements. Therefore, when discussing only healthy daylighting, the original one-bedroom balcony has the best circadian lighting performance. However, it is important to note that none of the units have healthy daylighting as all of the units failed to meet the WELL Standard in every orientation.

As discussed earlier, June solstice was the best performing date. Therefore, it was chosen again in conducting the ALFA simulations of the balcony space. A simulation summary could be seen in Table 27 below. The results were similar to that of the unit space, the percentage of floor area to meet EML requirements decreases as the depth of the balcony increases and the original one-bedroom balcony has the best circadian lighting performance. All unit types were able to pass the WELL Standard.

Table 27: Healthy daylighting comparison chart for the balcony space of original, outside and living balcony on June 21

JUNE 21 BALCONY SPACE SIMULATION RESULTS				
MODEL TYPE	SOUTH	EAST	NORTH	WEST
One Bedroom Apartment with Enclosed Balcony	9 am: 98 % 1 pm: 100 %	9 am: 88 % 1 pm: 83 %	9 am: 100 % 1 pm: 100 %	9 am: 100 % 1 pm: 100 %
One Bedroom Apartment with Enclosed Balcony as a Dining Space	9 am: 93 % 1 pm: 100 %	9 am: 90 % 1 pm: 80 %	9 am: 100 % 1 pm: 100%	9 am: 93 % 1 pm: 84 %
One Bedroom Apartment with Enclosed Balcony as a Living Space	9 am: 90 % 1 pm: 98 %	9 am: 85 % 1 pm: 80 %	9 am: 100 % 1 pm: 100 %	9 am: 82 % 1 pm: 85 %

4.4 Testing Vegetation levels for Usability

In this section, three levels of vegetation were tested in the simulations. The levels of vegetation and the plants included for the simulations were discussed in section 3.5. The effects of different vegetation levels were studied in relation to healthy daylighting. The effects of vegetation levels on healthy daylighting were discussed for the unit and for the balcony space.

4.4.1 March Equinox Results for Unit Space

ALFA simulation results for the March equinox are presented in this section. The other results follow the trend of the March equinox. A list of all simulation results can be found in the Appendix 8.1.6. Table 28 and 29 below summarized the results for the effects of plants on both open air and enclosed balconies for the unit space.

Table 28: Healthy daylighting comparison chart for different types of vegetation in open and enclosed balcony for the unit space

ALFA SIMULATION RESULTS FOR MARCH EQUINOX				
MODEL TYPE	SOUTH	EAST	NORTH	WEST
Open Balcony	9 am: 76 % 1 pm: 94 %	9 am: 100 % 1 pm: 72 %	9 am: 62 % 1 pm: 69 %	9 am: 61 % 1 pm: 78 %
Open Balcony with little vegetation	9 am: 80 % 1 pm: 100 %	9 am: 100 % 1 pm: 68 %	9 am: 59 % 1 pm: 69 %	9 am: 58 % 1 pm: 76 %
Open Balcony with large vegetation	9 am: 68 % 1 pm: 99 %	9 am: 100 % 1 pm: 59 %	9 am: 53 % 1 pm: 59 %	9 am: 50 % 1 pm: 61 %
Enclosed Balcony	9 am: 67 % 1 pm: 99 %	9 am: 100 % 1 pm: 52 %	9 am: 42 % 1 pm: 52 %	9 am: 44 % 1 pm: 56 %
Enclosed Balcony with little vegetation	9 am: 60 % 1 pm: 93 %	9 am: 99 % 1 pm: 49 %	9 am: 41 % 1 pm: 51 %	9 am: 46 % 1 pm: 52 %
Enclosed Balcony with large vegetation	9 am: 50% 1 pm: 78 %	9 am: 89% 1 pm: 38 %	9 am: 37 % 1 pm: 41 %	9 am: 36 % 1 pm: 46 %

Through simulations, it can be seen that the addition of vegetation to both open and enclosed balconies reduced the percentage of floor area to reach EML. However, the impact of plants to healthy daylight levels inside the unit was very minor. The east orientation was least affected by plants and was found to be the best orientation for circadian stimulus.

Table 29: Reduction percentage for different types of vegetation in open and enclosed balcony for the unit space

Comparison of Results for Different Vegetation Levels		
BALCONY TYPE	VEGETATION LEVELS	REDUCTION %
Open Balcony	Little Vegetation	9 am: 0.5% 1pm: 0 %
	Large Vegetation	9 am: 4.5% 1pm: 6.3%
Enclosed Balcony	Little Vegetation	9 am: 1.8 % 1pm: 3.5 %
	Large Vegetation	9 am: 10.3 % 1pm: 14 %

A summary of the results was presented in Table 30, which identified the orientations that pass and fail the requirements for Feature 54 in the WELL Standard. These results are solely for the

March equinox. As for the other June solstice, September equinox and December solstice, refer to the Appendix 8.1.7 for a list of numerical results.

Table 30: Pass and fail chart for different types of vegetation in open and enclosed balcony for the unit space

ALFA SIMULATION RESULTS FOR MARCH EQUINOX				
MODEL TYPE	SOUTH	EAST	NORTH	WEST
Open Balcony	9 am: PASS 1 pm: PASS	9 am: PASS 1 pm: FAIL	9 am: FAIL 1 pm: FAIL	9 am: FAIL 1 pm: PASS
Open Balcony with little vegetation	9 am: PASS 1 pm: PASS	9 am: PASS 1 pm: FAIL	9 am: FAIL 1 pm: FAIL	9 am: FAIL 1 pm: PASS
Open Balcony with large vegetation	9 am: FAIL 1 pm: PASS	9 am: PASS 1 pm: FAIL	9 am: FAIL 1 pm: FAIL	9 am: FAIL 1 pm: FAIL
Enclosed Balcony	9 am: FAIL 1 pm: PASS	9 am: PASS 1 pm: FAIL	9 am: FAIL 1 pm: FAIL	9 am: FAIL 1 pm: FAIL
Enclosed Balcony with little vegetation	9 am: FAIL 1 pm: PASS	9 am: PASS 1 pm: FAIL	9 am: FAIL 1 pm: FAIL	9 am: FAIL 1 pm: FAIL
Enclosed Balcony with large vegetation	9 am: FAIL 1 pm: PASS	9 am: PASS 1 pm: FAIL	9 am: FAIL 1 pm: FAIL	9 am: FAIL 1 pm: FAIL

The south and east orientation were least affected by plants. At 9 am, the south and east orientation passed all the WELL requirements. In addition, all model types of the south orientation passed the WELL requirements at 9 am. In the west orientation, only open balcony and open balcony with little vegetation passed at 1 pm. All other model types failed. Significantly, the north orientation is the worst orientation for circadian stimulus as all model types have failed in this orientation, regardless of the plants added.

4.4.2 June Solstice Results for Balcony Space

June solstice was selected to simulate the effects of plants on the healthy daylighting of the balconies, in order to compare the results with the existing balconies with no vegetation found in Section 4.2.2. Table 31 summarized the simulation results from ALFA.

Table 31: Alfa simulation results for June solstice testing different vegetating levels

ALFA SIMULATION RESULTS FOR JUNE SOLSTICE				
MODEL TYPE	SOUTH	EAST	NORTH	WEST
Open Balcony	9 am: 97 % 1 pm: 100 %	9 am: 100 % 1 pm: 98 %	9 am: 94 % 1 pm: 100 %	9 am: 94 % 1 pm: 97 %
Open Balcony with little vegetation	9 am: 96 % 1 pm: 100 %	9 am: 100 % 1 pm: 98 %	9 am: 93 % 1 pm: 98 %	9 am: 92 % 1 pm: 97 %
Open Balcony with large vegetation	9 am: 96 % 1 pm: 98 %	9 am: 100 % 1 pm: 96 %	9 am: 90 % 1 pm: 95 %	9 am: 93 % 1 pm: 96 %
Enclosed Balcony	9 am: 100 % 1 pm: 100 %	9 am: 100 % 1 pm: 100 %	9 am: 100 % 1 pm: 100 %	9 am: 97 % 1 pm: 100 %
Enclosed Balcony with little vegetation	9 am: 94 % 1 pm: 98 %	9 am: 100 % 1 pm: 93 %	9 am: 91 % 1 pm: 94 %	9 am: 90 % 1 pm: 95 %
Enclosed Balcony with large vegetation	9 am: 89% 1 pm: 95 %	9 am: 100 % 1 pm: 89 %	9 am: 88 % 1 pm: 89 %	9 am: 86 % 1 pm: 93 %

The results of June solstice indicated that the addition of plants to balcony reduced the overall floor area to reach 200 EML. As shown in Table 32, the reduction levels were higher in the enclosed balcony. This was an expected finding as plants can filter and block daylight penetration. The reduction in the open balcony was approximately 1-3 percent depending on the time of the day. The reduction in the enclosed balcony was higher than that of the open balcony as the reduction was around 5-9 percent. Nonetheless, all balconies, regardless of vegetation levels. Were able to meet the WELL Standard.

Table 32: Reduction percentage for different types of vegetation in open and enclosed balcony for the balcony

Comparison of Results for Different Vegetation Levels		
BALCONY TYPE	**VEGETATION LEVELS**	**REDUCTION %**
Open Balcony	Little Vegetation	9 am: 1 % 1pm: 0.5 %
	Large Vegetation	9 am: 1.5 % 1pm: 2.5 %
Enclosed Balcony	Little Vegetation	9 am: 5.5 % 1pm: 4 %
	Large Vegetation	9 am: 8.5 % 1pm: 8.5 %

5.0 Discussion

This section of the report discusses the implications of the research findings, reflection on the research process, and future directions within this field of study.

5.1 Reflection on Results

The study tested daylight availability in studio and one-bedroom apartments in ClimateStudio to see if these typical MURB arrangements can achieve the LEED Daylighting Credit and in ALFA to see if they could achieve WELL Circadian Lighting Design Feature 54. All design options in the simulations were consistent in having the same material properties as seen in section 3. The only difference in the design options were the apartment types, addition of glass to enclose the balcony, the size of the balcony and the levels of vegetation.

5.1.1 Open and Enclosed Balcony

An enclosed balcony offers apartment dwellers additional space to furnish and year-round access without altering the total floor space. However, not much has been written about the effects of enclosed balconies on daylighting and healthy daylighting. Therefore, it was necessary to study the effects of open-air and glass-enclosed balconies on daylight availability and healthy daylighting.

The results from section 4.1 indicated that enclosing the balcony to provide additional space had little effect on the daylight availability on the balcony. The daylight availability on the balcony was not changed with the addition of glass panels to enclose the balcony. This can be seen by the unchanged sDA percentage in the open and enclosed balconies of both apartment units. Generally, the daylight quality of the balconies was satisfactory as they achieved three daylighting credits for all orientations. As expected, the south orientation has the highest ASE level; indicating some potential problems of glaring and over lighting. However, these problems can often be controlled by the use of passive strategies such as the installation of shading devices.

In terms of daylight quality in the units, the addition of glass to the balcony reduced the sDA percentage for both sizes of units. This can be seen more in the studio apartment than the one-bedroom apartment. The sDA of the studio apartment was reduced by an average of 14 percent, whereas the one-bedroom apartment was reduced by 9 percent. This was consistent with the findings identified in the literature review where glazed balconies contribute to the light barrier effect and the amount of daylight is reduced when passing through an additional glazing layer. Based on the LEED daylighting requirements, the open-air studio apartment had the best daylight qualities and the second being the glass-enclosed studio apartment. This was an expected finding as the studio apartment had a smaller aspect ratio and needed less light penetration. Therefore, even with glass layer, the daylight in the studio apartment was still better than the one-bedroom apartment.

Similarly, the ALFA simulation results show that the studio apartment had the best performance among all other model types for obvious reasons like its dimensions and aspect ratio. Another expected finding was that the percentage of floor area to reach 200 EML decreases when the balcony is enclosed and deepened. This is because of two reasons: (1) daylight has to pass through an additional envelope, thereby reducing the amount of light that enters the unit and (2) deeper balconies require deeper daylight penetration to reach the back of the unit. Through simulations, it was also found that the south orientation is the best orientation for circadian stimulus and the east orientation is the second-best orientation. Due to the fact that the south orientation receives more daylight and more quantity of daylight can be provided for the unit. The east orientation receives more morning light and is the only orientation that passed the WELL standard on June 21st at 9 am.

Overall, the daylight conditions of both apartments for both open and enclosed balconies were inadequate when compared to the LEED daylighting and WELL circadian lighting requirements. This is due to the fact that the aspect ratios of both units are large and require deeper daylight penetration. Additional daylighting strategies should be incorporated to improve the daylight qualities of such units. Effective electric lighting is also needed in all model types, especially in winter months, to achieve healthy levels of EML. However, to answer the question of whether or not a balcony should be enclosed is difficult to answer as it is partly based on user preference. The simulation results only help to answer how much daylight and healthy daylight was affected by a glass-enclosed balcony, but cannot provide answers to whether daylight and functionality is more worthwhile to have. Having an enclosed balcony could provide all season access but the tradeoff is that it also limits the quantity of daylight in the unit. Therefore, this decision is dependent on the user preference so inhabitants should ideally have more choice and this knowledge when choosing their units.

5.1.2 Living and Dining Space

To explore options for usability of the balcony, the enclosed balcony of the one-bedroom unit was modified to accommodate a year-round dining and living space. A section of the new modified balcony can be seen in Figure 13 & 14. It was found through the ClimateStudio simulations that the sDA percentage was minimally affected for both the living and dining space balcony. The balcony showed no changes in sDA percentage when used as a dining space and only 8.2 percent reduction in the north orientation when used as a living space. This was expected as the north orientation received less daylight and the added depth of the living space would require more daylight. Similarly, the ASE percentage was reduced when the balcony was modified to accommodate a living and dining space. The ASE percentage was reduced in the dining and living space by 19 percent and 31.6 percent respectively. This is because the added depth helped to reduce issues like perimeter glaring and potential overheating. Overall, the daylight of both balconies was adequate when compared to the LEED Standards as 3 LEED credits were achieved in all orientations. In terms of the daylight quality in the units, the sDA percentage was reduced by 8 percent in the dining space and 9 percent in the living space. The ASE percentage showed no changes. Therefore, the effects of modifying balcony sizes to accommodate a dining and living space had minimal impact on the daylight availability in the unit and the balcony. Larger balconies could be incorporated with minimal tradeoffs.

The ALFA simulation results showed that there was less reduction in the total floor area to reach 200 EML when the balcony was used as a dining space. The finding was expected as the balcony of the living space was deeper and required more quantity of daylight. Unexpectedly, the south orientation performed better when used as a living space. One possible explanation could be that a deeper balcony was not as problematic on the south orientation because it was receiving enough light and in fact it helped to eliminate the perimeter glaring and make it more comfortable.

Overall, the daylight availability of both balcony types was affected minimally when modified. This implies that future balcony designs could consider different design options such as increasing the size of the balcony to accommodate more functional spaces without affecting much of the overall daylight availability. According to the WELL Standard, the dining space was found to have better performance than the living space in all orientations except the south orientation. Therefore, future MURB designs can incorporate different types of balcony designs based on the orientation to meet the needs of the occupants. For example, those who want an indoor-outdoor living room can consider an apartment on the south orientation and those who want an indoor-outdoor dining space can choose any other orientation but the south.

5.1.3 Vegetation Levels

The ALFA simulation results in Section 4.4 showed that the addition of plants to both open air and glass-enclosed balcony reduced the percentage of floor area to reach 200 EML. However, the reduction was minor, especially in the open-air balcony. In the enclosed balcony, the addition of large vegetation can be problematic as the reduction in floor area to reach 200 EML was up to 14 percent. An unexpected finding from the simulation was that in some cases, the addition of plants increased the floor area to reach 200 EML in the south orientation. A possible explanation for this finding could be that the plants help to filter lighting and block excessive daylight.

It can be concluded from the simulation results that there is minimal impact on the healthy daylighting of the unit from the addition of plants. Given the many health benefits of plants especially in urban settings, city dwellers should be encouraged to incorporate balcony plants for the well-being of occupants. However, this suggestion is based on the minimal effect on circadian lighting, other factors such as hygrothermal issues should be considered.

5.2 Design for Human Well-Being in MURB

It was evident that the existing conditions of the two balconies prior to the modification made to enclose and accommodate other functional spaces were insufficient to meet the requirements outlined in the LEED and WELL Standards. This was inevitable as the aspect ratio of the units are large, resulting in long and narrow floor plates that do not allow light to penetrate deep into the space. Therefore, none of the suggested design options passed the two metrics. To improve the daylight availability and healthy daylighting of the two tested apartment units, a number of considerations had to be made. However, this becomes more complex in multi-unit residential settings.

5.2.1 Complexity of MURB

Residential spaces are more complex than other housing typologies since they have a variety of program configurations in a small space often with light from only one side. It is extremely difficult to arrange programs such as living, dining and sleeping in a confined MURB setting where most units have access to daylighting from one direction at certain times in the day. Another major complexity was the difficulties in predicting how the inhabitants are using the space. Units need to adapt to the changing spatial needs to ensure that the needs of the occupants are met through various life stages. For instance, those living with children would require more space to play, relax, and learn. This can be a concerning issue, as the footprint of current and future development are decreasing in size to accommodate dense urban development. Therefore, the industry needs to reconsider how MURB are being designed and prioritize the needs and well-being of the occupants.

5.3 Early-Stage Design Tools for Predicting Performance

Early-stage design tools for environmental simulation are helpful in giving early feedback of a project before a project is built. This project used ClimateStudio and ALFA and they were relatively easy to learn and plug in to typical architectural software such as Rhino. The major advantage of employing them in design projects is that they can save time, cost and resources when the project is at early stage. This MRP benefited greatly from them as many design options were tested and results were received rapidly. The use of ALFA and ClimateStudio helped to identify circadian stimulus and daylight availability in MURB units. These tools should be encouraged for future projects and research areas.

5.3.1 Challenges in Early-Stage Design Tools

The workflow of these early-stage design tools was effective, but it was not without its challenges and inaccuracies. The biggest challenge with in all simulation-based research was the amount of model iterations that had to be built and tested. For this research, a total of 448 design iterations were built based on a combination of parameters needed for this study. Much of the project time was spent on simulations. Another challenge in simulation was the inaccuracies in modeling plants. To improve accuracy, these design tools could offer more material choices for plants and develop more databases of different types of trees with various shapes, gap and transmittance percentages. Furthermore, the occupancy schedules used in these early-stage design tools should be more tailored to residential settings. ClimateStudio uses an 8 am to 6 pm occupancy schedule to follow the LEED Daylight credit requirements. However, in reality, residential living arrangements do not follow the same way. Residential environments are unpredictable as occupants use space differently and differ from one individual to another. The challenges in understanding user behavior and making assumptions about how often people use spaces is a known challenge in the building industry.

6.0 Conclusions

The major findings from this research were that in most cases, the tested design options to explore more functionality of the space restricted the quantity of daylight and quality of healthy daylight. The problem originates from the original design of typical MURB units. Poorly designed apartment units with large aspect ratios require more consideration when designing. However, designing in MURB settings can be very difficult as user preference is unpredictable. Findings also highlight the need for MURB specific guidelines and standards with metrics suitably for living environments, not just for office settings. In conclusion, designing for daylight availability and healthy daylighting is often not prioritized in MURB designs. However, given the many benefits of daylight to human wellbeing, lighting design should be made a priority during early stages of design.

The following section summarizes the findings to the research questions identified in the introduction of this MRP. These questions include:

1. **How do open-air and glass enclosed balcony designs compare in terms of daylight availability and healthy daylighting for the units and balconies?**

In terms of daylight and healthy daylight, open-air balcony is better because enclosed balcony contributes to light barrier effects and limits the amount of daylight that penetrates the space. This can be significant especially in deep aspect ratio units studied in this MRP. For the balcony space, daylight availability was minimally affected by the additional glazing. For the unit space, the daylight availability was reduced by an average of 14 percent in the studio apartment and 9 percent in the studio apartment when the balcony was enclosed.

In regards to healthy daylighting, the percentage of floor area to reach 200 EML decreases when the balcony is enclosed and deepened. This is because of two reasons: (1) daylight has to pass through an additional envelope, thereby reducing the amount of light that enters the unit and (2) deeper balconies require deeper daylight penetration to reach the back of the unit.

2. **When enlarging the balcony to accommodate a living and dining space, how do daylight availability and healthy daylighting change for the units and balconies?**

The daylight availability of the balcony space was minorly affected when the balcony was enlarged to accommodate a living and dining space. In the units, the increase in depth of the balcony to make it accommodate a dining and living space made the daylight quantity inadequate as it was reduced to 0 percent in almost all orientations.

In the units, the healthy daylighting was less effected when the balcony was used as a dining space. This was an expected finding as the balcony of the living space was deeper and required more quantity of daylight. The healthy daylighting results of the balcony were similar to that of the unit space, the percentage of floor area to meet EML requirements decreases as the depth of the balcony increases and the original one-bedroom balcony has the best circadian lighting performance.

3. How does incorporating different amounts of plants affect daylighting for the units and balconies?

For the units, it was found that the addition of plants to both open and enclosed balconies reduced the percentage of floor area to reach EML in the units. However, the impact of plants to healthy daylight levels inside the unit was very minor. The biggest impact was seen in the addition of large vegetation in the enclosed balcony. For the balcony space, the added vegetation levels reduced the overall floor area to reach 200 EML minimally. The reduction levels were the highest in the enclosed balcony and when large amounts of plants were added. This was an expected finding as plants and glazing can filter and block daylight penetration.

7.0 Recommendations for Further Work in this Area

The findings from this research led to the following recommendations:

1) Simulation findings and recommended future work

- Through this research, it can be concluded that deep aspect ratio units such as the two floor plan types identified in this study have negative outcomes on daylight availability and circadian stimulus in the unit. Therefore, when testing new design parameters such as the glazed balcony, the daylight availability and healthy daylighting were significantly impacted. These unit types should be avoided in future MURB designs for the purpose of human well-being.
- As the surrounding buildings' massing context can affect the findings, research on MURB must take them into account. For instance, the quality or quantity of daylight entering a unit may be reduced or limited by the shadows that some buildings cast on one another, and units may also be exposed to building surfaces' reflectivity. Toronto is a dense city with numerous tall structures close to one another. Therefore, if there is a site location that is particular to the project, this should be something that is worth additional investigation.
- A larger balcony provides more functionalities, but deeper balconies have issues with daylight penetration and shading. In future work, shading issues should be evaluated to extend this study.
- Balconies are a complex subject of study. Aside from daylight, other parameters such as energy efficiency and thermal comfort should be considered when designing balconies. Balconies often create thermal breaks between interior and exterior spaces, resulting in poor thermal comfort and performance. This area of study must be incorporated in addition to daylight.

- This MRP focused on the four main cardinal orientations as the default. In reality, the building's actual orientation may not fall into this category. Therefore, a variation of different potential orientations should be studied to obtain the most optimal position depending on the project.
- This MRP did not study the impacts of larger balconies for studio apartments, but it did study the impact of plants on the unit and balcony's healthy daylighting. Through simulations, it was found that the studio unit was minimally affected when plants were added. The balcony space provided sufficient circadian stimulus even when plants were included. Therefore, given the benefits of plants to human well-being, plants are encouraged for city inhabitants. Another major finding of this research is that deep aspect ratio units should be avoided in order to meet adequate daylighting levels in the unit. This was seen in the existing daylight conditions of the studio apartment prior to the added new design options. Both open and enclosed studio units were unable to meet the LEED and WELL standards. Therefore, these units should be avoided or carefully programmed. As daylight cannot penetrate deep to the back of the unit, spaces with more human activities should be prioritized and other spaces such as the washroom and laundry room can be placed near the back of the unit where daylight is less needed.
- For the one-bedroom apartment, this research found that deeper balconies lowered the performance for healthy lighting (WELL) and daylight availability (LEED). This indicates that the balcony depth is crucial when designing as it will greatly impact the quality and quantity of daylight. When the balcony of the one-bedroom apartment was enlarged to accommodate a living and dining space, the option for the dining balcony size had the

least negative impact when compared to the other option. This was resulted from the deeper floor plate of the living balcony. However, despite the overall result, the south orientation actually performed better with a larger balcony as it shaded the over lit perimeter. Similar to the studio apartment, a general recommendation would be directed to the designers to not design units with deep aspect ratios. Space should be designed more carefully as there is more quantity of daylight near the perimeter.

2) Changes needed in simulation

- WELL measures EML at a vertical plane of 1.2 meters, which is the typical eye level of an adult when seated. However, this cannot be applied to children. Given that MURB are becoming predominant housing types, children need to be considered and accepted in the practice of daylight simulation. Access to daylight is crucial to the well-being and growth of children. An important goal for future MURB development is to provide innovative solutions to promote equity, well-being and participation in the built environment.
- LEED Daylight Credit should be more tailored to residential settings in contrast to an office. The work plane height should be adjusted so that it is less specific for office tasks. Future work should look at how task planes differ to accommodate various activities in MURB.
- As discussed earlier in this MRP, the occupancy schedule used in the simulation cannot be applied in a residential environment. Future work is recommended to understand how occupants use the space to develop occupancy schedules more suited for residential settings.

- To improve the accuracy of the simulation, development is needed to improve modeling of trees and plants in daylight simulation. As plants are often neglected in daylight practices due to its complex nature in modeling, design tools could offer more material choices for plants and develop more databases of different types of trees with various shapes, gaps and transmittance percentages.

3) Field work for validation in simulation results

- Gathering surveys, data, and measurements on site for comparison to the simulation results are essential in daylight research. This is significant because new findings might be integrated into further research and recommendations when assumptions are tested. One of the most important contributions to research is data that is gathered onsite since it provides a good understanding of what is occurring in the real world. In order to better understand how electric lighting might be used, who the residents are, and how they use the space, doing on-site investigations of apartments in Toronto will be helpful for projects of this type.

8.0 Appendices

8.1 Simulation Results

8.1.1 ClimateStudio Results for Balcony Space Testing Open and Enclosed Balcony

Summary of Results for LEED V4.1 OPTION1			
MODEL TYPE	sDA	ASE	LEED CREDIT
Studio Apartment with Open Inset Balcony	N: 100% E: 100% S: 100% W: 100%	N: 0% E: 91.7% S: 100% W: 83.3%	N: 3 E: 3 S: 3 W: 3
Studio Apartment with Enclosed Inset Balcony	N: 100% E: 100% S: 100% W: 100%	N: 0% E: 100% S: 100% W: 83.3%	N: 3 E: 3 S: 3 W: 3
One Bedroom Apartment with Open Inset Balcony	N: 100% E: 100% S: 100% W: 100%	N: 0% E: 89.3% S: 100% W: 78.6%	N: 3 E: 3 S: 3 W: 3
One Bedroom Apartment with Enclosed Inset Balcony	N: 100% E: 100% S: 100% W: 100%	N: 0% E: 89.3% S: 100% W: 78.6%	N: 3 E: 3 S: 3 W: 3

8.1.2 ClimateStudio Results for Unit Space Testing Open and Enclosed Balcony

Summary of Results for LEED V4.1 OPTION1			
MODEL TYPE	sDA	ASE	LEED CREDIT
Studio Apartment's Unit Space with Open Inset Balcony	N: 33.3% E: 40.3% S: 45.8% W: 40.3%	N: 0% E: 11.1% S: 13.9% W: 4.2%	N: 0 E: 1 S: 1 W: 1
Studio Apartment's Unit Space with Enclosed Inset Balcony	N: 18.2% E: 25.5% S: 34.5% W: 25.5%	N: 0% E: 9.1% S: 9.1% W: 3.6%	N: 0 E: 0 S: 0 W: 0
One Bedroom Apartment's Unit Space with Open Inset Balcony	N: 15.8% E: 19.5% S: 23.3% W: 18%	N: 0% E: 1.5% S: 0% W: 0%	N: 0 E: 0 S: 0 W: 0
One Bedroom Apartment's Unit Space with Enclosed Inset Balcony	N: 5.3% E: 9.8% S: 14.3% W: 9.8%	N: 0% E: 0% S: 0% W: 0%	N: 0 E: 0 S: 0 W: 0

8.1.3 ClimateStudio Comparison Results for Unit Space Testing Open and Enclosed Balcony

8.1.3.1 Balcony Space of Studio Apartment

Comparison of Results for Open and Enclosed Inset Balconies			
Orientation	**sDA**	**ASE**	**LEED CREDIT**
North	1. The sDA remains the same. 2. The addition of glass panels to enclose the balcony does not affect the sDA.	1. The ASE remains the same. 2. The addition of glass panels to enclose the balcony does not affect the ASE.	1. The LEED credit remains the same. 2. The addition of glass panels to enclose the balcony does not affect the LEED credit.
East	1. The sDA remains the same. 2. The addition of glass panels to enclose the balcony does not affect the sDA.	**1. The addition of glass panels to enclose the balcony increased the ASE% by 8.3%.**	1. The LEED credit remains the same. 2. The addition of glass panels to enclose the balcony does not affect the LEED credit.
South	1. The sDA remains the same. 2. The addition of glass panels to enclose the balcony does not affect the sDA.	1. The ASE remains the same. 2. The addition of glass panels to enclose the balcony does not affect the ASE.	1. The LEED credit remains the same. 2. The addition of glass panels to enclose the balcony does not affect the LEED credit.
West	1. The sDA remains the same. 2. The addition of glass panels to enclose the balcony does not affect the sDA.	1. The ASE remains the same. 2. The addition of glass panels to enclose the balcony does not affect the ASE.	1. The LEED credit remains the same. 2. The addition of glass panels to enclose the balcony does not affect the LEED credit.

8.1.3.2 Unit Space of Studio Apartment

Comparison of Results for Open and Enclosed Inset Balconies			
Orientation	**sDA**	**ASE**	**LEED CREDIT**
North	**1. The addition of glass panels to enclose the balcony decreased the sDA% by 15%.**	1. The ASE remains the same. 2. The addition of glass panels to enclose the balcony does not affect the ASE.	1. The LEED credit remains the same. 2. The addition of glass panels to enclose the balcony does not affect the LEED credit.
East	**1. The addition of glass panels to enclose the balcony decreased the sDA% by 15%**	**1. The addition of glass panels to enclose the balcony decreased the ASE% by 2%.**	**1. The addition of glass panels to enclose the balcony affects the LEED credit to drop to 0.**
South	**1. The addition of glass panels to enclose the balcony decreased the sDA% by 11%**	**1. The addition of glass panels to enclose the balcony decreased the ASE% by 5%.**	**1. The addition of glass panels to enclose the balcony affects the LEED credit to drop to 0.**
West	**1. The addition of glass panels to enclose the balcony decreased the sDA% by 15%**	**1. The addition of glass panels to enclose the balcony decreased the ASE% by 0.6%.**	**1. The addition of glass panels to enclose the balcony affects the LEED credit to drop to 0.**

8.1.3.3 Balcony Space of One Bedroom Apartment

Comparison of Results for Open and Enclosed Inset Balconies			
Orientation	**sDA**	**ASE**	**LEED CREDIT**
North	1. The sDA remains the same. 2. The addition of glass panels to enclose the balcony does not affect the sDA.	1. The ASE remains the same. 2. The addition of glass panels to enclose the balcony does not affect the ASE.	1. The LEED credit remains the same. 2. The addition of glass panels to enclose the balcony does not affect the LEED credit.
East	1. The sDA remains the same. 2. The addition of glass panels to enclose the balcony does not affect the sDA.	1. The ASE remains the same. 2. The addition of glass panels to enclose the balcony does not affect the ASE.	1. The LEED credit remains the same. 2. The addition of glass panels to enclose the balcony does not affect the LEED credit.
South	1. The sDA remains the same. 2. The addition of glass panels to enclose the balcony does not affect the sDA.	1. The ASE remains the same. 2. The addition of glass panels to enclose the balcony does not affect the ASE.	1. The LEED credit remains the same. 2. The addition of glass panels to enclose the balcony does not affect the LEED credit.
West	1. The sDA remains the same. 2. The addition of glass panels to enclose the balcony does not affect the sDA.	1. The ASE remains the same. 2. The addition of glass panels to enclose the balcony does not affect the ASE.	1. The LEED credit remains the same. 2. The addition of glass panels to enclose the balcony does not affect the LEED credit.

8.1.3.4 Unit Space of One Bedroom Apartment

Comparison of Results for Open and Enclosed Inset Balconies			
Orientation	sDA	ASE	LEED CREDIT
North	**1. The addition of glass panels to enclose the balcony decreased the sDA% by 10.5%.**	1. The ASE remains the same. 2. The addition of glass panels to enclose the balcony does not affect the ASE.	1. The LEED credit remains the same. 2. The addition of glass panels to enclose the balcony does not affect the LEED credit.
East	**1. The addition of glass panels to enclose the balcony decreased the sDA% by 10%.**	**1. The addition of glass panels to enclose the balcony decreased the ASE% by 1.5%.**	1. The LEED credit remains the same. 2. The addition of glass panels to enclose the balcony does not affect the LEED credit.
South	**1. The addition of glass panels to enclose the balcony decreased the sDA% by 9%.**	1. The ASE remains the same. 2. The addition of glass panels to enclose the balcony does not affect the ASE.	1. The LEED credit remains the same. 2. The addition of glass panels to enclose the balcony does not affect the LEED credit.
West	**1. The addition of glass panels to enclose the balcony decreased the sDA% by 8%.**	1. The ASE remains the same. 2. The addition of glass panels to enclose the balcony does not affect the ASE.	1. The LEED credit remains the same. 2. The addition of glass panels to enclose the balcony does not affect the LEED credit.

8.1.4 ALFA Simulation Results Testing Open and Enclosed Balconies for Studio and One Bedroom Apartment

MARCH 21 AT 9AM				
MODEL TYPE	SOUTH	EAST	NORTH	WEST
Studio Apartment with Open Balcony	76%	100%	62.0%	61%
Studio Apartment with Enclosed Balcony	67%	100%	42.0%	44.0%
One Bedroom Apartment with Open Balcony	60%	62%	40%	43.0%
One Bedroom Apartment with Enclosed Balcony	48%	63%	25.0%	24.0%

MARCH 21 AT 1PM				
MODEL TYPE	SOUTH	EAST	NORTH	WEST
Studio Apartment with Open Balcony	94%	72%	69.0%	78%
Studio Apartment with Enclosed Balcony	99%	52%	52%	56.0%
One Bedroom Apartment with Open Balcony	74%	43%	49%	58.0%
One Bedroom Apartment with Enclosed Balcony	63%	37%	32.0%	36.0%

JUNE 21 AT 9AM				
MODEL TYPE	SOUTH	EAST	NORTH	WEST
Studio Apartment with Open Balcony	72%	100%	72.0%	69%
Studio Apartment with Enclosed Balcony	64%	99%	52.0%	52.0%
One Bedroom Apartment with Open Balcony	56%	20%	52%	50.0%
One Bedroom Apartment with Enclosed Balcony	42%	13%	34.0%	32.0%

JUNE 21 AT 1PM				
MODEL TYPE	SOUTH	EAST	NORTH	WEST
Studio Apartment with Open Balcony	98%	76%	76.0%	90%
Studio Apartment with Enclosed Balcony	75%	57%	57.0%	60.0%
One Bedroom Apartment with Open Balcony	63%	45%	53%	60.0%
One Bedroom Apartment with Enclosed Balcony	53%	35%	37.0%	40.0%

SEPTEMBER 21 AT 9AM				
MODEL TYPE	SOUTH	EAST	NORTH	WEST
Studio Apartment with Open Balcony	85%	100%	63.0%	62%
Studio Apartment with Enclosed Balcony	71%	98%	46.0%	46.0%
One Bedroom Apartment with Open Balcony	63%	61%	42%	42.0%
One Bedroom Apartment with Enclosed Balcony	49%	62%	27.0%	29.0%

SEPTEMBER 21 AT 1PM				
MODEL TYPE	SOUTH	EAST	NORTH	WEST
Studio Apartment with Open Balcony	94%	70%	70.0%	85%
Studio Apartment with Enclosed Balcony	99%	53%	52.0%	58.0%
One Bedroom Apartment with Open Balcony	75%	39%	50%	59.0%
One Bedroom Apartment with Enclosed Balcony	63%	33%	31.0%	41.0%

DECEMBER 21 AT 9AM				
MODEL TYPE	SOUTH	EAST	NORTH	WEST
Studio Apartment with Open Balcony	64%	72%	39.0%	43%
Studio Apartment with Enclosed Balcony	62%	55%	24.0%	20.0%
One Bedroom Apartment with Open Balcony	49%	37%	23%	24.0%
One Bedroom Apartment with Enclosed Balcony	36%	33%	10.0%	12.0%

DECEMBER 21 AT 1PM				
MODEL TYPE	SOUTH	EAST	NORTH	WEST
Studio Apartment with Open Balcony	95%	58%	57.0%	66%
Studio Apartment with Enclosed Balcony	100%	42%	40.0%	46.0%
One Bedroom Apartment with Open Balcony	94%	30%	41%	49.0%
One Bedroom Apartment with Enclosed Balcony	74%	27%	24.0%	28.0%

8.1.5 Pass and Fail Charts for Studio and One Bedroom Apartment

JUNE 21 AT 9AM				
MODEL TYPE	SOUTH	EAST	NORTH	WEST
Studio Apartment with Open Balcony	FAIL	PASS	FAIL	FAIL
Studio Apartment with Enclosed Balcony	FAIL	PASS	FAIL	FAIL
One Bedroom Apartment with Open Balcony	FAIL	FAIL	FAIL	FAIL
One Bedroom Apartment with Enclosed Balcony	FAIL	FAIL	FAIL	FAIL

JUNE 21 AT 1PM				
MODEL TYPE	SOUTH	EAST	NORTH	WEST
Studio Apartment with Open Balcony	PASS	PASS	PASS	PASS
Studio Apartment with Enclosed Balcony	PASS	FAIL	FAIL	FAIL
One Bedroom Apartment with Open Balcony	FAIL	FAIL	FAIL	FAIL
One Bedroom Apartment with Enclosed Balcony	FAIL	FAIL	FAIL	FAIL

SEPTEMBER 21 AT 9AM				
MODEL TYPE	SOUTH	EAST	NORTH	WEST
Studio Apartment with Open Balcony	PASS	PASS	FAIL	FAIL
Studio Apartment with Enclosed Balcony	FAIL	PASS	FAIL	FAIL
One Bedroom Apartment with Open Balcony	FAIL	FAIL	FAIL	FAIL
One Bedroom Apartment with Enclosed Balcony	FAIL	FAIL	FAIL	FAIL

SEPTEMBER 21 AT 1PM				
MODEL TYPE	SOUTH	EAST	NORTH	WEST
Studio Apartment with Open Balcony	PASS	FAIL	FAIL	PASS
Studio Apartment with Enclosed Balcony	PASS	FAIL	FAIL	FAIL
One Bedroom Apartment with Open Balcony	PASS	FAIL	FAIL	FAIL
One Bedroom Apartment with Enclosed Balcony	FAIL	FAIL	FAIL	FAIL

DECEMBER 21 AT 9AM				
MODEL TYPE	SOUTH	EAST	NORTH	WEST
Studio Apartment with Open Balcony	FAIL	FAIL	FAIL	FAIL
Studio Apartment with Enclosed Balcony	FAIL	FAIL	FAIL	FAIL
One Bedroom Apartment with Open Balcony	FAIL	FAIL	FAIL	FAIL
One Bedroom Apartment with Enclosed Balcony	FAIL	FAIL	FAIL	FAIL

DECEMBER 21 AT 1PM				
MODEL TYPE	SOUTH	EAST	NORTH	WEST
Studio Apartment with Open Balcony	PASS	FAIL	FAIL	FAIL
Studio Apartment with Enclosed Balcony	PASS	FAIL	FAIL	FAIL
One Bedroom Apartment with Open Balcony	PASS	FAIL	FAIL	FAIL
One Bedroom Apartment with Enclosed Balcony	FAIL	FAIL	FAIL	FAIL

8.1.6 ALFA Simulation Results Testing Vegetation Levels on Studio Apartment Balcony

8.1.6.1 March Equinox

MARCH 21 AT 9AM				
MODEL TYPE	SOUTH	EAST	NORTH	WEST
Studio Apartment with Open Balcony	76%	100%	62%	61%
Studio Apartment with Open Balcony and little vegetation	80%	100%	59%	58.0%
Studio Apartment with Open Balcony and large vegetation	68%	100%	53%	50.0%
Studio Apartment with Enclosed Balcony	67%	100%	42%	44%
Studio Apartment with Enclosed Balcony and little vegetation	60%	99%	41%	46%
Studio Apartment with Enclosed Balcony and large vegetation	50%	89%	37%	36%

MARCH 21 AT 1PM				
MODEL TYPE	SOUTH	EAST	NORTH	WEST
Studio Apartment with Open Balcony	94%	72%	69%	78%
Studio Apartment with Open Balcony and little vegetation	100%	68%	69%	76%
Studio Apartment with Open Balcony and large vegetation	99%	59%	59%	61%
Studio Apartment with Enclosed Balcony	99%	52%	52%	56%
Studio Apartment with Enclosed Balcony and little vegetation	93%	49%	51%	52%
Studio Apartment with Enclosed Balcony and large vegetation	78%	38%	41.0%	46%

8.1.6.2 June Solstice

JUNE 21 AT 9AM				
MODEL TYPE	SOUTH	EAST	NORTH	WEST
Studio Apartment with Open Balcony	72%	100%	72.0%	69%
Studio Apartment with Open Balcony and little vegetation	69%	100%	68.0%	69.0%
Studio Apartment with Open Balcony and large vegetation	61%	100%	62.0%	56.0%
Studio Apartment with Enclosed Balcony	64%	99%	52.0%	52.0%
Studio Apartment with Enclosed Balcony and little vegetation	55%	94%	51%	52%
Studio Apartment with Enclosed Balcony and large vegetation	46%	86%	48.0%	46%

JUNE 21 AT 1PM				
MODEL TYPE	SOUTH	EAST	NORTH	WEST
Studio Apartment with Open Balcony	98%	76%	76%	90%
Studio Apartment with Open Balcony and little vegetation	95%	76%	73%	85%
Studio Apartment with Open Balcony and large vegetation	81%	65%	65%	65%
Studio Apartment with Enclosed Balcony	75%	57%	57%	60%
Studio Apartment with Enclosed Balcony and little vegetation	66%	59%	57%	58%
Studio Apartment with Enclosed Balcony and large vegetation	57%	49%	48%	49%

8.1.6.3 September Equinox

SEPTEMBER 21 AT 9AM				
MODEL TYPE	SOUTH	EAST	NORTH	WEST
Studio Apartment with Open Balcony	85%	100%	63%	62%
Studio Apartment with Open Balcony and little vegetation	84%	100%	61%	59.0%
Studio Apartment with Open Balcony and large vegetation	73%	100%	52%	52%
Studio Apartment with Enclosed Balcony	71%	98%	46%	46%
Studio Apartment with Enclosed Balcony and little vegetation	63%	97%	45%	47%
Studio Apartment with Enclosed Balcony and large vegetation	56%	88%	39%	42.0%

SEPTEMBER 21 AT 1PM				
MODEL TYPE	SOUTH	EAST	NORTH	WEST
Studio Apartment with Open Balcony	94%	70%	70%	85%
Studio Apartment with Open Balcony and little vegetation	100%	69%	67%	78%
Studio Apartment with Open Balcony and large vegetation	100%	59%	56%	62.0%
Studio Apartment with Enclosed Balcony	99%	53%	52%	58%
Studio Apartment with Enclosed Balcony and little vegetation	91%	49%	51%	57%
Studio Apartment with Enclosed Balcony and large vegetation	80%	45%	36%	47%

8.1.6.4 December Equinox

DECEMBER 21 AT 9AM				
MODEL TYPE	SOUTH	EAST	NORTH	WEST
Studio Apartment with Open Balcony	64%	72%	39%	43%
Studio Apartment with Open Balcony and little vegetation	65%	67%	34%	38%
Studio Apartment with Open Balcony and large vegetation	59%	62%	25%	26%
Studio Apartment with Enclosed Balcony	62%	55%	24%	20%
Studio Apartment with Enclosed Balcony and little vegetation	46%	52%	22%	20%
Studio Apartment with Enclosed Balcony and large vegetation	41%	42%	17%	16%

DECEMBER 21 AT 1PM				
MODEL TYPE	SOUTH	EAST	NORTH	WEST
Studio Apartment with Open Balcony	95%	58%	57%	66%
Studio Apartment with Open Balcony and little vegetation	100%	56%	55%	60.0%
Studio Apartment with Open Balcony and large vegetation	100%	48%	51%	48.0%
Studio Apartment with Enclosed Balcony	100%	42%	40%	46%
Studio Apartment with Enclosed Balcony and little vegetation	100%	39%	45%	46%
Studio Apartment with Enclosed Balcony and large vegetation	99%	33%	31%	32%

8.1.7 Pass and Fail Charts for Test Simulations of Vegetation Levels on Studio Apartment Balcony

8.1.7.1 March Equinox

MARCH 21 AT 9AM				
MODEL TYPE	SOUTH	EAST	NORTH	WEST
Studio Apartment with Open Balcony	PASS	PASS	FAIL	FAIL
Studio Apartment with Open Balcony and little vegetation	PASS	PASS	FAIL	FAIL
Studio Apartment with Open Balcony and large vegetation	FAIL	PASS	FAIL	FAIL
Studio Apartment with Enclosed Balcony	FAIL	PASS	FAIL	FAIL
Studio Apartment with Enclosed Balcony and little vegetation	FAIL	PASS	FAIL	FAIL
Studio Apartment with Enclosed Balcony and large vegetation	FAIL	PASS	FAIL	FAIL

MARCH 21 AT 1PM				
MODEL TYPE	SOUTH	EAST	NORTH	WEST
Studio Apartment with Open Balcony	PASS	FAIL	FAIL	PASS
Studio Apartment with Open Balcony and little vegetation	PASS	FAIL	FAIL	PASS
Studio Apartment with Open Balcony and large vegetation	PASS	FAIL	FAIL	FAIL
Studio Apartment with Enclosed Balcony	PASS	FAIL	FAIL	FAIL
Studio Apartment with Enclosed Balcony and little vegetation	PASS	FAIL	FAIL	FAIL
Studio Apartment with Enclosed Balcony and large vegetation	PASS	FAIL	FAIL	FAIL

8.1.7.2 June Solstice

JUNE 21 AT 9AM				
MODEL TYPE	SOUTH	EAST	NORTH	WEST
Studio Apartment with Open Balcony	FAIL	PASS	FAIL	FAIL
Studio Apartment with Open Balcony and little vegetation	FAIL	PASS	FAIL	FAIL
Studio Apartment with Open Balcony and large vegetation	FAIL	PASS	FAIL	FAIL
Studio Apartment with Enclosed Balcony	FAIL	PASS	FAIL	FAIL
Studio Apartment with Enclosed Balcony and little vegetation	FAIL	PASS	FAIL	FAIL
Studio Apartment with Enclosed Balcony and large vegetation	FAIL	PASS	FAIL	FAIL

JUNE 21 AT 1PM				
MODEL TYPE	SOUTH	EAST	NORTH	WEST
Studio Apartment with Open Balcony	PASS	PASS	PASS	PASS
Studio Apartment with Open Balcony and little vegetation	PASS	PASS	FAIL	PASS
Studio Apartment with Open Balcony and large vegetation	PASS	FAIL	FAIL	FAIL
Studio Apartment with Enclosed Balcony	PASS	FAIL	FAIL	FAIL
Studio Apartment with Enclosed Balcony and little vegetation	FAIL	FAIL	FAIL	FAIL
Studio Apartment with Enclosed Balcony and large vegetation	FAIL	FAIL	FAIL	FAIL

8.1.7.3 September Equinox

SEPTEMBER 21 AT 9AM				
MODEL TYPE	SOUTH	EAST	NORTH	WEST
Studio Apartment with Open Balcony	PASS	PASS	FAIL	FAIL
Studio Apartment with Open Balcony and little vegetation	PASS	PASS	FAIL	FAIL
Studio Apartment with Open Balcony and large vegetation	FAIL	PASS	FAIL	FAIL
Studio Apartment with Enclosed Balcony	FAIL	PASS	FAIL	FAIL
Studio Apartment with Enclosed Balcony and little vegetation	FAIL	PASS	FAIL	FAIL
Studio Apartment with Enclosed Balcony and large vegetation	FAIL	PASS	FAIL	FAIL

SEPTEMBER 21 AT 1PM				
MODEL TYPE	SOUTH	EAST	NORTH	WEST
Studio Apartment with Open Balcony	PASS	FAIL	FAIL	PASS
Studio Apartment with Open Balcony and little vegetation	PASS	FAIL	FAIL	PASS
Studio Apartment with Open Balcony and large vegetation	PASS	FAIL	FAIL	FAIL
Studio Apartment with Enclosed Balcony	PASS	FAIL	FAIL	FAIL
Studio Apartment with Enclosed Balcony and little vegetation	PASS	FAIL	FAIL	FAIL
Studio Apartment with Enclosed Balcony and large vegetation	PASS	FAIL	FAIL	FAIL

8.1.7.4 December Equinox

DECEMBER 21 AT 9AM				
MODEL TYPE	SOUTH	EAST	NORTH	WEST
Studio Apartment with Open Balcony	FAIL	FAIL	FAIL	FAIL
Studio Apartment with Open Balcony and little vegetation	FAIL	FAIL	FAIL	FAIL
Studio Apartment with Open Balcony and large vegetation	FAIL	FAIL	FAIL	FAIL
Studio Apartment with Enclosed Balcony	FAIL	FAIL	FAIL	FAIL
Studio Apartment with Enclosed Balcony and little vegetation	FAIL	FAIL	FAIL	FAIL
Studio Apartment with Enclosed Balcony and large vegetation	FAIL	FAIL	FAIL	FAIL

DECEMBER 21 AT 1PM				
MODEL TYPE	SOUTH	EAST	NORTH	WEST
Studio Apartment with Open Balcony	PASS	FAIL	FAIL	FAIL
Studio Apartment with Open Balcony and little vegetation	PASS	FAIL	FAIL	FAIL
Studio Apartment with Open Balcony and large vegetation	PASS	FAIL	FAIL	FAIL
Studio Apartment with Enclosed Balcony	PASS	FAIL	FAIL	FAIL
Studio Apartment with Enclosed Balcony and little vegetation	PASS	FAIL	FAIL	FAIL
Studio Apartment with Enclosed Balcony and large vegetation	PASS	FAIL	FAIL	FAIL

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