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Daylight Simulation for Multi-Unit Residential Buildings: Occupant-Centered Approaches to Assessment

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Abstract: *New simulation tools for daylight have been tested on specific building types, mostly offices and schools. To date there have been very few simulation-based studies of daylighting in multi-unit residential buildings. Recent studies have shown strong connections between daylight and occupant wellbeing, not only in places where people work and study, but also in the home. New climate-based computer simulation tools allow designers the chance to test design options to better focus on daylit environments that promote wellbeing and quality of life, as well as productivity and energy conservation. This paper is derived from a larger, ongoing study and it evaluates design options for several differently shaped and oriented apartment floorplans using DIVA, a computational daylight simulation software. The paper offers findings specifically about the particular daylight issues related to multi-unit residential buildings. Further, the paper suggests new methods for including wellbeing in current daylight simulation workflows.*

Keywords: *design, daylight, multi-unit residential building (MURB), occupant-centered, wellbeing.*

INTRODUCTION

As the trend toward urban intensification continues in cities around the world, and especially here in Canada, a higher proportion of new housing is being developed in the form of multi-unit residential buildings (MURBs). Unlike single family detached houses, access to acceptable levels of daylighting is much more challenging in the MURB typology where fenestration is predominantly provided across a single aspect facade rather than being distributed across a number of exterior wall facade orientations.

Most contemporary daylighting metrics are applied to office environments where daylighting autonomy and issues related to glare dominate the assessment criteria. Unlike offices where persons typically occupy their work areas for extended periods of time, dwelling inhabitants generally enjoy higher degrees of freedom to access the daylight levels and views they desire and to control against glare and privacy. In daylight simulations, the focus on offices means a preoccupation with 'tasks' and task illumination, which means the amount of daylight hitting the horizontal workplane. People's expectations in their homes vary, as studies have shown in MURB buildings types people are aging in place, working from home, and having families. Daylight impacts a range of environmental design criteria, such as energy consumption, and occupant comfort.

There are no design tools, standards or metrics relevant for daylight, despite its relation to housing design quality and wellbeing. Daylight has a range of benefits, and the design implications of effects of light on circadian rhythm, emotional wellbeing and physical health are understudied in the context of daylight simulation. Regardless of specific residential types or patterns of inhabitation, numerous studies in design, public health and environmental psychology support the need for adequate daylighting in the living environment for occupant wellbeing (Veitch and Galasiu 2012; Aries, M., Veitch, J., Newsham, G. 2010). Augmenting daylight with artificial illumination does not significantly impact energy consumption in most dwellings, hence the critical consideration in residential daylighting design tends to be creating appealing spaces for occupant satisfaction and wellbeing. MURBs present unique challenges in housing design and some of these are explored here. This paper explores both the modeling techniques needed to assess residential daylighting as well as the development of appropriate metrics that are correlated to wellbeing and quality of life.

METHODOLOGY

In the last decade, there has been a move away from evaluating daylight in rooms based on the established metric of Daylight Factor (DF) as it is insensitive to climate, location, or orientation. DF is a ratio of the internal horizontal illuminance in a space compared to the unobstructed external horizontal illuminance (Mardaljevic 2013). Climate-based daylight modelling (CBDM) takes a different approach, using realistic sun and sky conditions and building orientation at a location. CBDM is accepted as best practice in research and practice (Mardaljevic and Nabil, 2005; Mardaljevic, 2006; Mardaljevic and Christoffersen 2017). CBDM relies on the use of standardized weather files, which although widely available are based on historical data and therefore problematic in simulating future scenarios.

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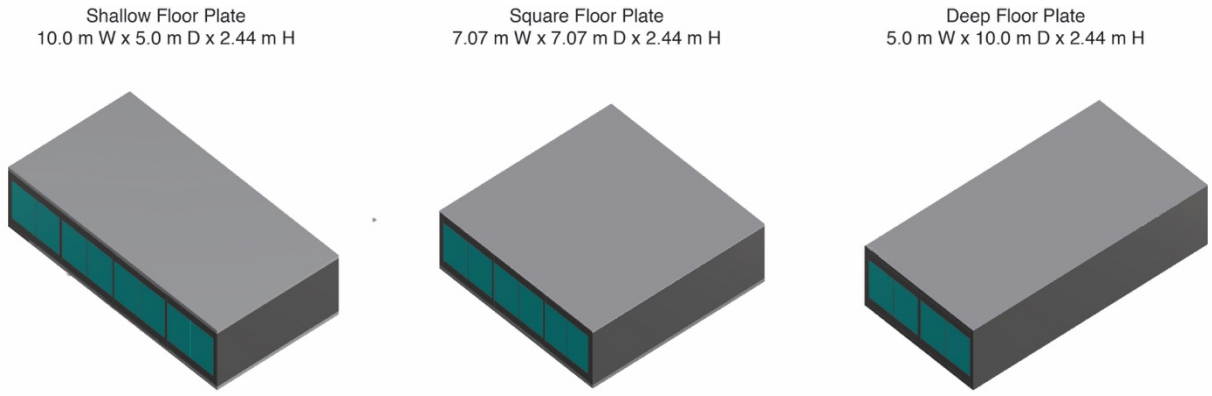

Figure 1. Typical apartment suites assessed in the daylighting study.

The method evaluates daylight over a period of time (normally annually). For this study, CBDM is used because it employs realistic, time-varying sky and sun conditions and considers hourly levels of absolute daylight illuminance to produce an annual percentage.

Spatial Daylight Autonomy (sDA) is a well used metric that allows a designer to quantify and compare daylight in a space (Reinhart, Mardaljevic, Rogers, 2006). sDA describes the percentage of floor area that receives a specified target illuminance for at least half of the space's annual occupied hours. The newest version of global green building standard Leadership in Energy and Environmental Design (LEED v4) has included a performance-based compliance pathway, rather than solely prescriptive guidelines and Daylight Factor (DF) measurement for determining daylight in buildings. In LEED v4 CBDM simulation can be used to measure sDA combined with an analysis of Annual Sunlight Exposure (ASE) to determine if a space is daylit and to award either one or two points for credits. DIVA developer and researcher Reinhart (2016) praised the performance-based approach generally, but critiqued the emphasis on restricting direct sunlight in this LEED credit. The recent introduction of CBDM-based simulation workflows into standard evaluation tools like LEED v4 needs to be paired with a critical evaluation of standards or metrics that take into account building program and occupant wellbeing.

To accurately evaluate MURBs, current parameters in daylight simulation need to be reconsidered. For example, in a home setting, determining occupancy is problematic. Dogan (2017) found the question of adapting simulations to residential settings difficult to resolve and he created a new metric relating to this with his rDA. Another primary consideration is the typical target illuminance threshold of 300 lux. This is not necessarily appropriate as a threshold in all settings, and researchers acknowledge this, but few have tested other thresholds either higher or lower than this target illuminance. The study presented is part of a larger study to specifically focus on daylight considerations of health and wellbeing of people and spatial qualities, rather than more typically including these considerations if possible after focusing primarily on building energy efficiency.

Daylight Study – Analysis of MURB Floorplans

A single geographical location is presented in the paper, Vancouver, BC, Canada, but the larger study considers various climatic regions and geographic locations in BC. MURBs suites in this locale tend to be small in size, have nearly fully glazed exteriors, and many are single aspect so these features are taken into account.

Unit Geometry Study

The MURB floor plans studied are all single aspect, side lit, one-bedroom units, with floor-to-ceiling heights of 8' (2.438m). Three simple unit geometries of various width to depth aspect ratios are studied as depicted in Figure 1: the deep floor plate (1:2 aspect ratio); the square floor plate (1:1 aspect ratio); and the shallow floor plate (2:1 aspect ratio). The unit's height above the ground and location in the building's floor plan and in relation to nearby buildings are not considered. It is assumed that the unit's solar orientation and window-to-wall ratios (WWR) are the most important considerations. WWR is an important variable for daylight, ventilation and views.

Two WWR ratios were studied as depicted in Figure 2: 70% WWR; and 80% WWR to reflect common MURB design practices. To maximize unit numbers in a building rather than unit sizes, and therefore increase profitability, floorplates tend to be deep plans, and there are only requirements for windows in bedrooms, living and dining areas (OBC, 2017). Research indicates that high WWRs exceeding 60% in MURBs lead to poor energy performance (Ozkan, Kesik, O'Brien, 2016) and have

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adverse implications for privacy, thermal comfort, and glare. Additionally, it can be argued that too much glazing gives the building an institutional aesthetic, impacts privacy, and makes units impractical to furnish.

The daylighting rule of thumb (DRT) is used by most sustainable designers in daylight design Reinhart (2005). DRT relates window-head-height to the depth of the daylit area adjacent to a façade and it is relevant here given the simple geometries studied. DRT remains useful because it is easily understood and verifiable by designers, whereas sDA offers an annual percentage of the floor area, which gives a result that is hard for designers to feel is intuitive. For sDA, it takes time to gain an understanding of how to interpret results, and how to spot errors in calculations, or do spot measurements to verify.

Occupancy, Materials, Desired Target Illuminances, Orientation

The simulations software required certain assumptions be made about occupancy, materials, desired target illuminances and building orientation and climate. For simple comparison all geometries studied used the same parameters. This study assumed the units are occupied 8am-6pm with Daylight Savings Time (DSTI) invoked, analyzed in 60 minute increments. For the analysis grid, the node height and spacing assumptions are 0.5 m high, the node spacing is 0.5 m apart. For DA, the units were analyzed for three target illuminances: 300, 200 and 100 lux. Furniture and partitions are highly variable and so the maximum potential illumination was examined. The façade glazing simulated represents commonly used MURB façade materials.

Table 1. Surface reflectance and glass transmittance used in the DIVA simulations.

Material	Reflectance/ Transmittance*
Ceiling	70%
Floor	20%
Glazing*	65%
Glazed balcony panels*	88%
Other facades	35%
Interior Walls	70%
Outside ground	20%
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Daylight Simulation Challenges Specific to MURB Typologies

In adapting climate-based daylight simulation software for MURB units, four important aspects have emerged as challenges requiring new assumptions when focusing on this building type: critically considering the 'daylit' home (target illuminance), rethinking patterns of inhabitation (occupancy schedules), considering angles and heights in relation to daylight quality (analysis grid), and understanding varying requirements (room-specific activities/tasks with similar geometries).

Target illuminance is a required input for daylight simulation of sDA yet there is no consensus about what constitutes a comfortable lit or daylit space in a residential environment. IESNA recommends minimum lux for bedrooms 200 lux; lounge lux, bathroom 100 lux, office 300 lux (IESNA & Rea 2000). LEED requires 300 lux as the target illuminance in calculating DA in a range of building types without varying this target with the activities in the room (for example a bedroom vs a living room vs a library study room would all be very different). Reinhart and Weissman 2012 found that 300 lux correlated well to human experience of a well daylit space in a lecture room and more studies like this need to be carried out to better understand the link between standards and experience specific to the home.

Evaluating a daylit space requires an assumption about people and our behavior. For a daylight simulation an occupancy schedule is required. In offices, spaces are normally used 9 AM - 5 PM weekdays (perhaps except lunch hour), year round, and it is assumed the building's users have uniform daylight needs and desires, and that they are sitting at a desk throughout the day with little freedom to move around and follow the daylight. In the home, the occupancy schedule would vary widely depending on day of the week, season and personal scheduling. Additionally, there needs to be a more nuanced study than 'daylit' or 'not' as the requirement for achieving the DA requires the meeting of a target illuminance 50% of the time which seems arbitrary. Why not 60% or higher? In a residential setting, it could be argued that the 'occupancy' is before people wake up, from sunrise. For many people, having a residential unit with access to morning light from the time of sunrise offers a valuable quality of light for enjoying breakfast, reading, dressing, etc. Likewise in the evening, even if the quantity of light does not meet the target illuminance, the benefits of the fading light and evening sunset should be considered.

Related to the occupancy information is the specification of the analysis grid. When simulating an office floorplan in DIVA for example, the analysis grid would likely be a desk, so evaluating daylight coming into the room at 0.8m above the floor is typical, and the spacing of these node points would be 0.5 apart to consider the different spaces in the room. In the home, the target illuminance varies with the room and considerations of the 'task' of living. It is argued here that a wide variety of target illuminances could be acceptable, from 100-300 lux could all be considered adequate for sitting and chatting in a living room. The

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analysis grid spacing of 0.5m apart is appropriate but the height of a chair or coffee table may be a more appropriate height, hence 0.5m is tested in this paper.

In any environment, there are varying activities and tasks. In a MURB floorplan, it can be assumed in a single aspect side lit one-bedroom apartment, that typically the living room and separated by a wall, the bedroom, face the main fenestrated façade. There are varying daylight and darkness requirements in a living room and a bedroom and this impacts occupancy schedules and target illuminances. Depending on the inhabitant, a living room could be a work from home space, a family room, a media room or a hobby room. These likely require a mix of electric task lighting and natural daylight. A bedroom requires darkness during sleeping hours and numerous green building studies have advocated for the health and wellbeing requirements of bedrooms as being relaxing spaces (quiet, well ventilated and safe), that respond to the body's circadian rhythms. (Beranova, S., et al 2015). A recent study on health and the home identified the need for well ventilated bedrooms with cooler temperatures and warned of relying on electric lighting after dark, but stopped short of specifying specific light qualities for bedrooms (UK Green Building Council 2016). In MURB design, building details and environmental parameters in daylighting metrics normally designed for office buildings must be modified to provide more meaningful results.

RESULTS

Three simple, single aspect unit floorplan geometries were studied: the deep shoebox (1:2 aspect ratio), the square box (1:1 aspect ratio), and the wide floorplan (2:1 aspect ratio).

Findings on Relationship between DA and Unit Geometry: The deep shoebox geometry fared the worst of the units studied in terms of DA. Studied in four orientations, the best illumination was expectedly the South-facing suite (see Figure 3).

The deep aspect ratio with 70% WWR achieves DA_{300lux} [50%] = 2%. The 'daylit' area is a narrow band 500mm deep along the front middle of the façade. Daylight does not permeate into the floorplan. Since DA is a percentage of the entire floor area being evaluated, in this case a condo unit with a 1:2 ratio, it is clear that unless this unit has light from other sources, it will score poorly since the area of the room influences the result. At 200 lux the DA is unchanged at and at 100 lux there is some improvement (DA_{100lux} [50%] = 5%). When tested with 80% WWR, the results were the same.

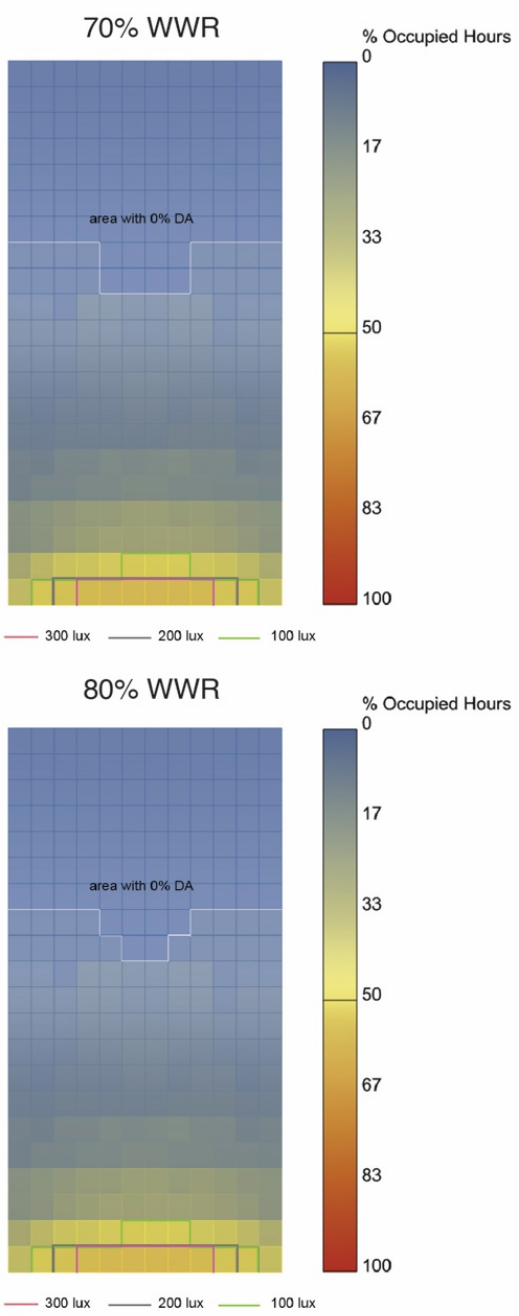

Figure 3. Three sDA thresholds for South-facing deep (shoebox) floor plate situated in Vancouver, BC.

The square unit geometry also had a low score in terms of DA and the best illumination was again the South-facing suite (see Figure 4).

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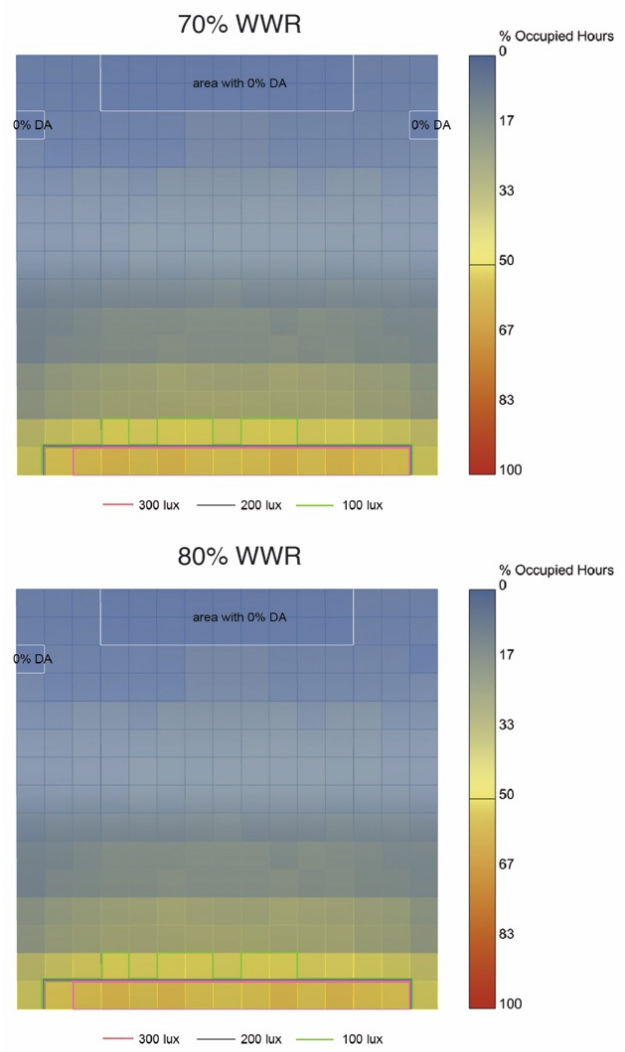

Figure 4. Three sDA thresholds for South-facing square floorplate situated in Vancouver, BC.

The square aspect ratio with 70% WWR achieves DA300lux [50%] = 4%. When tested at different illuminance targets the results were still very low but there was some increase: (DA200lux [50%] = 6% of floor area) and (DA100lux [50%] = 7%). Daylight manages to permeate nearly to the back of the floorplate in very low quantities. When tested with 80% WWR, the results were virtually unchanged.

The wide aspect ratio achieved the highest DA but only marginally so and the score is still unacceptably low when benchmarked to LEED or any other metric, even at the lowest target illuminance threshold. The best illumination was expectedly the South-facing suite (see Figure 5).

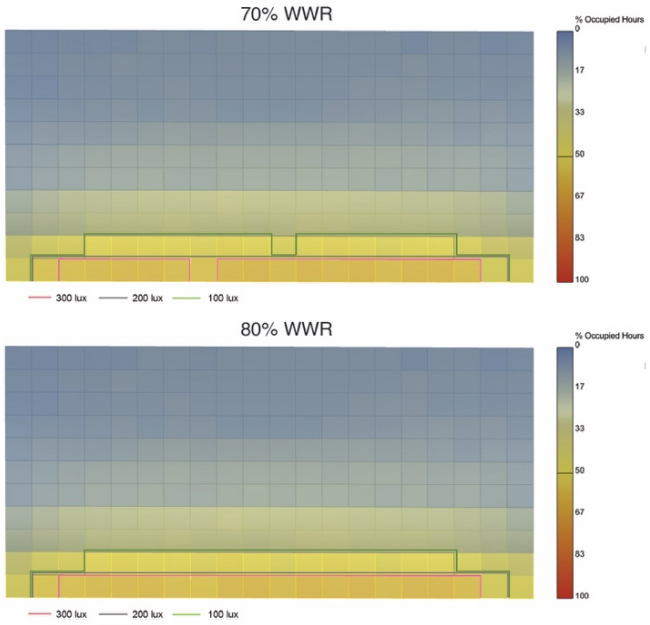

Figure 5. Three sDA thresholds for South-facing shallow floor plate situated in Vancouver, BC.

The unit has a 70% WWR and DA300lux [50%] = 6%. When tested at different illuminance targets the results were still very low: (DA200lux [50%] = 8%) and (DA100lux [50%] = 11%). Daylight manages to permeate to back of the floorplate in low quantities. When tested with 80% WWR, the results were unchanged.

An additional study was carried out to better understand the impact of small balconies. These units tend to have small balconies which shade the unit below, and when both the 70% and 80% WWR were simulated with a balcony, the DA is negatively impacted, even at the lowest tested illuminance threshold (DA100lux [50%] = 0%). Further studies need to be carried out about the impact of balconies on daylighting in MURBs but from this simple study it is obvious that balconies negatively impact daylight quality indoors.

Findings on Relationship between WWR and DA: WWR in MURBs is considered an important indicator of daylight. With a standard 8' (2.4m) ceiling height, how important is WWR with the aim of positively impacting daylight quantity? Using the deep floorplate geometry, facing South, a range of WWRs were tested and there was only a very minor difference between 60% and 100% WWR. Increasing WWR in a standard 8' ceiling height is not where the greatest impact to DA can be gained.

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Table 2. Changes in DA for a South-facing suite with a deep floor plate (1:2 width to depth) corresponding to increasing window to wall ratio (assuming Wall ratio of 5000mm wide and 2400mm wide with glazing at 5000 wide and centered on height of façade)

Window to Wall Ratio	Spatial Daylight Autonomy
WWR 60%	DA300lux [50%] = 0%; (mean DA 8%) DA200lux [50%] = 3%; (mean DA 8%) DA100lux [50%] = 3%; (mean DA 9%)
WWR 70%	DA300lux [50%] = 0%; (mean DA 8%) DA200lux [50%] = 3%; (mean DA 8%) DA100lux [50%] = 3%; (mean DA 9%)
WWR 80%	DA300lux [50%] = 0%; (mean DA 9%) DA200lux [50%] = 3%; (mean DA 9%) DA100lux [50%] = 3%; (mean DA 10%)
WWR 90%	DA300lux [50%] = 3%; (mean DA 9%) DA200lux [50%] = 3%; (mean DA 9%) DA100lux [50%] = 3%; (mean DA 10%)
WWR 100%	DA300lux [50%] = 3%; (mean DA 9%) DA200lux [50%] = 3%; (mean DA 10%) DA100lux [50%] = 3%; (mean DA 10%)

Window Head-Height Study: The south facing square geometry with a typical 70% WWR and an 8' ceiling height was examined as a starting point, and a study tested a range of floor heights with a uniform 1' band at the floor and ceiling being non-glazed, and the rest of the façade glazed using the parameters above (thereby impacting the WWR). The results in Table 3 indicate that there is not significant benefit in terms of daylighting by simply increasing the ceiling height and thereby the head-height of the glazing.

Table 3. Impact of window head-height on daylight autonomy for a South-facing suite.

Ceiling Height	DA100lux [50%]
8' (2.438m)	6%
9' (2.743m)	8%
10' (3.048m)	9%
12' (3.657m)	10%
14' (4.267m)	13%
16' (4.876m)	13%

Findings on Relationship between DA and Experience: Research supports DA as an important climate-based metric for understanding daylit interiors. However, the annual calculation of the percentage of the floorplan that achieves the target illuminance does not describe the experience of being in the space. Figure 6 compares the results of four point in time illuminance analyses.

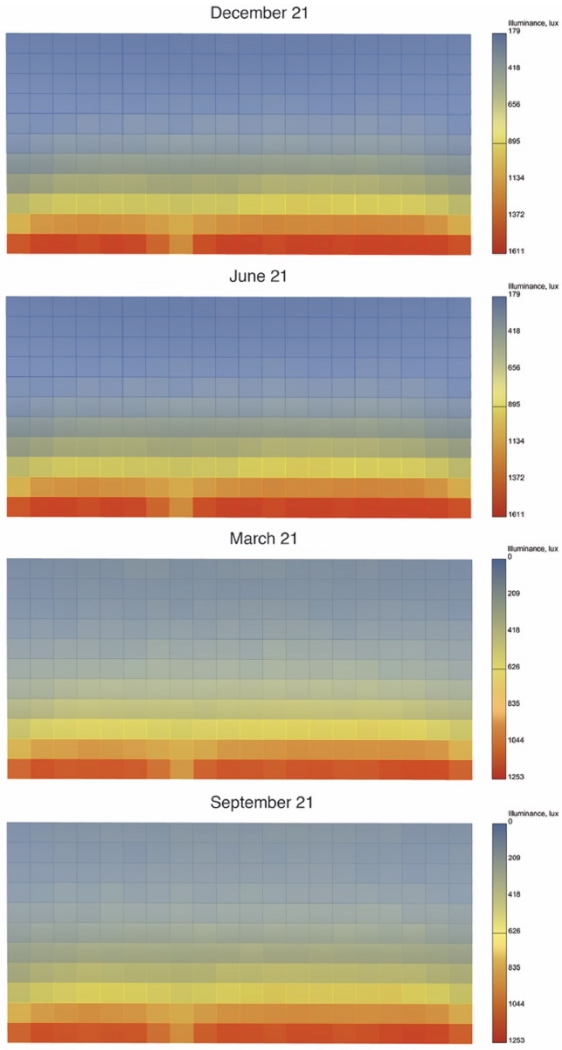

Figure 6. Illuminance in South-facing suite with shallow floor plate under CIE overcast conditions at noon throughout the four seasons.

These studies show that the averaged annual results do not account for highs and lows and only tell part of the story of daylight experience. This is particularly relevant for MURBs rather than office buildings, as MURBs are homes for people who will experience them over the course of the day by moving around them, with a more personal relationship with the space. The South-facing wide floor plan (2:1 ratio) was tested with illuminance studies assuming a CIE Overcast sky. This was considered the

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most relevant given Vancouver's climate and further studies could consider a range of sky conditions. Four dates were evaluated, December 21 at noon (illuminance values varied from 0 to 537 lux); March 21 at noon (illuminance values varied from 81 lux to 1253 lux), June 21 at noon (illuminance values ranged from 179-1611 lux), and September 21 at noon (illuminance values ranged from 61-1253 lux). The range of lux values varies considerably given the small floor areas. Simulations of Toronto sky conditions revealed only minor differences in illumination levels.

DISCUSSION

The discussion that follows highlights the significant factors and issues related to daylighting metrics for MURBs.

WWR study

This study has shown that excessively high (70-80% or higher) WWR does not in itself positively impact on daylighting levels. Table 2 shows that single aspect, side lit units with deep unit geometries do not benefit from high levels of glazing as expected. In the studies above there were typically no appreciable differences observed between 70% and 80% WWR. There needs to be a better awareness amongst those commissioning and designing MURBs that higher WWR do not necessarily lead to better daylighting. The WELL Standard awards points for appropriate WWR for residential environments, recommending living rooms have 30%-60% WWR and bedrooms 20%-40% WWR (WELL).

WWR is not an objective measure of quantity of daylight because the percentage of WWR does not describe where the glazing is in the space. For example, there is less benefit to an extra foot of glazing at floor level than extending higher level glazing because daylight depends on orientation and enjoyment of daylight depends on views and room arrangement. Introducing dual aspect units would be a better strategy to improve daylighting. Figures 3-5 show that in single aspect, side lit, residential units in MURBs the orientation followed by window head height and suite aspect ratios are the biggest influences on daylight.

Orientation Study

For single aspect units of a typical depth, only South facing suites attain reasonable illuminance levels.

North-facing orientation: Regardless of suite geometry, WWR, or target illuminance, there is no DA and no variation in mean DA in any of the North-facing suite geometries studied. This orientation performs extremely poorly from a daylight standpoint and this study concludes that units should not be designed as single aspect north facing.

East-facing orientation: While faring better than North-facing, irrespective of suite geometry, target illuminance or WWR, there is no DA in any of the geometries studied. There are some minor differences in the three geometries, and WWR is not a significant parameter. Notably, the wide floorplan achieves very low levels of daylight at all areas of the floorplan. The differences in how significantly the floorplate areas were below the 50% DA threshold is revealed by looking at the mean DA across the space: Deep Shoebox (5-6%), Square box (8-9%) and Wide (11-13%)

South-facing orientation: DA is achieved to a very low degree in all three geometries at all three target illuminances. With 70 WWR, the Deep Shoebox geometry for both 300 and 200 lux is 2% increasing to 5% at 100 lux. For the Square geometry: DA300lux [50%] = 4%; DA200lux [50%] = 5%; DA100lux [50%] = 6%. For the Wide geometry DA300lux [50%] = 6%; DA200lux [50%] = 8%; DA100lux [50%] = 11% at 70%WWR. The wide floorplan achieves very low levels of daylight at all areas of the floorplan. The highest performing geometry is the wide floorplan, and the highest performing orientation is south facing, yet this is still unacceptably low for a DA result. In each case, the DA is virtually unchanged with 80 WWR. To compare with the other geometries in this orientation study, the mean DA of the South orientation is: Deep Shoebox (8-10%), Square box (12-15%) and Wide (19-22%)

West-facing orientation: Irrespective of suite geometry, target illuminance, or WWR, there is no DA in any of the geometries studied. There are some minor differences by geometry but as in the other orientations, WWR is not a significant parameter. The wide floorplan achieves very low levels of daylight at all areas of the floorplan. The differences in how significantly the floorplate areas were below the 50% threshold is revealed by looking at the mean DA across the spaces in the various geometries: Deep Shoebox (5-6%), Square box (8-9%) and Wide (12-14%) Compared to the East facing study, in terms of mean DA, the shoebox geometry and the square box score the same, the wide floorplan performs a bit better with the west orientation.

Varied Daylight Requirements

Different rooms in housing have particular daylighting requirements and expectations so it is difficult to set a singular target illuminance. Good practice for daylight design encourages design of rooms and layout with the sun in mind. For example, the kitchen and breakfast rom would benefit from more light in the morning, the living room from afternoon sun, and the bedroom of a house should be kept well ventilated and dark. These depend on the inhabitant, but currently MURB design shows no evidence of following any rules of thumb or practical guidance about

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daylight design. The idea that a higher WWR gives better daylight is not true, it depends more on the unit geometry, and the climate and orientation. The placement and arrangement of rooms is often as critical as aspect ratios. In MURBs, typically living room and bedroom are arranged along the façade so these are the main spaces with access to daylight. Kitchens and bathrooms are the spaces that logically need ventilation yet they do not benefit from any natural light in a single aspect MURB layout.

Appropriate Daylighting Metrics for MURBs that take into account issues such as: varying target illuminance for different rooms, target illuminances linked to occupant wellbeing as well as building efficiency, consider the role of artificial lighting as task lighting, consider utilization efficiency (the fraction of available daylight versus what actually gets into the dwelling unit), and that better consider room layout, would enable meaningful indicators of daylight in MURBs.

New metrics and tools must challenge the assumption that daylight *quantity* is most important. Increasingly researchers are developing tools and metrics for human-centric perspectives on daylight design and analysis (Ámundadóttir M.L. et al., 2017). New interdisciplinary studies are using computational simulation tools combined with observation and monitoring of building occupants in daylight spaces focusing on time, space and circadian responses of individuals (Soto Magan V.E. and Andersen M., 2017). In sustainable design research there has been a shift from efficiency to effectiveness, focusing on the role of the building user and their behaviour as a key component of building performance. A more occupant centric focus in daylight design offers real potential to design for user experience and perception and also to better allow designers to predict the performance of their designs before they are built, to simulate architectural spaces in dynamic daylight conditions.

The enjoyment of daylight is not only direct exposure. In environmental psychology the concept of prospect-refuge considers the desire for people to be on the edge of a space or landscape, to have proximity and the opportunity to experience it (prospect) while remaining outside of it and safe (refuge) (Appleton 1975). In relation to daylight in the home, it might be that sitting next to and viewing a beam of sunlight hitting the wall or the view of a sunny corner is enjoyable, and part of the experience of a well daylit interior. This quality is difficult to quantify and measure.

In some cultures, it is said that people should not inhabit dwellings in which plants will not thrive. It would be interesting to test whether or not a strip of exterior facade perimeter with access to direct sunlight for part of the day provides adequate daylighting for human health and wellbeing. It would be very helpful if such indicators as plant health were relevant to human health because this "canary in the mine" would be much more accessible to the average MURB dweller than a battery of simulations.

Development of new residential daylighting metrics and correlating these to MURB forms, suite layouts and solar orientations. Recent research into more meaningful residential daylighting metrics, such as the Residential Daylight Score (Dogan and Park, 2018) start to combine DA with direct solar access to form hybrid scorecards of residential daylight quantity. But these metrics do not capture daylight quality and they are not yet correlated to post-occupancy evaluations of inhabitants' satisfaction with both daylighting quality and quantity in their dwellings. This reinforces the notion that the building sciences and the health sciences need to converge in order to better manage the assessment of daylighting adequacy in housing.

CONCLUSIONS

Designing for daylight needs to be comprehensively reconsidered in MURB design to achieve sustainable, healthy homes for people. Design for daylight that integrates architectural concept, prioritizes inhabitant wellbeing and incorporates strategies to encourage an enjoyment of daylight requires a different and more nuanced framework and set of tools than designing buildings to merely achieve minimum illuminance requirements. The assumption that building performance is isolated from human behaviour and experience is being challenged in sustainable architecture, and increasingly studies of occupant behaviour and occupant-centered design are influencing practice and research.

If contemporary building science is to improve daylighting in typical MURB developments, then it is essential to develop reliable methodologies and metrics for assessing daylighting quantity and quality. In this paper, the intention was to explore climate-based daylight modelling as a means of developing practical design guidelines for enhanced daylighting in MURBs, instead a number of challenging issues have been identified. They are still useful in formulating future research efforts and developing meaningful metrics. This section summarizes the interim conclusions stemming from the study underlying this paper.

1. Daylight autonomy is not as useful a metric for residential daylighting design as it is for office buildings.
2. Views, visual interest and a range of daylighting levels cannot be ignored.
3. Different target illuminance levels are appropriate for different room types.

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4. Acceptable daylighting in MURBs with single aspect facades and typical floor to ceiling heights is only achievable to a very limited degree (and not meeting LEED or other metrics) in South-facing suites.
5. Beyond a 60% WWR, there is no appreciable difference in daylighting quality with higher WWR.
6. For typical MURB floor-to-ceiling heights, there is no appreciable daylight penetration beyond a depth of 2 metres from the face of the exterior glazing into the dwelling. After 0.5m DA at 300 lux is no longer possible and lower target illuminance thresholds need to be evaluated considering specific room uses and needs
7. The aspect ratio of the suite (width to depth) and the arrangement of principal rooms and interior walls are equally critical factors influencing daylighting quality.
8. The metrics and indicators for daylighting in MURBs need to be standardized to meaningfully predict outcomes such as occupant wellbeing.

This paper is derived from an ongoing research project into better daylighting design for multi-unit residential buildings. Numerous challenges were encountered in using simulation software and adapting common daylighting metrics and indicators to MURBs.

Future work should consider balconies as they have an important geometric influence on daylighting as they shade units below. Also, balconies are linked to views and access to nature. A follow up study will focus more on orientation, and include studies of N/E, S/E, S/W and N/W orientations. Varying sky conditions relevant to standard methodologies for residential illuminance will also be examined.

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