PERKINS+WILL

Research Journal

2017 / VOL 09.01

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PERKINS+WILL **RESEARCH JOURNAL** 2017 / VOL 09.01

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Acknowledgements: *We would like to extend* **our APPRECIATION** *to everyone who contributed to the research work and articles published within this journal.*

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JOURNAL OVERVIEW

The Perkins+Will Research Journal documents research relating to the architectural and design practice. Architectural design requires immense amounts of information for inspiration, creation, and construction of buildings. Considerations for sustainability, innovation, and high-performance designs lead the way of our practice where research is an integral part of the process. The themes included in this journal illustrate types of projects and inquiries undertaken at Perkins+Will and capture research questions, methodologies, and results of these inquiries.

The Perkins+Will Research Journal is a peer-reviewed research journal dedicated to documenting and presenting practice-related research associated with buildings and their environments. The unique aspect of this journal is that it conveys practice-oriented research aimed at supporting our teams.

This is the seventeenth issue of the Perkins+Will Research Journal. We welcome contributions for future issues.

RESEARCH AT PERKINS+WILL

Research is systematic investigation into existing knowledge in order to discover or revise facts or add to knowledge about a certain topic. In architectural design, we take an existing condition and improve upon it with our design solutions. During the design process we constantly gather and evaluate information from different sources and apply it to solve our design problems, thus creating new information and knowledge.

An important part of the research process is documentation and communication. We are sharing combined efforts and findings of Perkins+Will researchers and project teams within this journal.

Perkins+Will engages in the following areas of research:

- Market-sector related research
- Sustainable design
- Strategies for operational efficiency
- Advanced building technology and performance
- Design process benchmarking
- Carbon and energy analysis
- Organizational behavior

EDITORIAL

This issue of Perkins+Will Research Journal includes four articles that focus on different research topics, such as building envelope-integrated thermal actuators, wellness approach for designing healthcare environments, design of an emergency room that supports behavioral health, and methods for achieving Passive House Standard in school buildings.

"Natural Harmony: Designing with Thermal Actuators" discusses prototype building and an experimental study of a novel building envelope-integrated system that responds to environmental conditions. The system includes thermal-actuating pistons, and the prototype was constructed using laser cutting, 3D printing and metalworking. Its performance was evaluated using sensors, where loggers were used to monitor temperature in a skylight application. The results indicate that this system shows a promise for controlling ventilation, daylight and heat gain in a semi-passive approach.

"Patient-Population Based Design: A Wellness Approach for Designing Healthcare Environments" considers how wellness can be one of the driving considerations in the design of healthcare facilities. The article provides a literature review, and outlines a needs assessment matrix as a practical tool for design professionals. The matrix has been applied in a case study, and the article discusses redesign of a clinic for a specific patient population.

"A protectED Room: Design of Responsive and Acuity Adaptable Behavioral Health Room for Emergency Departments" presents methods for designing emergency department rooms that support behavioral health services. The research included a qualitative study, literature review, historical review of behavioral health facilities, observational study of existing facilities, and design of a new model for emergency rooms that addresses patients' medical and behavioral health needs.

"Comparing and Adapting Pitt River School to the Passive House Standard" discusses a recently built school building as a case study. The article analyzes target metrics associated with the Passive House requirements, characteristics of this school project, and design changes that would need to be implemented to achieve the standard. Specifically, overlap of BIM and Passive House energy modeling process are presented, as well as the impact of thermal bridging and building envelope components.

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01.
NATURAL HARMONY:
Designing with Thermal Actuators

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ABSTRACT
Building in harmony with nature allows for the comfort and well-being of inhabitants of a home, building, neighborhood, or even a district. In this research, we studied the ways in which harmony is achieved in nature, and the ways in which it is achieved in existing building science. We propose a novel bridge between active and passive mechanical systems, a "semi-passive approach", which requires no external regulation or monitoring, and responds to changing environment conditions. This type of system trades the intelligence and adaptability of traditional mechanical systems for resilience, autonomy, economy, and simplicity. In contrast to simply passive systems, the "semi-passive" approach offers some level of flexibility to changing conditions. To study this concept, we designed a novel intervention that uses thermal actuators that respond to changes in environmental conditions to extend and retract a piston, and collected data regarding its performance in the Vancouver studio of Perkins+Will. The apparatus acts to allow control of ventilation, daylight, and heat gain. While our particular climactic zone may not find year-round applications for such an approach, there are applications for the holistic toolkit of Climate Adaptive Building Skins (CABS).

KEYWORDS: biomimicry, envelope, energy, comfort, passive systems

1.0 INTRODUCTION

An important role that architecture fulfills is to find solutions to accommodate basic human needs while creating deeper meaning and delight. Solutions that work seamlessly with the environment have an elegance that is effortless. Natural systems have this elegance – a sunflower tracks the path of the sun across the sky, animals regulate their temperature through evapotranspiration, exploiting phase change of water to conduct heat energy. In pursuit of this type of elegance, we ask how we can address fundamental needs that we need to recognize as architects, while finding a natural harmony with the basic characteristics that we face. Such solutions require minimal inputs, do not consume energy made through complex means, and are enduring. Primitive buildings, prior to the development of elaborate mechanical systems, attempted to work within these constraints. As buildings became more elaborate, and as technologies developed to enable greater control over comfort, distance emerged between natural harmonious approaches, and the mechanically enabled substitutes.

Our study focused on facade-integrated thermal actuators, aiming to explore how semi-passive technologies can be used to regulate and respond to environmental conditions with minimal energy usage and controls. We designed and constructed a prototype with thermal-actuating pistons, using laser cutting, 3D printing and metalworking. The prototype was evaluated using sensors. The next sections provide background, as well as detailed description of the research methods, collected data and results.

2.0 HOMEOSTATIC MECHANISMS

Animal physiology throughout the phylogenetic tree is filled with mechanisms that exist to keep order within anatomical systems.

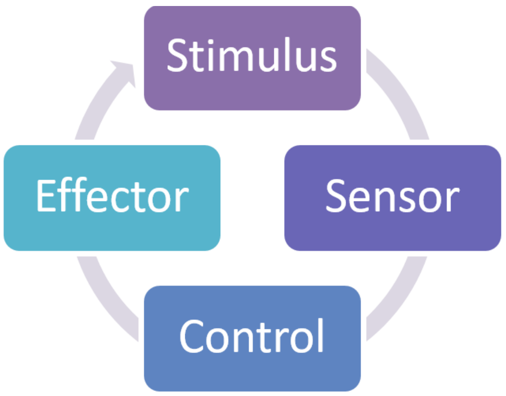
One of the most well-known examples of homeostasis is warm-blooded animals' ability to thermoregulate their body temperature. Figure 1 shows an example of this process, particularly focusing on humans. The outcome is not solely based on a physical sensation, as a psychological response is triggered as well. That is, the individual that is in an uncomfortable temperature will try to seek shade or warmth, depending on the situation.

One key thing to note with regard to homeostasis in our own case is that it is usually maintained through the hypothalamus, which processes sensory signals and triggers an appropriate physiological response. This is not unlike the thermostat in a building, which responds by turning on the appropriate boiler or chiller based on a pre-set temperature. Thus, the system has intelligence added to it with an external regulator.

In the case of our study, we argue that removing the regulator adds a layer of resilience to a system by reducing the complexity of it. However, this is at the expense of intelligence, and requires great foresight.

The dwelling unit, building, neighbourhood, or the district can be looked at as units in which homeostasis in a variety of factors can be achieved and is desirable for the well-being of its occupants. If we use the cell membrane or skin as an analogous condition in the natural world, these building blocks of architecture present an opportunity to maintain their own homeostatic balance through this interface. To scale the down the scope of this article, we will look at the homeostatic conditions of buildings alone, and this leads us to Climate Adaptive Building Systems.

As Dewidar et al. explain, a building's envelope is "a complex membrane capable of energy, material and energy exchange"[1]. It is part of a building's metabolism, and contributes to the well-being of its occupants.



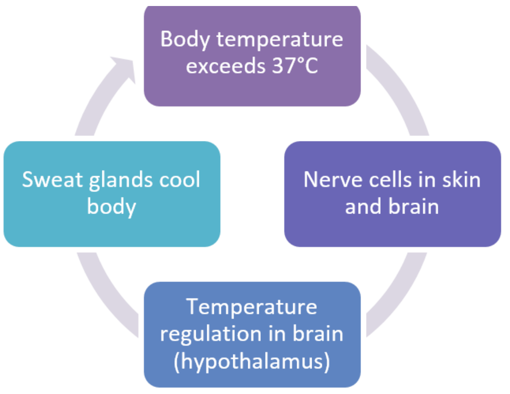


Figure 1: A general mechanism for homeostatic response on left. On the right, a basic model of thermoregulation processes in humans.

3.0 CLIMATE ADAPTIVE BUILDING SKINS (CABS)

Climate-Adaptive Building Skins (CABS) have the potential to reduce energy loss and gain, given the proper design response to climactic conditions and user requirements. There is no silver bullet to this process, and instead what designers need are tools to respond to unique requirements of the conditions that they face, including social, material, economic and environmental constraints. Biomimicry, as in many architectural problems, poses an opportunity to provide solutions for a given region[2].

Adaption of a building skin can respond to the following environmental considerations:

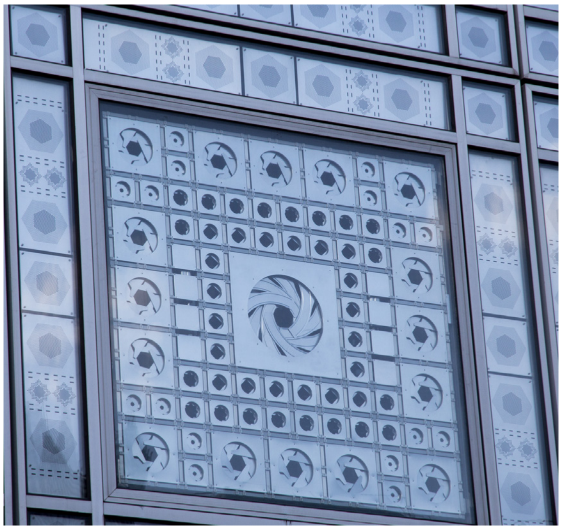
1. Heat transfer
2. Visual light transmission
3. Ventilation
4. Water retention/storage/evaporation
5. Electrical power generation.

A prime example of an active CABS is Jean Nouvel's Institut du Monde Arabe, which has a system of mechanical irises that respond to daylight by either opening or closing. A vast array of these identical units creates unique patterns as clouds pass across the sky, providing both visual interest and improved performance.

To criticize this precedent, the electromechanical action and complexity of the system has apparently resulted in numerous malfunctioning units on the facade[3]. Due to its complexity, a system such as this has not only high start-up costs, but also maintenance costs. From a life cycle assessment perspective, this causes issues that conflict with the sustainable and economic benefits of having an adaptable building skin. The ideas required to achieve a CABS are thus not ones necessarily out of complexity, the ingenuity almost comes from the simplicity of the approach.

Perhaps the best example of a CABS is a manual blind, which can control heat gain and visual glare through human intervention. The effect is the same as that of the aforementioned precedents, but the intelligence is lost (though at an exchange of greater control and manual overrides). In contrast, the passive fixed screens which are increasingly-popular offer a "one-size fits all" solution, which sacrifices intelligence and operability in exchange for robustness, simplicity, and consistency in environmental control.

Actuation of a facade to environment conditions does not need to be expensive, nor complicated[4]. Simplifying the process of actuation has the potential for less maintenance requirements, less opportunity for error, and removing the need for external regulation of the system. This is striking the right balance between "robustness" and "flexibility", a realm of research in which there is still much work to be done[5].



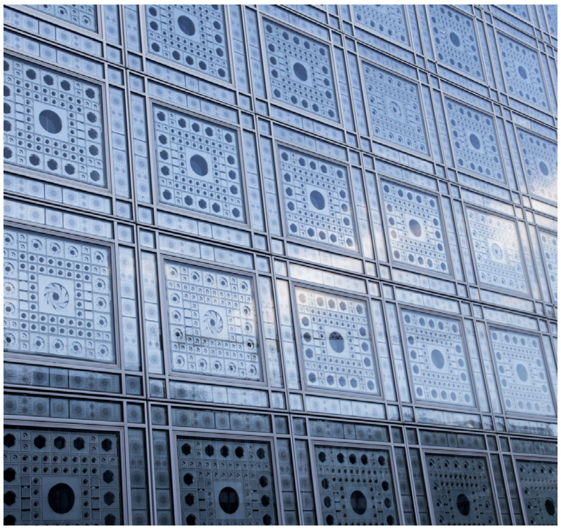


Figure 2: Jean Nouvel's Institut du Monde Arabe's mechanical iris system. Through an array of similar systems, a dynamic change happens as environmental conditions change.

4.0 THERMAL ACTUATORS

A thermal actuator is a device that translates temperature-related changes in matter into movement. Typically, there are two types of thermal actuators: gas-based and wax-based. In each case a medium (either the gas or wax) is contained in a housing, coupled with a single outlet where the expansion or contraction may be relieved. Heat gain causes the medium to expand, which is then translated into the linear motion of a piston. This elegant and simple mechanism is utilized in an array of applications related to thermal control, such as automotive thermostats, mixing valves, and controlling vents on greenhouses. Moreover, where reliability is prized such as in aerospace, thermal actuators are used to control valves associated with fuel and hydraulic systems, or in common machines like automatic dishwashers to operate detergent dispensers. Wax-based thermal actuators are also commonly known as wax motors, but are effectively a motor and thermostat in one.

A benefit of gas-based thermal actuators are often capable of being adjusted or "tuned" to a specific temperature range by mechanically increasing or decreasing the volume of the housing. Wax-based thermal actuators are not generally adjustable in the same way, instead, the chemical characteristics of the wax itself can be customized to transition at set temperature thresholds.

Depending on the application, thermal actuators may be activated by the thermal conditions of the atmosphere, of a medium the actuator may be in contact with, or through the introduction or removal of heat via electrical resistance. In the simplest application, relying on atmospheric conditions alone to initiate activity may allow a system to be resilient, autonomous, and reliable – but at the expense of intelligence and adaptability. To minimize inputs in the applications envisaged in this study, the only input we foresee is atmospheric heat imposed by the sun. In the purest form, the system uses the actuators in a "semi-passive approach", where parts still move in response to environmental conditions, but without the need for external regulation. Figure 3 shows an example of a thermal actuator used in this study, while Figure 4 shows the basic operating principle in a window application.

Figure 3: A thermal actuator, used in this study. The body on the left contains wax or oil that expands when exposed to heat. The piston on the right creates a "stroke", pushing out due to this expansion.

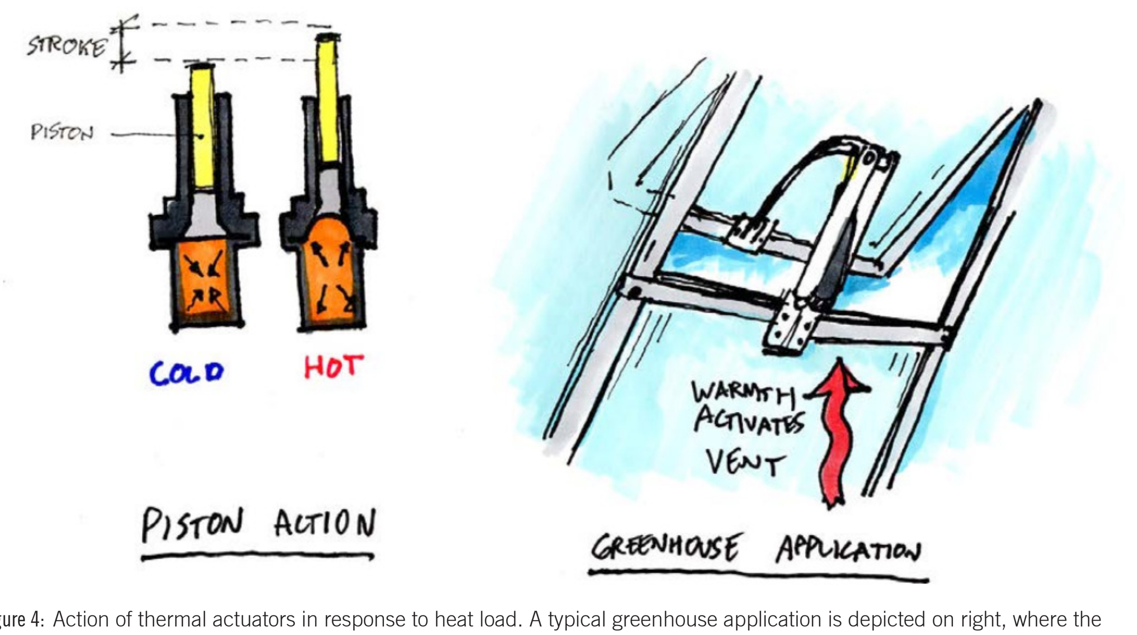


Figure 4: Action of thermal actuators in response to heat load. A typical greenhouse application is depicted on right, where the load of the window causes the actuator to retract as it cools.

In order to rely on the simplicity which this approach implies, the desired action must have a simple correlation with temperature increase or decrease. The characteristics of the actuator must therefore be matched with the conditions targeted. The cylinders as tested in this project have an expected service life of at least 10 years[6].

5.0 ARCHITECTURAL OPPORTUNITIES

Passive architectural features have advantages over complex electromechanical systems. Less usage of energy, ease of use, and fewer moving parts (which results in a more resilient system) characterize passive responses. While overhangs, thermal separation, and improved glazing performance are all indicative of passive features, motion in architecture is largely controlled by active electromechanical systems. "Semi-passive" thermomechanical systems thus provide an opportunity for improvements in reliability and energy usage, as well as responding in harmony to natural forces without the need for complex computation or motors[7]. Figure 5 shows potential options for application of thermal actuators.

Passive solar shading can be achieved by properly orienting the building in response to solar exposure, and by using exterior shading devices. The appropriate application of these methods depends on the climate, region, building site and type, social expectations and economic impacts. Figure 6 shows external shading for the NMAAHC building, located in Washington, DC. Figure 7 shows building envelope design for a transit station, where transparency of the shading screen corresponds to the orientation of the panels.

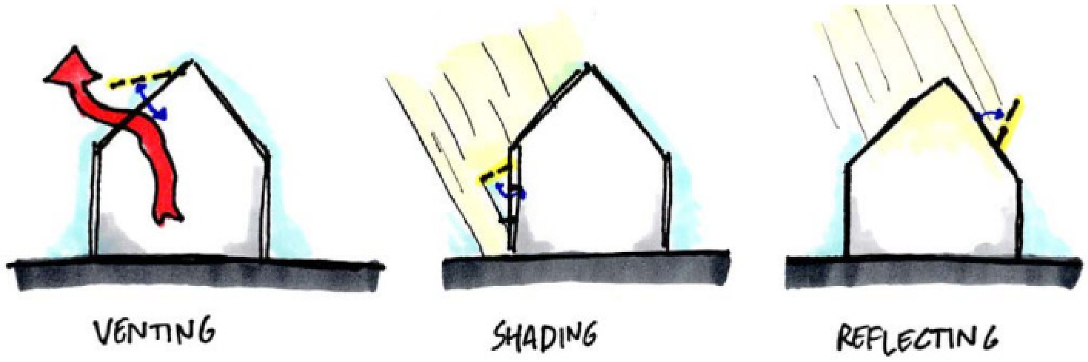


Figure 5: Potential options for applications of thermal actuators.

Figure 6: External shading through a screen defines the form of the NMAAHC. This application balances views and solar performance.

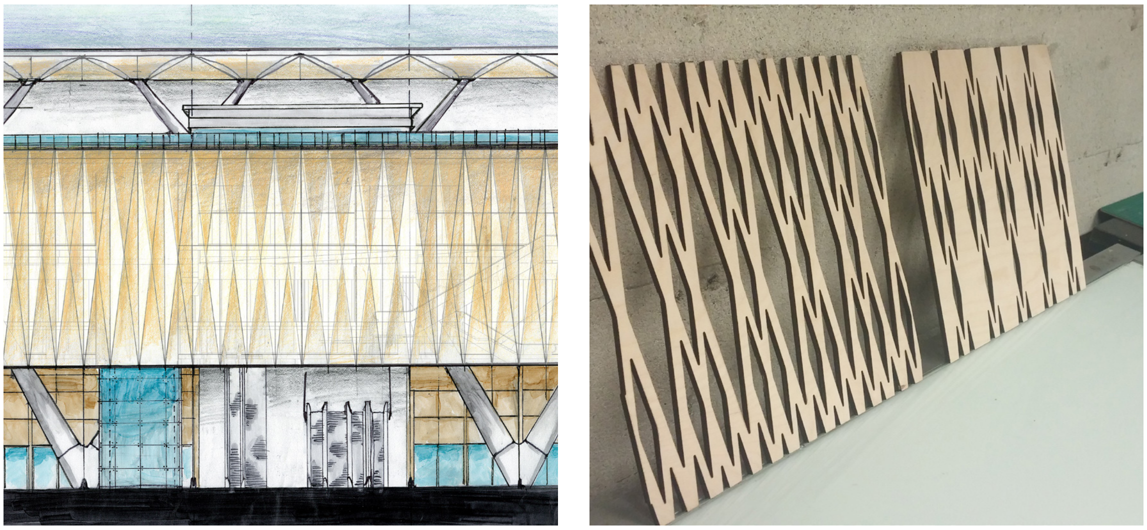
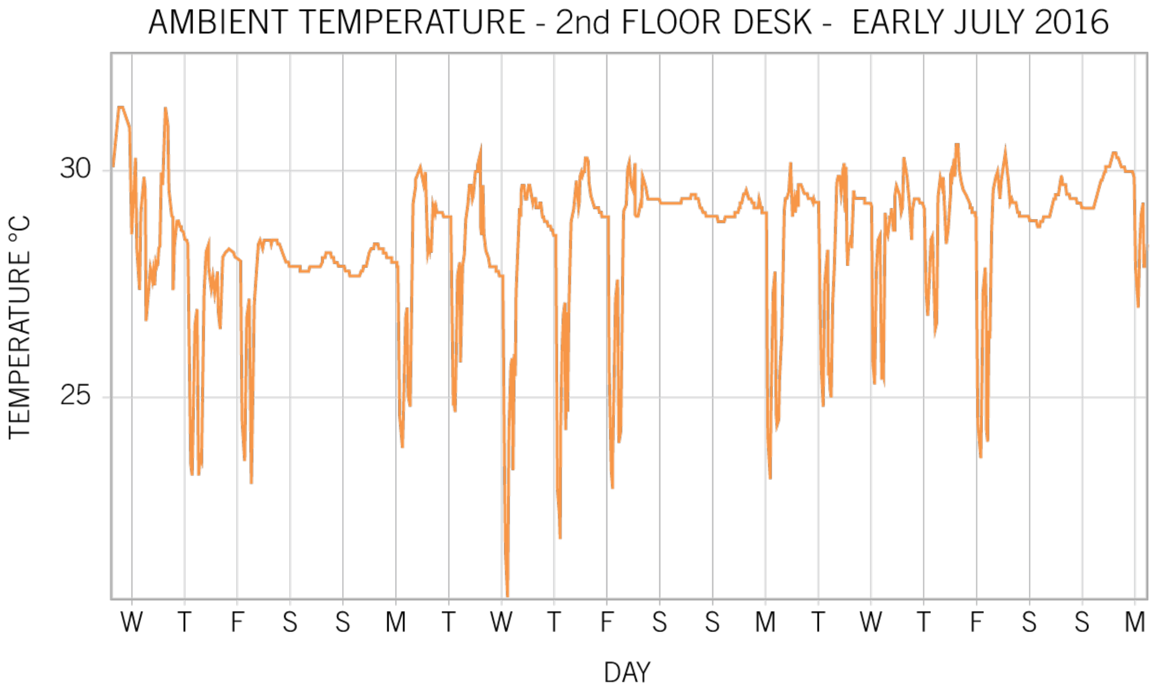


Figure 7: The screen on this transit station proposal floats above the plaza below. Depending on the solar orientation of the panels, the screen is modified in transparency (right). A semi-passive variant of this facade could adapt to changing conditions.

A previous study has focused on the architectural application of thermal actuators for facades at length, identifying several important caveats when deploying this technology to the built environment for climate control[8]. Most important is the difference between surface temperature of the actuator in direct sunlight, and ambient temperature. Actuators are often painted black to absorb heat from direct sunlight, but this impacts how they are "tuned" to their environment. To work around this constraint, miniature greenhouse enclosures were constructed for the actuators that stabilized solar gain. The second major innovation in that research was the use of a self-latching mechanism that holds the actuator. The result of the latch is an actuator that can remain open at a consistent extension for a longer period, versus responding to temperature fluctuations in a smooth gradient[8].

6.0 DATA

An assessment of potential interventions was completed using a portable temperature logger. By taking linear records of temperature over time, the location where actuators could be installed to affect internal comfort was inferred to be in a skylight frame over the main atrium of Perkins+Will's Vancouver office. This data also allowed us to customize our selection of actuators by tuning the threshold and speed at which they activated in response to heat gain. Figure 8 shows ambient temperature collected over time for two locations, while Figure 9 shows surface temperature for interior side of the roof. Figure 10 shows temperature range and response profile for the thermal actuator used in this research.



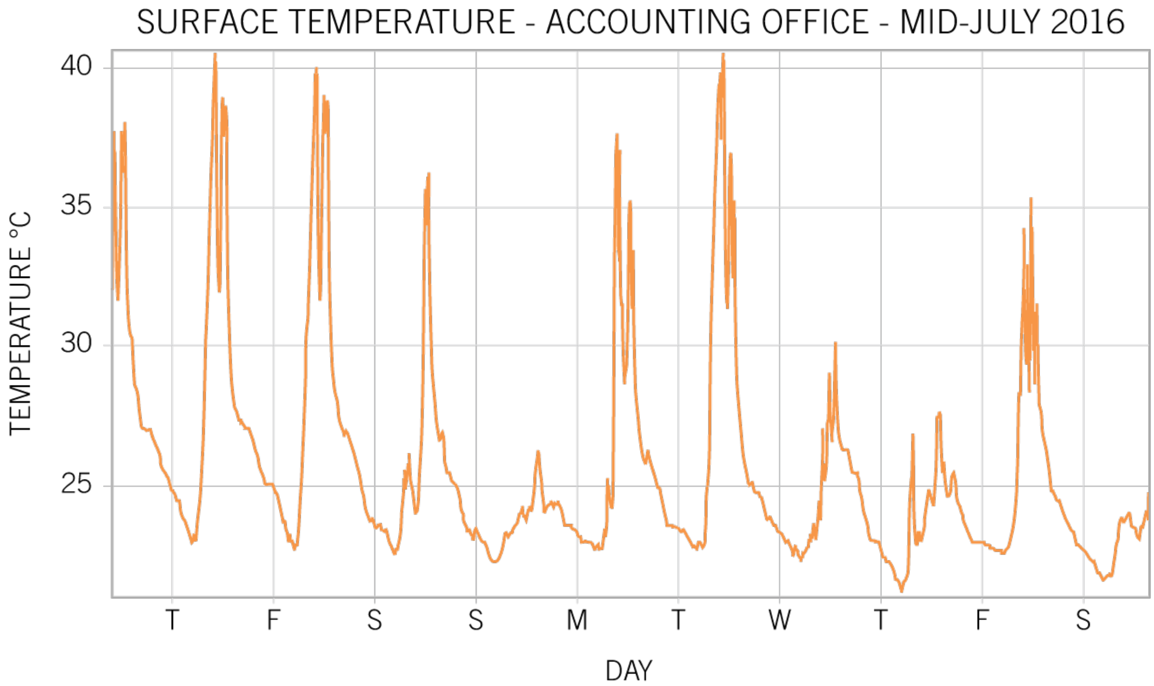


Figure 8: Collected temperature data over time from a desk and accounting office in the Vancouver studio of Perkins+Will. The troughs during the week are the building exhaust flushes, which influence only ambient temperature and not areas exposed to direct sunlight.

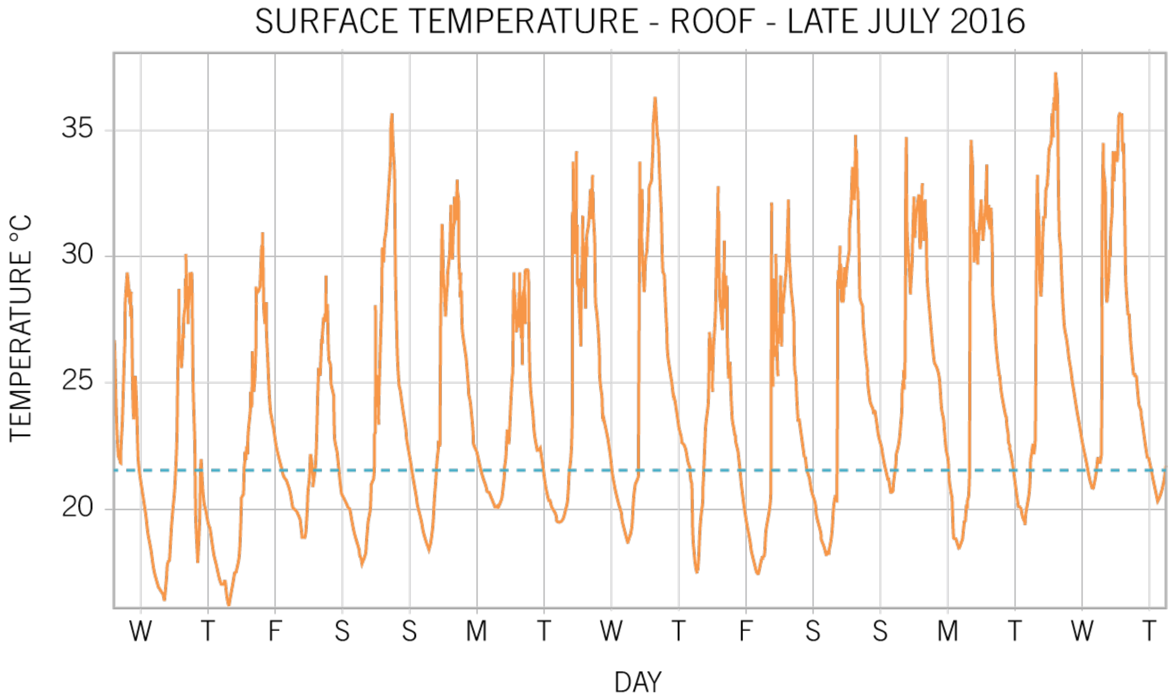


Figure 9: Surface temperature data from the roof of the Vancouver studio of Perkins+Will. The area above the line demonstrates where the actuator profiled below would be mostly closed.

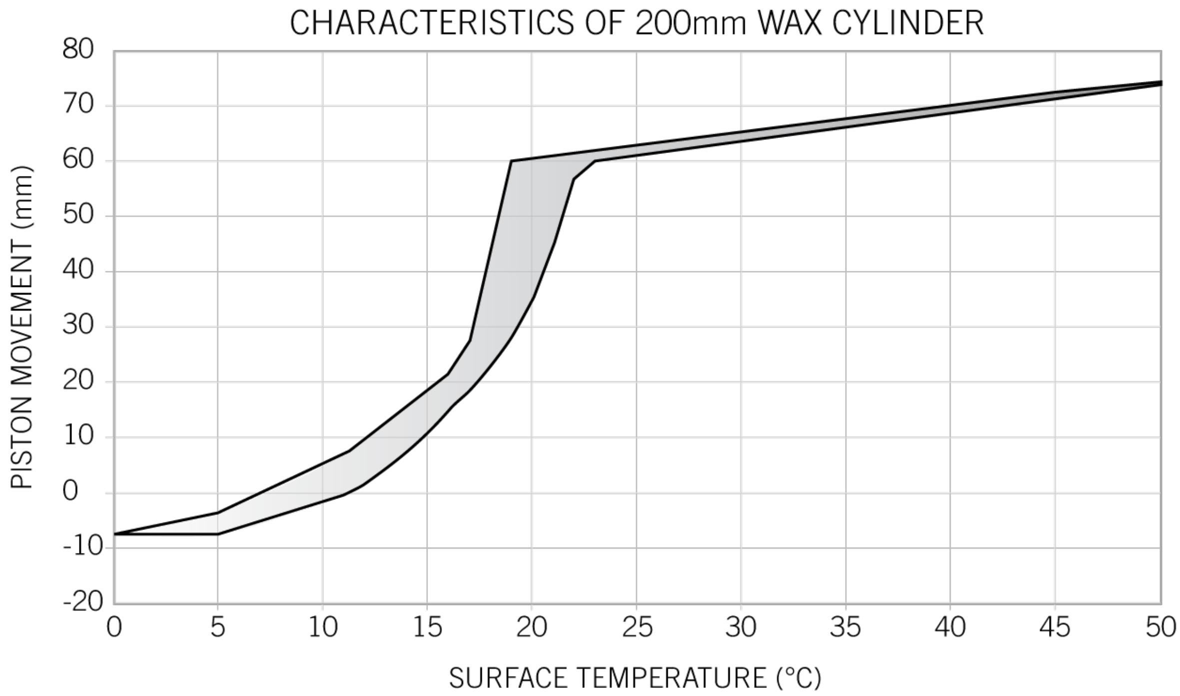


Figure 10: A sample response profile for a thermal actuator given in a temperature range. The response can vary, and is represented by an area (Adapted from E20D profile)[6].

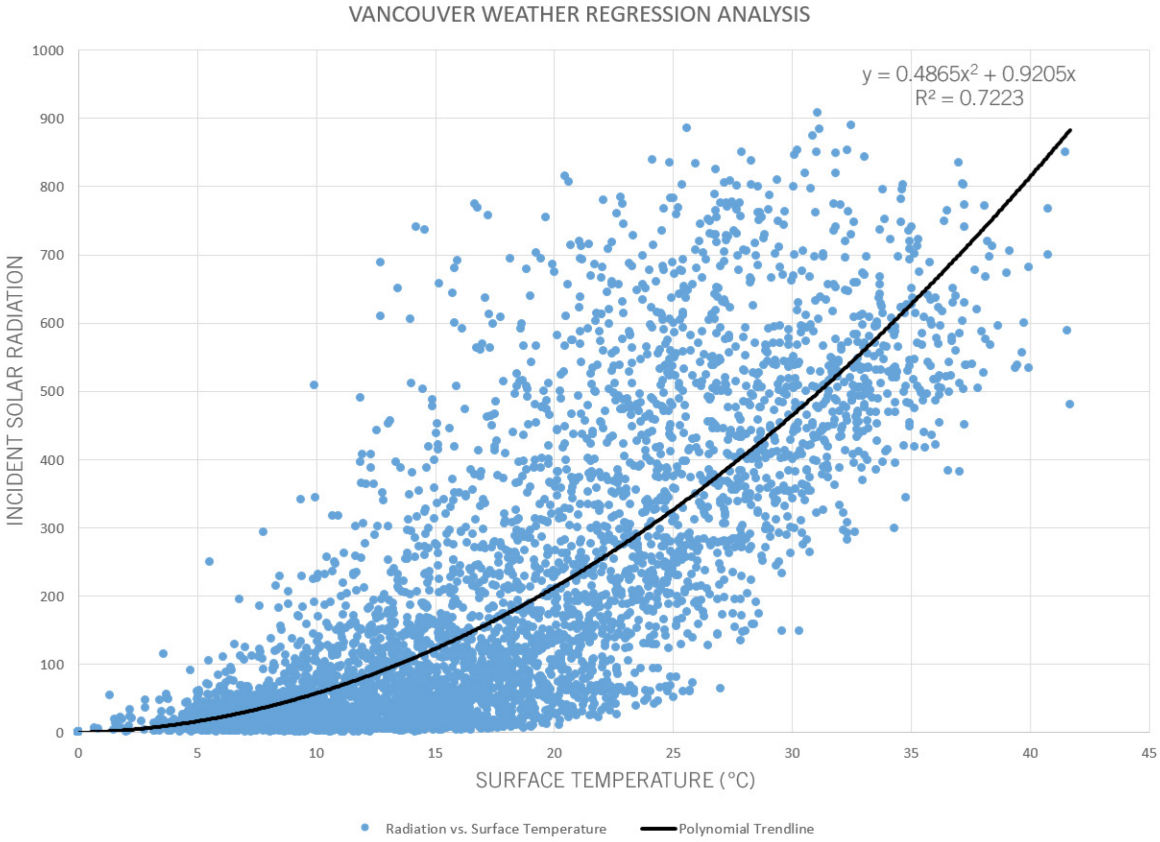


Figure 11: Coefficient of determination between incident solar radiation and surface temperature for Vancouver climate data.

An energy model study was conducted to understand how to properly utilize thermal actuation technology. Using Vancouver climate data, the model demonstrated a polynomial coefficient of determination (R^2) or 0.7223 between incident solar radiation and surface temperature, as seen in Figure 11.

This relationship implies that the surface temperature increases as solar radiation increases. An actuator that expands when temperature increases could reliably assist in blocking solar gain, if the mechanism itself impedes solar access.

Thus, the proposed apparatus was designed with the intent of shielding an opening as temperature increases, with the intent of improving thermal comfort using an autonomous semi-passive system.

7.0 PROTOTYPE CONSTRUCTION

The prototype as studied to test the principles of thermal actuation uses three layers of screens to respond to heat. One layer is fixed, and the other two layers respond to ambient temperature using two different degrees of actuation and piston movement. The result is a screen that is completely open when below approximately 8 degrees, and completely closed when above 20 degrees using the response curve in Figure 10.

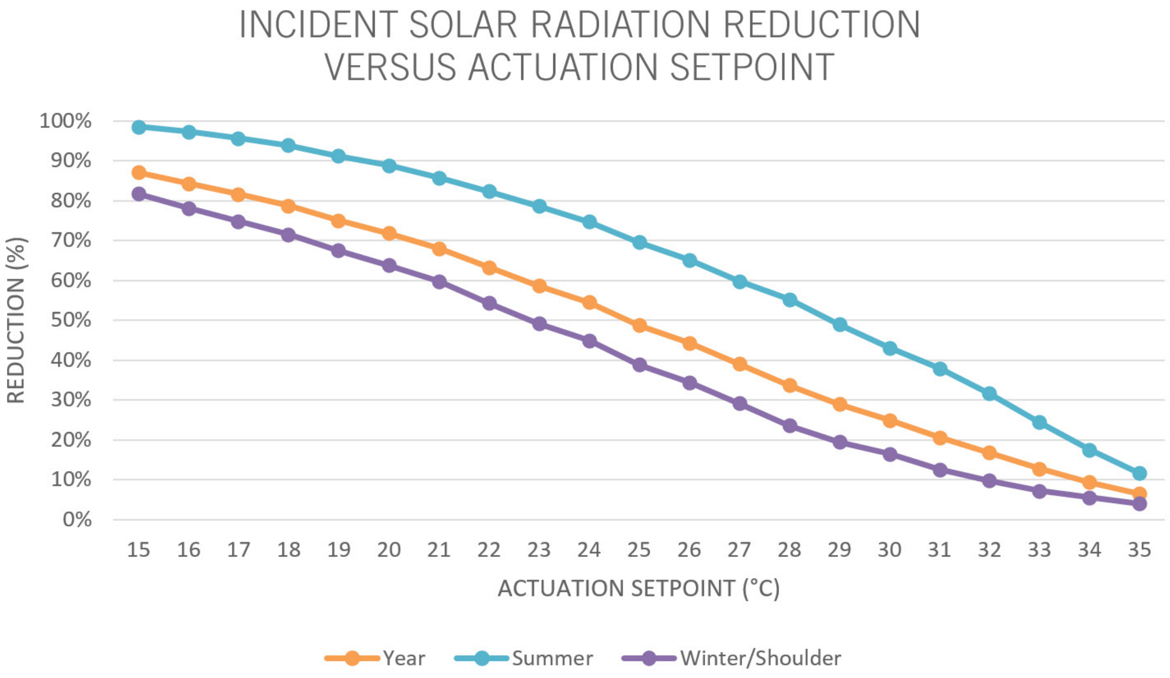
Positioning the prototype horizontally and in direct sunlight carries with it some unintended consequences. As previously mentioned, the actuators were exposed to direct sunlight, and were thus not responding to the ambient temperature. The result was that it closed quicker than anticipated. Tuning of the actuators is key to any environment and orientation, and for this reason, expanding the installation to a permanent and generalizable building component may benefit from using adjustable gas cylinder as opposed to our set wax cylinders.

Figure 12: The completed prototype placed in position on the test site. Bottom Left: Temperature above 20°C (59°F). The ambient air temperature closes the shutter and limits solar gain. Unfortunately, Vancouver has not had a sunny day in over two weeks at this point. Bottom right: Apparatus installed, visible from below. Temperature below 15°C (59°F).

8.0 POST-CONSTRUCTION ANALYSIS

The installation functioned as expected, however, in the temperate climactic region of Vancouver the technology only applies at certain times of the year. In regions closer to the equator, the range of use becomes more of a year-round consideration, and thus a greater return on investment. As expected, the ease with which thermal actuation is integrated into a basic shading strategy and the reliability of the system could see this potentially applied to building facades with relative success.

A simple model of the actuation strategy is reflected in comparing the potential reduction in incident solar radiation to a space using Vancouver's weather data, as shown in Figure 13. Its reveals that our model will be partially active year-round. Tuning the actuation to the climate is of the utmost importance, and designers need to evaluate if a sacrifice of radiation gain is acceptable during the winter. In northern climates, this may not be the case.



		ACTUATION TEMPERATURE (°C)																				
		15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35
INCIDENT SOLAR REDUCTION	Year	87%	84%	82%	79%	75%	72%	68%	63%	59%	55%	49%	44%	39%	34%	29%	25%	21%	17%	13%	9%	6%
	Summer	99%	97%	96%	94%	91%	89%	86%	82%	79%	75%	70%	65%	60%	55%	49%	43%	38%	32%	24%	18%	12%
	Winter/ Shoulder	82%	78%	75%	72%	68%	64%	60%	54%	49%	45%	39%	34%	29%	24%	19%	16%	13%	10%	7%	6%	4%

Figure 13: Energy model results illustrating the reduction in incident solar radiation (Y axis) versus the theoretical set-point at which the actuator triggers (X axis), using Vancouver's weather data assuming a south orientation.

Figure 14: A prototype for a manually-actuated solar cell facade[3].

These results indicated several important considerations for this particular apparatus and technology:

1. A facade orientation that is more likely to receive direct sunlight would allow for greater temperature spikes and more ability to “tune” the actuators to their particular siting.
2. The apparatus would be appropriate for climactic regions with more consistent temperature swings.
3. Passive House design methods, which eponymously focus on systems that are passive, such as shading and envelope improvements, could benefit from this “semi-passive” approach. Instead of fixed overhangs which continually block solar gain, there is a potential application for deployable awnings that do not block out the much needed light during winter months in northern climates.
4. There is also great potential for expression and articulation of the actuation process. It would be an interesting experiment to combine collapsible membranes with the automatic actuation technology, as seen in Figure 14. Theoretically, the expansion of the actuator could be used to deploy solar panel collectors during the day and retract them at night. Tuning of the actuators is key, and so climates that are much more consistent (such as equatorial climates) would be better applications for this approach.

9.0 CONCLUSION

This study was an endeavor to think differently about our energy consumption and use existing technologies in a new way. Thermal actuators offer the potential for buildings to operate in tune with nature’s cycles, in a way that requires less maintenance, parts, and monitoring of activity. The proper utilization of these components implies an understanding of the local climate and its variations, as well as the ability to model the response and tune it on site. In a theoretical sense, being able to balance all the variables would result in improved energy performance, but tradeoffs need to be balanced against occupant comfort, security, and daylighting.

The prototype confirmed this proposal by responding in the expected way, although there is much room for the aforementioned tuning. Being only one panel, the opportunities and gains obtained by operating at scale are unrealized. The current architectural exploration in screens could have their efficiency bolstered by responding to thermal conditions. During darker, colder, days the screen could be more permeable, allowing for a clearer view out of the building. The key is intelligence and planning for peak demand. Computational modelling of daylight can provide for the resources needed to understand where thermal actuation technology would be an appropriate response for a particular CABS.
Once the ability to properly model expected thermal conditions is achieved, and actuators are able to be properly tuned and controlled, it is viable that this type of system could see permanent physical installations in the near future.

Acknowledgements

We would like to thank Cheney Chen of the Perkins+Will Energy Lab for his energy model of the actuator and its theoretical performance in Vancouver's climate.

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02.
PATIENT-POPULATION BASED DESIGN:
A Wellness Approach for Designing Healthcare Environments

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ABSTRACT
This is a practice-based research investigation, not a scientific enquiry, intended to consider how wellness can be first and foremost in the design of our healthcare environments. In this investigation, designing with wellness means going beyond hospitality design meant to soften institutional care, aiming instead on designs that acknowledge illness with the intent of uncovering the support needed to maximize well-being.

The result of this investigation is a process and a tool that acknowledges health as a fluctuating continuum between wellness and illness, and as such, what an individual may need to maintain wellness anywhere on this spectrum.

The process is referred to as Patient-Population Based Design, and the tool is a practical application known as a "needs assessment" matrix. This article highlights how the process and tool resulted in a re-designed clinic floor plan for a specific patient population, thus increasing their chance of independence from their disease.

KEYWORDS: health, wellness, needs assessment, clinical diagnosis, clinical presentation, competence-press model, cognitive maps, neuro-psych continuum, patient-population based design

1.0 INTRODUCTION
The design of modern healthcare facilities is dominated by code and equipment criteria, where codes are categorized by medical intervention, and equipment classified by diagnostic or treatment capability; consequently, our healthcare facilities focus on illness.

> *Can wellness flourish when the built environment begins with an illness perspective? Can we craft healthcare facilities that signal wellness, while also meeting the requirements to diagnose and treat disease?*

It is important that the design of our healthcare environments begin with these questions in mind in order to address how we can promote health, beyond suppressing disease, by designing from a perspective of wellness rather than illness.

1.1 Health Continuum
This is a practice-based research investigation, not a scientific enquiry, intended to consider how wellness can be first and foremost in the design of our healthcare environments. In this investigation, designing with wellness means going beyond hospitality design meant to soften institutional care, aiming instead on designs that acknowledge illness with the intent of uncovering the support needed to maximize well-being. To achieve this, two questions are pertinent. Where on the continuum does health end and disease begin? And, how can our environment leverage what little health a diseased individual may have?

The result of this investigation is a process and a tool that acknowledges health as a fluctuating continuum between wellness and illness, and as such, what an individual may need to maintain wellness anywhere on this spectrum.

1.2 Patient-Centric Process

The context of health-as-a-continuum is patient-centric rather than disease-centric; with the focus on the patient, we are able to see what the patient needs from the environment, as opposed to what the disease demands of the environment. In other words, the focus is on spatial impacts or environmental supports needed to maximize wellness for a patient with a particular ailment, as opposed to the environment supporting function for the treatment or diagnostic modalities for that disease.

This patient-centric process is referred to as Patient-Population Based Design, and the tool is a practical application known as a "needs assessment" matrix. The four-step process focuses on the particular patient illness being cared for in order to determine the fundamental needs that foster wellness for that patient population. The tool outlines each step in the process by creating a matrix of four fields: clinical diagnosis, clinical presentation, environmental goals, and environmental features. Completing this needs-assessment matrix helps the designer translate what wellness would look like for a specific patient population; the end objective is an environment that fosters patient independence from their disease or aliment.

2.0 HYPOTHESIS

The line of inquiry for this research began with the question: where on the continuum does health end and disease begin? The World Health Organization defines health as the complete physical, mental, and social well-being, not merely the absence of disease[1]. Therefore, we can hypothesize that disease "begins" when any one of the physical-mental-social triad is "incomplete" or is lessened in any way.

This theory presents an opportunity to seek what in the environment "makes complete" or supports the physical-mental-social triad. The assumption is that seeking and finding these supportive elements will guide designers toward creating spaces that foster wellness. Furthermore, note we must first understand how the disease presents itself in the environment, to then know how the environment might counter the disease impacts in order to best support patients with a particular ailment.

2.1 Methodology

The approach for researching this issue began with the question: how can our environment leverage what little health a diseased individual may have? A disease-specific example might be: how can a neurology clinic serving M.S. patients support individuals who may be comfortable only walking short distances? The answer to this question can be discovered in a matrix outlining the "needs" that must be addressed for this specific disease.

The methodology used in this research begins with a needs-assessment matrix, detailing the four fields of: clinical diagnosis, clinical presentation, environmental goals, and environmental features, which are then cross referenced with the specific patient illness being served by the institution or healthcare provider. A sample needs-assessment matrix is shown in Table 1 with the four fields noted on the left and the patient populations across the top; the three populations exhibited here, dementia, psychosocial, and complex medical, are three of six distinct patient populations from a specific long-term care institution serving residents in an inpatient setting.

Table 1: Sample needs-assessment matrix.

	Dementia	Psychological	Complex Medical
Clinical Diagnosis	• Alzheimer's Disease • Multi-Infarc Dementia (MID) • Short-term memory impairment • Judgment impairment due to perception problems (such as left/right neglect) • Impulse control due to an unmet need or anxiety (such as wandering)	• Spinal cord injury • Multiple sclerosis • Substance abuse • Delusional presentations • Depression • Judgment impairment or impulse control due to behavioral problems (such as acting out)	• Mild retardation • Spinal cord injury • Cerebral vascular accident (CVA) • Continuous Dialysis (CAPD) • Diabetes • Wound care • Huntington's
Clinical Presentation	Unable to manage self-care at home or in community settings due to progressive dementia or non-progressive cognitive impairments. Indefinite length of stay	Complex psychosocial problems often due to a medical diagnosis. Rehabilitation is the ultimate goal for this population. Goals of treatment include lessening of symptom severity, improvement in ability to relate to others, improvement in ability to perform activities of daily living, and reduction of specific target behaviors that impact the resident's ability to interact safely and socially in another environment. Varied length of stay	Multiple medical problems with concomitant psychosocial issues. Most residents are alert, oriented and able to communicate. However, despite being cognitively intact, many have significant social or behavioral issues. Unlike the Psychosocial population whose therapeutic goal is rehabilitation back into the community, the Complex Medical residents' behavioral goal is to restore social interactions for maximum independence in a group setting Indefinite length of stay
Environmental Goals	Dependent upon environment for a therapeutic setting with the goal of safety and security.	Like Dementia residents, Psychosocial residents are also dependent upon their environment as a therapeutic setting, but the goal is clarification of the environment as opposed to comfort and predictability of the environment.	Due to the psychosocial component of Complex residents' care, their environmental needs are similar to the Psychosocial residents' needs with an additional requirement to accommodate medical care.
Environmental Features	Cueing opportunities (such as which room is their bedroom, where is the toilet room, etc.) provide important visual "clues". • Personalization of rooms (such as "memory cabinets", picture rails, etc.) helps reclaim a sense of self-identity, maximizes attention span, and reinforces directional cueing. • Stimulation control (such as private bedrooms, small-group dining rooms, etc.) help minimize intake overload. • Stimulation outlets (such as indoor/outdoor wandering paths, come-and-go activities, etc.) allow release of anxiety and agitation. • Security issues (such as protection from aggressive residents, non-axial entries and exits, etc.) increases feelings of security and improves emotional well-being. • Creative resolution of paradoxes (such as need for stimulation but problems of over stimulation, need for predictability versus value of prompting curiosity, etc.). • High spatial/storage needs to accommodate bulky assistive devices unique to the declining dementia resident (such as "ultimate walkers".)	Orientation to place (such as wayfinding) helps the resident adjust to the environment. • Personalization of rooms (such as private rooms) helps reclaim a sense of self-identity as well as reduce territorial issues. • Behavior control (such as small-group dining rooms, time-out rooms, etc.) helps modify inappropriate actions. • Behavior outlets (such as access to the outdoors, vigorous activities, etc.) • Range of security issues (such as protecting frail residents from psychosocial residents, observation of the residents for behavior control, etc.) • Rehabilitation opportunities (such as cooking &/or housekeeping, self-medication, group therapy, egalitarian rooms, etc.) • Average spatial/storage needs associated with skilled care residents.	• Orientation to place (such as wayfinding) helps the resident adjust to the environment. • Personalization of rooms (such as private rooms) helps reclaim a sense of self-identity as well as reduce territorial issues. • Behavior control (such as small-group dining rooms, time-out rooms, etc.) helps modify inappropriate actions. • Behavior outlets (such as access to the outdoors, varied activities, etc.) • Range of security issues (such as protecting the frail from psycho-social residents, observation of residents for behavior control, etc.) • High spatial/storage needs to accommodate numerous assistive devices unique to the medicallydependent Complex Medical resident, which are often bulky and high maintenance (such as Vail beds, Broda chairs, PVC toilet frames, power wheelchairs that need re-charging, etc.)

The genesis of the needs-assessment matrix as a tool began with a client's report re-assigning patients to care units based on their clinical diagnosis rather than on a random assignment. This report outlined two fields, clinical diagnosis and clinical presentation, from which the author later added two environmental design fields; from this original report, the four-field matrix was fully developed.

2.2 Application

For clinical validity, applying the tool requires that the clinical diagnosis and clinical presentation fields in the needs-assessment matrix be developed by clinicians specializing in the patient populations being served; the environmental goals and environmental features are then developed by the architectural team through a review of the literature, evidence-based documentation, and anecdotal but established experience.

The matrix has been designed as a flexible tool capable of generating specific results for any patient population; having a tool that can be applied to a variety of settings ensures that a consistent process can be realized. Prior to this process, healthcare environments did not have a standard design process; for example, healthcare design specific to age-based populations (such as pediatrics or senior care) were subconsciously or intuitively modified to be child or elderly "friendly" designs, but the formal, conscious tool proposed here creates a reliable process for determining what will maximize well-being for any patient population.

It is important to note that this process is not prescriptive, which differs from "accessibility" design where high standards are set but unintentionally restrict options (and lessens accessibility) for some patient populations. By accommodating individuals with varying abilities, the needs-assessment tool is inherently flexible, addressing any patient-population need.

The objective of a patient-population based tool that can be generalized to a variety of patients in a variety of settings is to ensure that healthcare environments will be designed to foster health rather than emphasize illness. The overarching process has been labeled as Patient-Population Based Design.

3.0 RESEARCH

Research theories from various classic and current studies have been influential for the concept of Patient-Population Based Design. In particular, the value of a matrix format led to the discovery of counter-intuitive but interrelated features, such as the balance between stress and ease built into the environment. The first use of Patient-Population Based Design was for a long-term care facility in need of a residential (as opposed to institutional) ambiance with a rehabilitation focus, therefore the Competence-Press Model by Lawton and Nahemow helped shape the concept of the need for stress (press) in the environment as a positive challenge contributing to an individual's rehabilitation (competence); remarkably, adaptive behavior and personal satisfaction are the products of a balance between competence and press[2]. Another early study by Carpman et al. provided the classic perspective on the significance of easy wayfinding, in particular: "The close proximity of common destinations, availability of visual clues that provide landmarks (such as windows, plants, artwork, changes in floor covering), easily understood terminology, clear floor and room numbering systems, availability of well-trained staff for giving directions, and the signage system should all work together as an integrated system"[3]. Had this latter study been reviewed in isolation, the value of "un-ease" or stress as noted in the initial study by Lawton would have been missed.

As different healthcare settings and different patient populations emerged as candidates for this research, further readings influenced the concept of Patient-Population Based Design. In addition to the predecessor theories above, two theories were highly informative: Cognitive Maps theory and Sense of Coherence (SOC) by Antonovsky[4]. The concept of cognitive maps originated in the 1940s based on the research of Tolman (1948), Golledge (1998) and others, from which Alan Dilani later applied to healthcare settings[5,6]. Cognitive maps are key to the neurological and psychiatric patient population for this article's case study, and this concept is discussed in detail in the section below.

For the reader's further interest, one of the most challenging patient populations to design for are patients with a psychiatric condition; for this population, Dr. Jan Golembiewski, on the faculty of Built Environment at the University of New South Wales, is developing a wealth of new material that spans both neuroscience and architecture for this demanding patient population[7].

3.1 Case Studies

To date, Patient-Population Based Design has been employed in a range of facilities, as diverse as acute to long-term care. An example in acute care concerns a major medical center serving two million people as the designated trauma center, burn center, and spinal cord injury center. This facility is currently under construction and was designed based on the unique population needs for traumatic brain injury (TBI) and spinal cord injury (SCI) patients; Patient-Population Based Design was used to support the decision to convert all 280 beds to meet the same criteria as the 64-licensed rehab beds for TBI and SCI patients. An example in long-term care concerns a 1,200-bed inpatient facility designed for the unique population needs that spanned acute, skilled, rehab, dementia, and hospice patients. This new facility, with patient rooms customized to meet these specific needs yet flexible enough to meet other patients' needs, has been in operation for four years, and in 2014, more patients were rehabilitated and discharged back into the community for the first time in its 150-year history, where previously they were expected to live the remainder of their life in this institution. This paper details the use of Patient-Population Based Design in an outpatient setting, further reinforcing the validity of this universal process for a wellness-based approach to healthcare design regardless of occupancy type.

The case presented is a newly constructed translational medicine facility, combining research labs with patient clinics dedicated to serving severe neurological and psychiatric diseases. The Centre for Brain Health at the University of British Columbia in Vancouver, is a 135,000-square-foot clinical research facility containing wet and dry labs in addition to patient clinics, all of which are dedicated to serving the full range of neuropsychiatric diseases from Lou Gehrig's disease, Multiple Sclerosis, Parkinson's, and Alzheimer's to resistive Psychosis. Designing environments for the treatment and cure of chronic neurological and psychiatric disorders is one of the greatest challenges in healthcare architecture, made even more so when the driving vision for this institution was to maximize patient research.

The success of Patient-Population Based Design was crucial in this case study because the client's objective was to strive for 100 percent patient participation in clinical research. As a benchmark for this high expectation, patient participation in research is known to range from as low as 2 percent based on a 2007 study of US cancer clinical trials, to as high as 67 percent according to a 2007 study of Canadians volunteering for randomized, controlled trials[8,9]. Notably, even if research funds are unlimited, little research will be done if there are no patients upon which studies can be conducted; therefore, patient participation is critical. Research participation is always a patient dilemma and especially so for the neurological patient, as he or she may feel "untreated" in a controlled study and donating brain tissue post-mortem requires sensitive ethical considerations; clinical trials for cancer patients carry similar risks as there is always a chance a new treatment may be ineffective or worse than their current treatment. For patients of any clinical diagnosis, before they can commit to clinical research they must first have felt cared for—and that means the architectural environment must meet their physical and emotional needs. This is an issue of more than patient comfort—this is about patient trust.

While it may seem obvious that the built environment is important for patients' sense of confidence with their care, little research exists to corroborate how the physical environment may be essential to facilitating patient commitment in research. Carpman et al. highlighted a seemingly unrelated article concerning Boston City Hall that noted visitors' disorientation with wayfinding may surface as generalized hostility toward the organization, alluding to the relationship between environmental discomfort and distrust[3] Lawton and colleagues in a later study found that residential well-being has considerable bearing on psychological well-being, alluding to how an elderly person's sense of comfort in their environment leads to their ease of mind—comfort equals confidence[10].

The Centre for Brain Health case study is ideal for exhibiting the universal potential for Patient-Population Based Design, because the needs of neuro-psychiatric patients are frequently contradictory. For example, patients with neurological diseases most often have opposing movement disorders, such as the simple need to stop and rest, while others have difficulty starting and stopping altogether. Patients with psychiatric disorders need shielding from overstimulation, but simultaneously need to visually scan all that the environment may pose for them; lack of spatial clarity stresses both patient populations for different reasons, such as neurological patients distracted by the physical effort navigating even simple environments, while psychiatric patients become easily confused due to the mental effort navigating unfamiliar settings. Developing a matrix of environmental needs for this range of patients highlights features that support both populations, while calling attention to features that exacerbate either patient's condition. While Patient-Population Based Design hones in on specific patient needs, the objective is a facility design that is not narrowly customized to one single patient population, but instead is flexible enough to support a variety of patient needs.

"Before" and "after" floor plans illustrate how Patient-Population Based Design thinking was utilized to support the neuro-psychiatric patient population, while remaining functional for the general patient population.

The pre-design diagram (Figure 1) shows the preliminary clinic layout as a loop corridor with doors at both ends of the loop and a single waiting zone. The final design diagram (Figure 2) shows the patient-based clinic layout with a single primary corridor, only one option for both entry and exit, and internal clinic sub-waiting in addition to the main waiting zone.

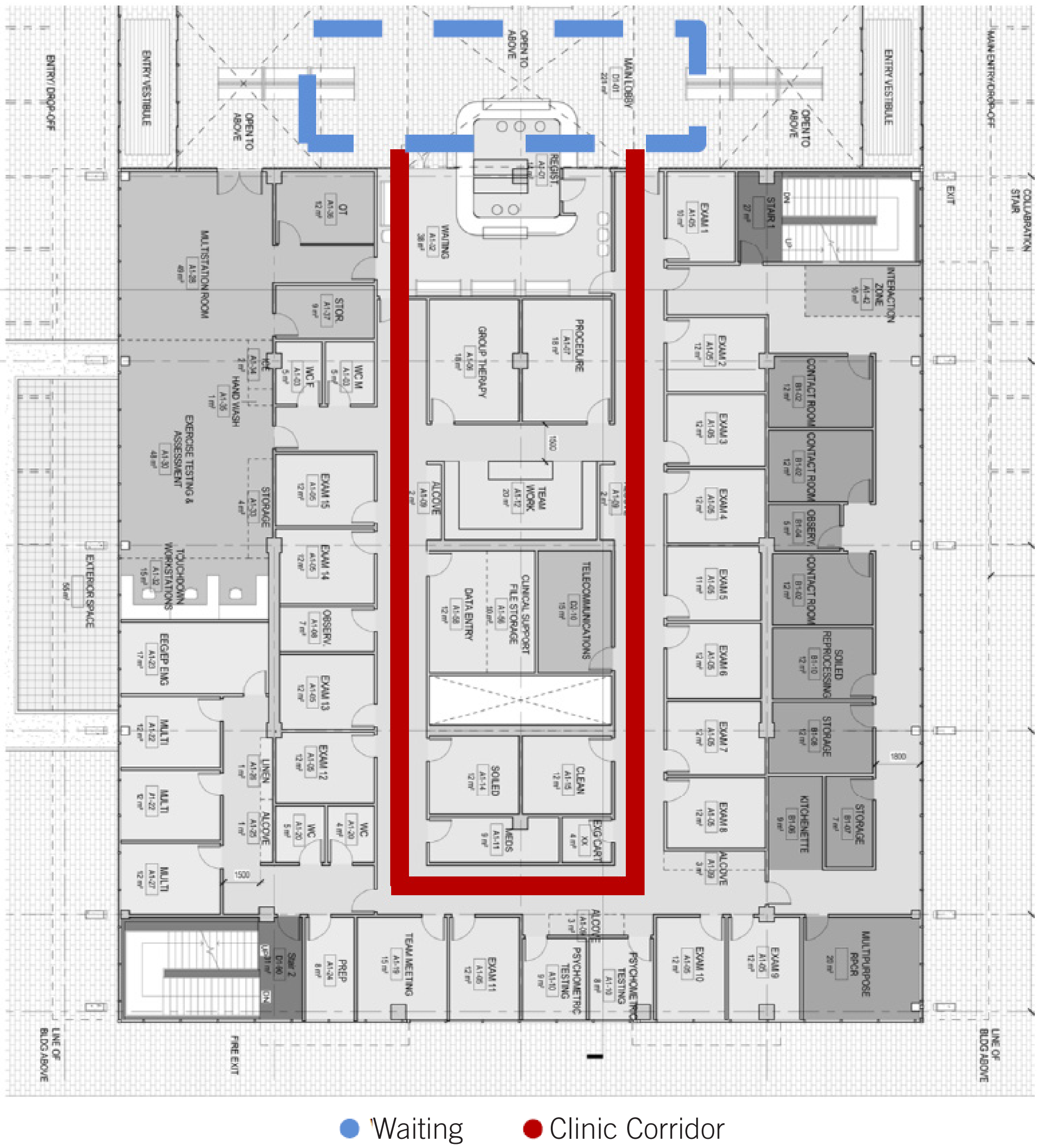

Figure 1: Pre-design clinic plan.

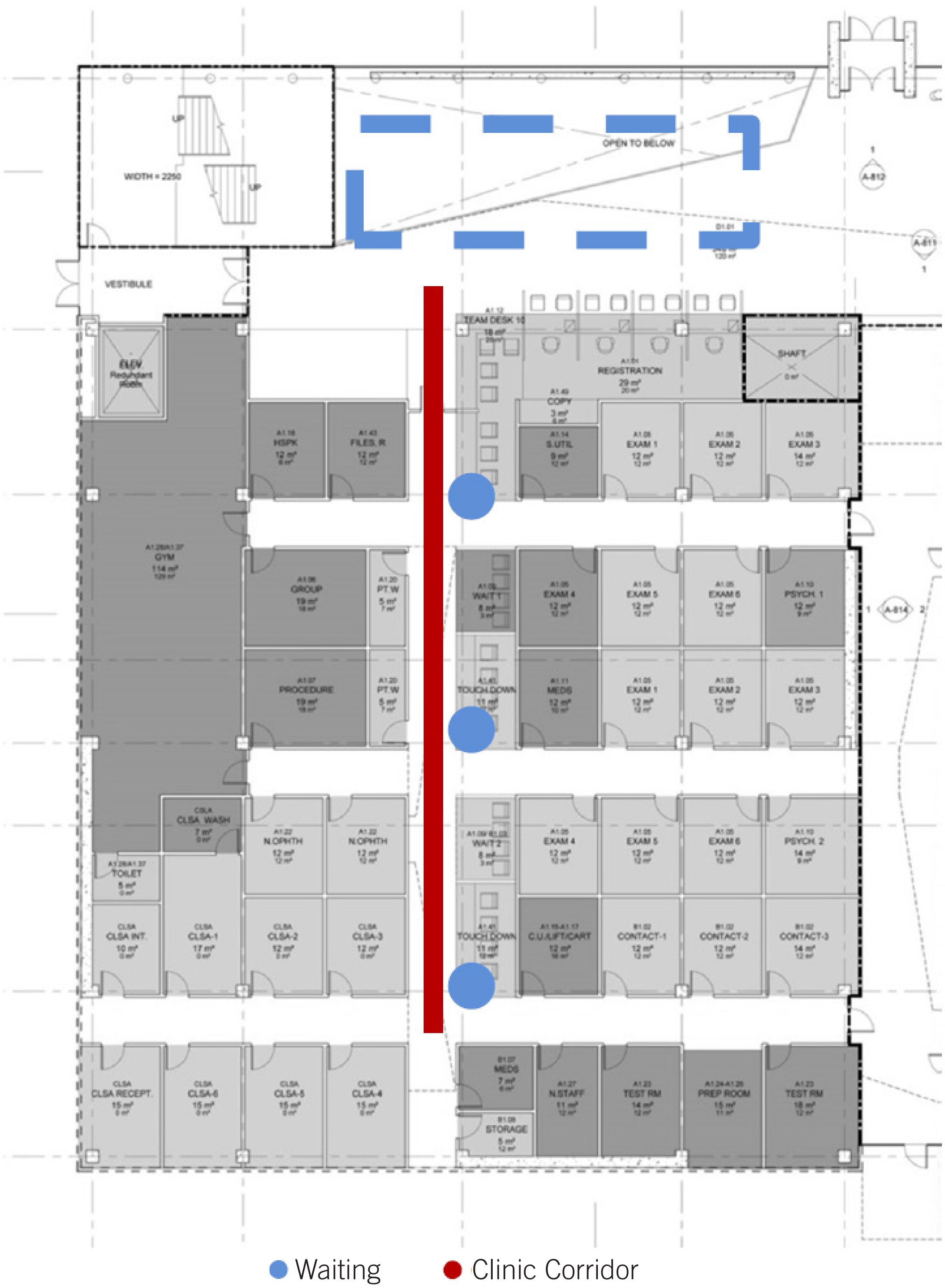

Figure 6: Pulling angles of polycaprolactone stretched beams. *Courtesy of: AADRL.*

The final clinic floor plan represents an entirely different building footprint; the building was completely reconfigured to efficiently maximize the research labs above without inefficiently penetrating the clinic spaces below with stairwells and duct shafts. In the final clinic layout, three critical design parameters were established:

- Single clinic entry and exit
- Redundant pathway
- Break points.

How these three design elements maximize the environment for both neurologically impaired patients as well as patients with psychiatric conditions is summarized in Table 2.

Table 2: Neuro-psych case study needs.

Centre For Brain Health	Population	
	Neurological	**Psychiatric**
Single Clinic Entry Exit	Same way in and out is physically more manageable with less seek-and-find wasted movement due to its predictability;	Same way in and out is emotionally more manageable with less unknowns and requires less thought due to its predictability;
Redundant Pathway	Single shorter corridor is physically more manageable with less seek-and-find wasted movement due to its predictability; Single decision point (one turn off corridor) is physically more manageable with less seek-and-find wasted movement due to its simplicity;	Single corridor is emotionally more manageable with less unknowns and requires less thought due to its predictability and visibility; Single decision point (one turn off corridor) is emotionally more manageable with less thought due to its memorability;
Break Points	Sub-waiting alcoves offer stopping points for rest of physical movement; Sub-waiting alcoves offer landmarks from which to mark physical progress.	Sub-waiting alcoves offer escape points to pull away from corridor traffic; Sub-waiting alcoves offer landmarks from which to gauge mental effort.

These three design parameters for the Centre for Brain Health each address the unique day-long clinic visits experienced by both patient populations, who typically cycle in and out of waiting and clinic exam rooms between various procedures or consultations. For the reader's interest, general environmental needs not specific to this case study but to be anticipated for any facility serving neurologic and/or psychiatric patients are summarized in Table 3.

Table 3: General environmental needs for the neuro-psych continuum.

Movement	Cognition	Psychosis
• Pacing is key to theirmovement through the environment; • Focus on features thatallow stopping & starting, such as: - Corridor 'pull outs' or niches; - Deeper elevator / entry vestibules; • Create a 'new normal'environment by acknowledging / celebrating differences / imbalance through asymmetry such as: - Corridors lit from one side; - Parallel planes treated differently; • Predominately seatedpopulation, therefore: - Assume low view angle with focus on floor more than ceiling (typical 60-degree cone of vision is from about 8 feet, 6 inches down to the floor); - Consider wheelchair 'rear view mirrors' for backing out of elevators, exam rooms, etc.; - Assume reach is limited regardless of front or side approach; - Push plates needed throughout patient pathway.	• Guide their (limited)thinking; • Focus on features that aretouched more so than seen and offer simple decisions, such as: - Bathroom stall swivel latches; - Sliding doors where ever possible (5# limit). • Therapeutic way finding,such as: - Strong differentiation between left versus right; - Shortest distance to meaningful space; - Previewing of adjacent spaces through transparency will create visually open plans for orientation; - Details that differentiate (asymmetrical color coding, staggered doors, etc.) will trigger individual cueing.	• Limit choice & decision-making; • Focus on features that areseen more so than touched and offer predictable cues, such as: - Hand rail different color than wall; - Small alcoves with 1 or 2 seats; • Avoid creating paradoxesthrough predictable spaces that progress from small to large (alcove, sub-waiting, full waiting to lobby); each space will act as transition space and enhance their sense of control; • Stimulating spaces willover stimulate; smaller groups & waiting rooms help minimize intake overload/over stimulation and reduce territoriality; • Simple decision points atmeaningful spaces (a space they will use) reduces anxiety; • Behavior outlets (accessto the outdoors, quite rooms, time-out rooms, etc.) help dissipate or modify inappropriate actions.

3.2 Neuro-Psych Patient Population

Broadly speaking, the environment for the neuro-psych patient-population continuum should support physical (movement) and mental (cognitive) needs, and some evidence supports this. Patterson and Zangwill's article focuses on brain lesions[11]. Cooney and Gazzaniga's research focused on neurological disorders[12]. And most recently, Davidson and Straus investigated psychiatric conditions and sense of self[13]. From these studies, we might assume that patients with neurological ailments have a weakened sense of space with safety as a primary concern, therefore design parameters should focus on things they touch; patients with psychiatric conditions have a vulnerable sense of self with composure as a primary concern, therefore design parameters should focus on things they see. Combined, the above three references form a cohesive relationship between the neurological disorders ranging from brain lesions and space to psychiatric conditions and the sense of self.

A review of the literature reinforced and influenced the environmental parameters that would be ideal for neuro-psychiatric patients. One concept put forward by Antonovsky states that individuals with numerous emotional resources, referred to as a high SOC, were more confident and therefore better able to adapt to stressful situations[14]. Patient-Population Based Design assumes that patients may have a high SOC, and offers them an environment with choices to meet their physical and mental needs when in a stressful situation; more importantly, for patients who do not have a high SOC, the patient-population designed environment offers supportive features appropriate for several levels of coping ability.

The concept of cognitive maps put forward by Dilani stresses that landmarks in buildings are closely related to the perception of stress, and can serve as reference points for easier orientation[15,16]. In the Centre for Brain Health, the sub-waiting alcoves are distinct elements creating a cognitive map that fosters the neurological patient's need for rest and reassures the psychiatric patient's need for escape, thereby reinforcing the well-being of both populations.

3.3 Clinic Efficiency

Beyond the concern for Patient-Population Based Design, two concepts in the final clinic layout were specific to maximizing overall clinic efficiency for the Centre for Brain Health: clinic pods and dual-purpose exam rooms. First, the total 18-exam room clinic was re-configured into three, self-contained pods, each comprising six exam rooms, two support rooms, and a touch-down space for staff and sub-waiting alcove for patients. This clinic pod concept simplified the patients' experience by reducing their exposure down to a smaller number of rooms, while increasing the staff's efficiency through in-the-pod access to support rooms and work space. Second, the exam room functions either for an exam-table neurological assessment or for a group-seating psychiatric consultation. This dual-purpose exam room concept was achieved by fixing only the door and sink location with all other items being movable, allowing the clinic to flex from neuro to psychiatric services as needed.

These design concepts are efficient not only for this patient population but can be applicable to a variety of patient populations if the institution's staffing model supports a pod-like model of care and/or an exam room conversion concept.

4.0 CONCLUSION

The facility in this case study was open for only a few months at the time of this research, therefore, the effects of the Patient-Population Based Design process have yet to be proven or disproven. While the outcome of this process is not known at this time, the process did inform the design and ideally, a post-occupancy evaluation conducted a full year or more after opening would greatly inform the validity of this process.

Specific to the case study presented in this paper, there is a clear need for studies that examine patient participation in clinical research, but the objective of a wellness-based setting is to allow less-well patients to consider research dilemmas and prepare them for time sacrificed, tissue or organs donated, and risk missing a miracle drug or treatment. For translational medicine research facilities, a wellness-based setting should reinforce patients' trust that researchers and clinicians are committed to the patient's care regardless of the outcome.

The primary intervention described in this paper focused solely on the spatial relationships without considering the other physical elements that were modified, such as access to daylight, sensitivity to color, and asymmetrical interior design elements, all of which were undertaken in order to have a significant, positive impact specific to this neuro-psychiatric patient population. The research for this paper focused on the case study patient population, but in the hope that Patient-Population Based Design gains acceptance, future research for broader populations is highly recommended.

The objective of Patient-Population Based Design is to create a standardized process for wellness-based design in healthcare settings to increase the likelihood that healthcare environments will be designed to foster health rather than emphasize illness. This process is currently being taught to healthcare executives in a graduate program for healthcare design so that they may influence the architecture before design begins, and set the stage for a wellness-based environment.

Future steps in research should begin with identifying valid and reliable metrics to measure the intended outcomes, followed by testing conceptual design options to predict the desired outcomes. Initially this may require selecting a specific patient population to confirm the process and the intent of patient-population based design.

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03.
A protectED ROOM:
Design of Responsive and Acuity Adaptable Behavioral Health Room for Emergency Departments

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ABSTRACT
This article explores how a responsive, acuity adaptable emergency room design can actively contribute to patient well-being along the continuum of care without sacrificing operational efficiencies. Increasing medical knowledge, prevalence, and social awareness of behavioral health issues have made it imperative to design therapeutic spaces that respond to the whole person, in addition to medical treatment needs. The method for conducting this qualitative study included historical review of behavioral health facilities, expert interviews, bedside care-team simulations, and the observational study of existing facilities. The Perkins+Will team met with an ED director, Nurse managers, Behavioral Health Medical Director, a Lean and Six Sigma expert, and conducted observational studies of existing conditions at multiple sites. The result of this study is a protectED room design that includes architectural solutions to address patient medical and behavioral health acuity needs. The design utilizes architecture as a tool to support patients in the same compassionate language as the care teams that treat patients and not simply an apathetic undersigned room to hold them until they can be admitted. It is recognized that staff skill-mismatch, inpatient psychiatric bed availability, and other complex factors will impact patient care and flow through the emergency department.

KEYWORDS: behavioral health, mental health, emergency department (ED), acuity adaptable, headwall, turn-time, emergency severity index (ESI)

1.0 INTRODUCTION:
Research indicates that better integration of behavioral healthcare services into the broader healthcare continuum can have a positive impact on quality, costs and outcomes of healthcare practices[1]. The 2010 Affordable Care Act (ACA) required insurance plans to offer behavioral health coverage as an “essential health” benefit, thereby expanding paid care options for millions of previously underinsured Americans. This increase in funding has led to increased patient volumes on already overburdened emergency departments and accelerated society’s response to how people are treated in primary and emergency care environments. While the ACA’s future is unknown, a review of the past research reveales a general trend towards acceptance and integrative mental and physical healthcare. In this article, behavioral health (BH) is defined as mental illness and substance abuse disorders.

A behavioral health patient’s symptoms can be intensified in the emergency department by the patient’s current mental state, previous traumatic experiences, stigma, mistrust, and loss of control. Thoughtful, empathetic, and informed design that supports and promotes a positive patient experience for this vulnerable group is paramount. The objective of this research was to investigate design of an acuity adaptable room that responds to the continuum of care intensity within the emergency department (ED), giving special attention to the need for therapeutic design. The following guiding principles were used to provide direction for the overall design of the protectED room:

1. Create a humane and therapeutic patient room for all
2. Maximize flexibility and adaptability of the room for behavioral health and medical emergency patients of differing severities
3. Create a supportive environment designed to stabilize the patient, reduce stress, and progress the initial treatment plan
4. Create a healing environment that promotes patient well-being and sensitivity in patient care by staff.

2.0 METHODOLOGY

Current behavioral health design guidelines reflect the sentiment that creating a physical, interpersonal, and psychologically safe environment that supports the therapeutic milieu is essential to the recovery process[2]. To gain a compassionate understanding of the challenges faced by the behavioral patient, the team listened to staff accounts of patient experiences in the Emergency Department and inpatient behavioral health units. A historical review of the evolution of mental health environments and care concepts from the 1800s to today informed how the current state evolved (Figure 1). The team evaluated existing design guidelines. Observational studies of selected emergency departments, accompanied by interviews with experts, helped identify potential areas for focused study. Interviews with experts ranged from an ED Director, Nurse Manager, Behavioral Health Medical Director, Lean and a Six Sigma expert. Observations and findings from InSytu Advanced Healthcare Simulations with multi-disciplinary, multi-day workflow simulations in a newly built ED and an Inpatient Behavioral Health Unit identified opportunities for improvements related to the space, and this process informed the final design.

2.1 Historical Context

Figure 1 below is a summarized illustration depicting some of the milestone events over the last two hundred years that have helped shape our psychiatric care model.

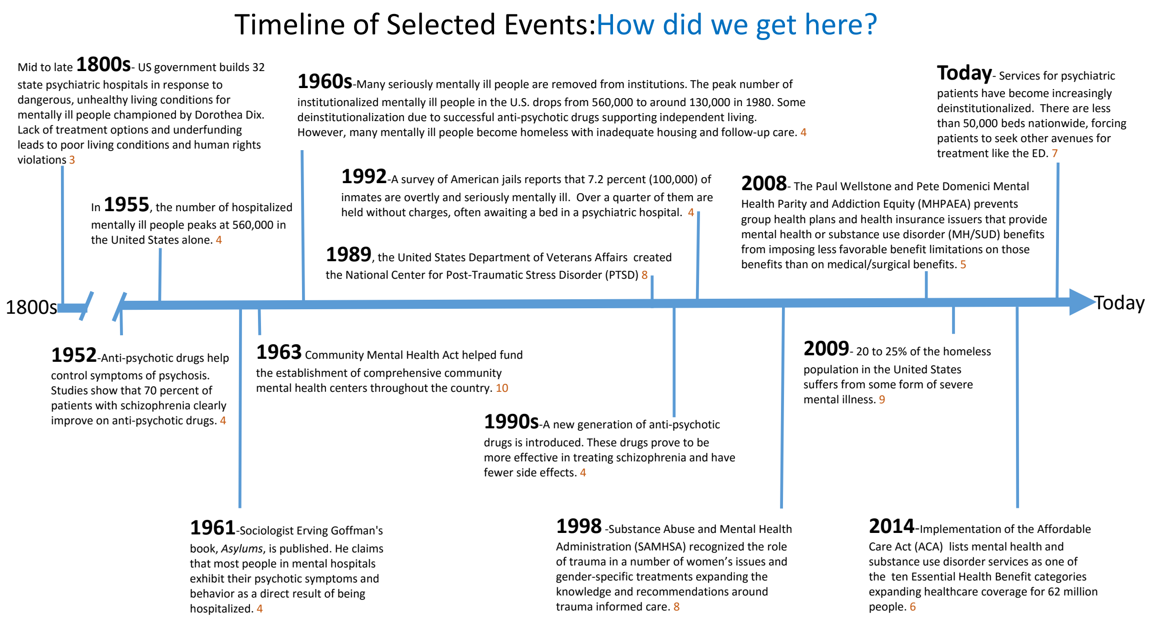


Figure 1: Historical psychiatric and department crisis management[3, 4, 5, 6, 7, 8, 9, 10].

2.2 Mental Healthcare Today

The Substance Abuse and Mental Health Services Administration (SAMHSA) reports that 18 percent of Americans have some mental illness, including conditions such as depression, bipolar disorder or schizophrenia[11]. With this knowledge, it is no longer appropriate or effective to separate the physical and mental health needs of an emergency patient.

Currently, 1 in 8 emergency department cases are related to mental disorders and/or substance abuse[12] and of those patients who need to be admitted, 21.5 percent are boarded[13] in the ED waiting for an inpatient bed, compared to 11 percent of all ED patients boarded. Regardless of admission status, average length of stay in the emergency department is 4 hours for a Medical Patient versus 18.5 hours for a Behavioral Health patient[14]. Figure 2 illustrates the prevalence of behavioral health diagnosis types.

Regardless of the reason for the ED visit, all patients are entitled to a medical evaluation by the Emergency

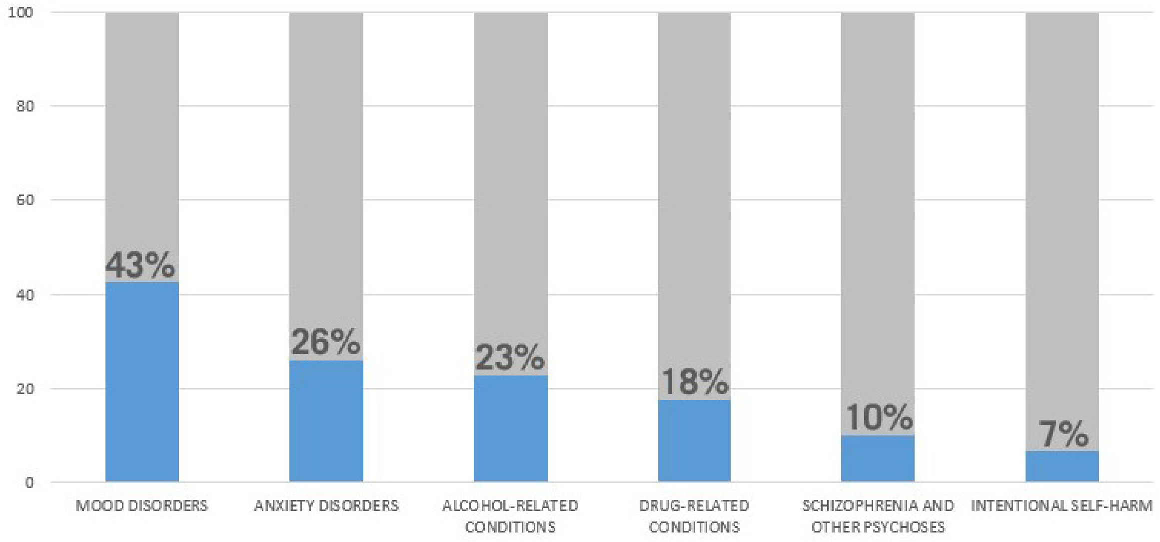


Figure 2: Prevalence of the Behavioral Health diagnosis types.

Medical Treatment and Labor Act (EMTLA) law. EMTLA requires a medical evaluation to ensure stability and risk of injury[15]. To complicate matters, many behavioral health (BH) patients present agitation, which makes initial assessments challenging. When this happens, the healthcare team must simultaneously implement de-escalation techniques, and an observational primary survey to determine risk of injury, possible delirium, or psychiatric causes of symptoms[16]. This practice can happen in the ambulance bay while the patient is still on the EMS gurney, registration area, or preferably in a dedicated triage room that provides a safe and private environment for all involved (Figure 3).

Figure 3: Behavioral Health patient assessment.

2.3 Current Behavioral ED Treatment Model

Delirium represents a decompensation of cerebral function in response to one or more pathophysiological stressors and is caused by severe medical illness, metabolic imbalance, medication or poisoning, infection, surgery or withdrawal, which requires a comprehensive medical evaluation and treatment. Whereas cognitive, known psychiatric condition, intoxication or withdrawal, or other causes such as anxiety, depression, or anger require an abbreviated medical exam and specific skills to minimize symptoms[17].

Included in the risk of injury evaluation is danger to self or others and immediate ability to act on a plan. If the patient is determined to be at risk, a medical hold or restraints maybe needed for safety. This requires careful, thoughtful and compassionate care that fulfills all medical-legal requirements. Ideally, ED treatment plans for the behavioral health patient focus on acute symptom management and expeditious transfer to the inpatient unit. However, the psychiatric inpatient bed supply and demand mismatch requires the ED team to board patients. This mismatch is severe; up to 70 percent of institutions have to board psychiatric patients for more than 24 hours and 10 percent for a week or more[18].

Globally, mental health advocates agree with the right to the highest attainable standard of physical and mental health[19]. These following aspects are particularly important:

1. Access to appropriate services
2. The right to individualized treatment
3. The right to rehabilitation and treatment promoting autonomy
4. The right to community-based services
5. The right to the least restrictive services
6. Protection of human dignity.

The protectED design specifically responds to goals 2, 5, and 6 with incremental, patient specific features that support medical and behavioral health needs. The right environmental adjustments empower the ED team to tailor interventions beyond patient safety, minimizing restraints application.

Environments should de-stigmatize mental illness by integrating treatments for the whole person's physical and mental health. Focus needs to be on the continuum of care to make sure patients get the right kind of care in the right setting. Providing patients control over environmental lighting and sounds help deescalate feelings of agitation and anxiety and the behaviors that express these feelings.

2.4 Current Behavioral Health ED Environment and Expert Observations

Changing care models, decreasing stigmas, and increased accessibility to emergent behavioral healthcare is accelerating change in the architectural design response. Conventional design elements and processes employed to ensure a safe BH patient care environment include removing and securing room items, or sliding and hiding unsafe elements, use of secured cabinets, patient seclusion, and/or use of restraints when all else fails.

The practice of dedicated BH rooms and medical treatment rooms often require reshuffling patients or holding treatment rooms empty while patients are held in the waiting room. Typically, single purpose behavioral health treatment rooms are not well suited for treating patients with medical conditions and often sit unused even in cases when the ED waiting room is full. Some multi-purpose rooms with garage door design create extreme noise conditions for patient care areas and are not aesthetically pleasing or conducive to patient well-being.

ED design that supports normalized and patient-centered versus controlled-centered care should be implemented. The design needs to create healing environments that integrate natural lighting, art, colors and reduce barriers between caregivers and patients to provide positive clinical outcomes.

2.5 Behavioral Health ED Case Studies

The following three case studies were selected based on their relevance to behavioral health design and unique characteristics that shape the healthcare environment. Qualitative studies of the units through observation, expert interviews with staff and designers, and event simulations helped inform this research.

Swedish ED Behavioral Health Pod C, Edmonds, WA: An observational walkthrough of the Edmonds ED behavioral unit (Figure 4) with its four treatment rooms and two separate acuity adaptable rooms helped identify behavioral health design features that work effectively. It is noted that the acuity adaptable rooms sized at 190 square feet (13'-8" x 14'-0") each are underutilized due to lack of direct visibility from the nurse stations. The metal garage doors that conceal the headwall, computer on wheels and all wall-mounted equipment, the hygiene area along with the nurse server are noted as a noise hazard. Staff complained that psychiatric patients bang on the metal doors disturbing other patients in the unit. The nurse servers are two-sided with access from inside and outside the room and accommodates soiled linen, clean linen, and PPE. The flex room has an encased tamper-proof TV. The room doors are four feet wide, with a vision panel and integrated operable shades.

Figure 4: Swedish Edmonds ED Behavioral Health treatment room.

Swedish Behavioral Health Inpatient Unit, Seattle, WA: A walkthrough of the new 22-bed inpatient unit at Swedish Ballard Behavioral health Unit provided the opportunity to study current design trends in behavioral health. Simulation studies in the unit explored the effectiveness of safety procedures during emergencies. The inpatient unit (Figure 5) has single and double patient rooms with reversible-hinged doors and anti-ligature fixtures. The “mini” headwalls conceal power and gases. Patient bathrooms have capped sliding doors with soft-closure. The interior palate is composed of cool tones and natural wood accents. Ceiling panels made from compressed wood wool provide a secure, durable, and sound absorptive surface out of reach. The unit has indirect cove lighting throughout. The sections of the multipurpose corridor wall protection doubles as a dry-erase board for daily information. One of the unique spaces in the unit is the patient meditation rooms with customizable lighting color and music that calm the patients.

Figure 5: Swedish Ballard Behavioral Health Inpatient Unit.

St. Vincent's, Portland, Oregon, WA: St.Vincent's has an ED behavioral health unit adjacent to a behavioral health inpatient unit. The team investigated the advantages of patient intake and overflow between the two units through expert interviews and walkthroughs. The behavioral ED unit (Figure 6) is a locked unit separate from the main ED with six treatment rooms and two holding rooms, staffed with Psychiatric and ED RNs. Psychiatric patients arrive in an enclosed area near the ambulance bay. Co-operative and acute crisis patients arrive at the ED through separate routes. The pre-hospital transport crew includes EMS staff, police officers, and/or hospital security. Patients are registered as soon as they enter and triage happens in a dedicated room in the unit. Each of the two holding rooms for acute crisis patients contain only a floor-mounted bed. Supervision is from a shared staff area between the rooms. Cooperative patients are directed to the patient treatment room, which has a patient bed, hand wash sink, cabinet and headwall. The patient treatment rooms allow patients to operate a sink. Other special features of the treatment room include seamless floors with no pattern, doors with a vision panel, magnetic locks and piano hinges, and a window with integral blinds. Furniture in the room is tamperproof. Non-ligature fixtures, recessed lighting, security camera, flush mounted digital clock. Staff control lighting and temperature from outside. In the inpatient unit, encouraging patients to explore the wide corridors with calming music and 27000K colored LED promote patient wellness and independence.



Figure 6: St. Vincent's Behavioral Health room.

3.0 RECOMMENDATION: DESIGNING AN ADAPTABLE BEHAVIORAL HEALTH ROOM

The protectED flex treatment room is a standardized, flexible room that responds to the continuum of care intensity within the emergency department. It is an adaptable room, which gives special attention to the need for therapeutic design and communicates to patients in the same compassionate language as the care team that treats patients. The article proposes a series of guidelines and design strategies that address safety, dignity, flexibility, acuity adaptable, efficient, positive distraction, acoustics, lighting control, therapeutic interventions, and compassion. All of these aspects strive to create a more therapeutic, holistic design approach while improving outcomes[20].

3.1 Flexibility

Technological advancements have given designers new tools to respond to known design challenges in the emergency department. The conflicting need to balance the one-time capital construction costs have often over-powered the harder to defend and measure, yet equally important building lifetime workflow efficiencies, staff satisfaction and patient outcomes beyond immediate safety. To that matter, typical or current emergency department patient rooms were planned to serve most patients with little variation, a static response. Specialty rooms for extreme care needs are seen in the development of trauma and behavioral health in an attempt to balance cost, need, and efficient turn times. Patient care spaces should perform at a more fluid level of operation, allowing for flexible configurations that can respond to specific patient care needs, thus having the capability of treating medical patients and also adhering to FGI guidelines for behavioral treatment and holding rooms (Figure 7). From a staff point of view, it is important to have adequate area within the room to accommodate necessary equipment, linen, waste, personal protective equipment (PPE), and headwall mounted accessories. By categorizing these into three separate zones, rooms are customized to the individualized needs of the patient and staff (Figure 8). Upon entering the room, located on the left hand side, zones 1 and 2 act as separate alcoves for hygiene/PPE and equipment/linen, and soiled storage, with separate interior ceiling hung, track doors that can be opened/closed by staff. Zone 3 is an adjustable headwall, composed of six panels that independently rotate 180 degrees (Figure 9). Independent panels allow for patient specific care, as more or less of the headwall is reveled. The diagnostic side of each panel contains medical gasses, pumps, power, monitoring, and accessories, while the backside is a section of a custom printed graphic mounted on impact resistant laminate (Figure 10).

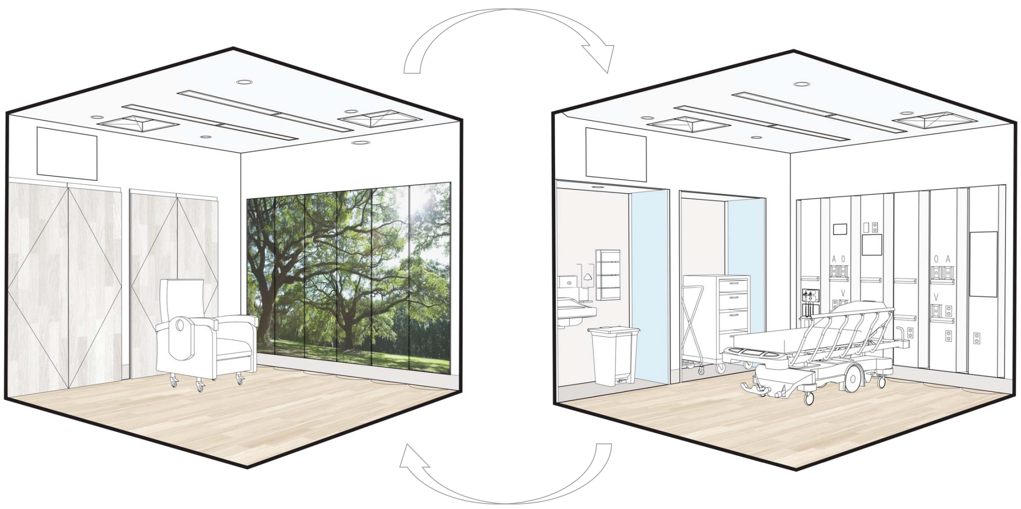


Figure 7: Treatment room transformation..

Figure 7: Treatment room transformation.

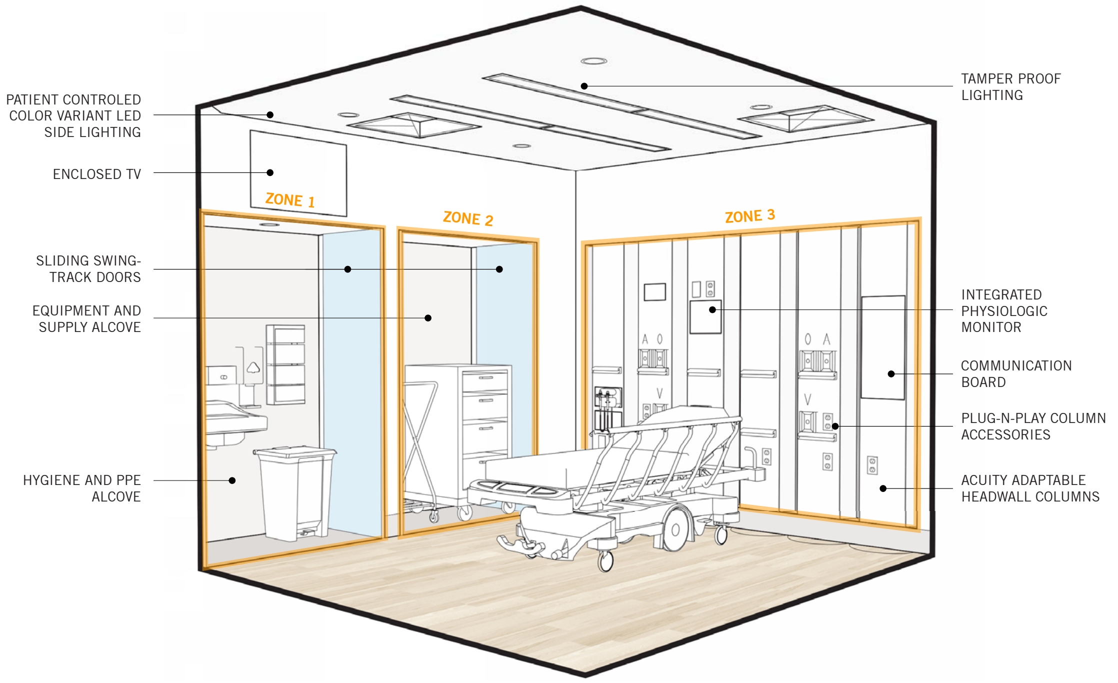


Figure 8: Treatment room features.

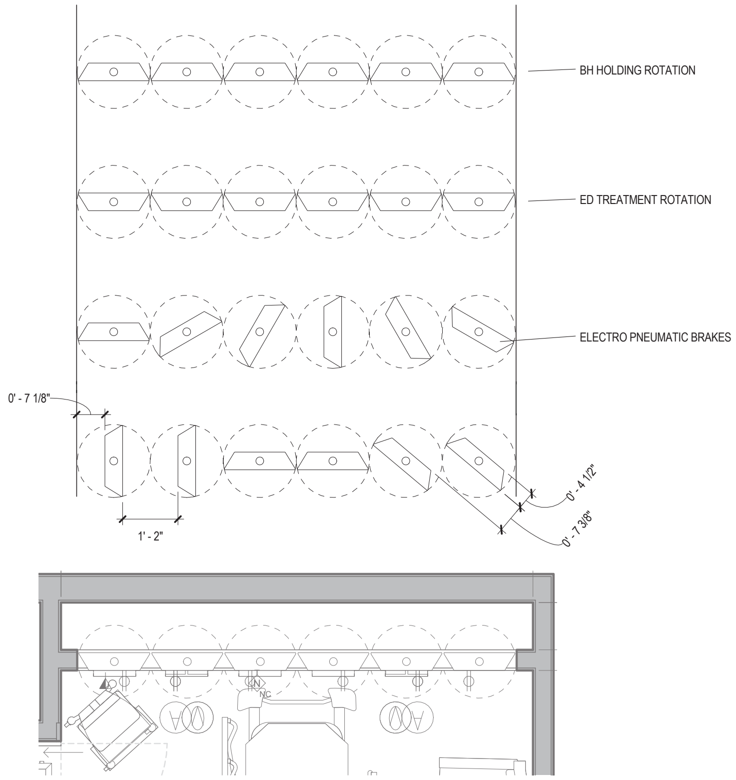


Figure 9: Adaptable headwall.

Figure 10: Headwall functionality.

3.2 Acuity Adaptation

The protectED room can incrementally respond to individualized medical patient needs along the Emergency Severity Index (ESI) (Figure 11), a tool used to triage and determine medical acuity level of patients within the emergency department. Figure 11 illustrates the complexity and variability of medical and behavioral health patients in the ED. Each patient is triaged upon arrival for urgency and acuity of care. The blue ESI patient type examples demonstrate the intensity, urgency of care, and number of interventions needed with "V" requiring the least and "I" the most. In addition to medical stability, BH patients require an evaluation to ensure safety in the environment of care. The ED treatment team will implement the least restrictive measures to ensure safety for all. From pink to red BH patients require careful assessment through interview and observations with restraint and seclusion being the most restrictive, applied only when all other interventions have failed. The violet area encloses patients who agree to the treatment plan and the orange area designates patients with a risk assessment that requires involuntary treatment (ITA) or "hold/detention" until evaluation by a County Designated Mental Health Professional (CDMHP) has assessed the patient's need for inpatient care.

Uniquely, the protectED room can respond to the emotional and physical safety of patients and staff as well. The dynamic feature responsible for this is the operable headwall, which allows for multiple configurations in response to the patient's needs. By rotating headwall panels, the treatment space can flex from an ESI V patient in need of a simple prescription refill to an ESI II patient with severe chest pain (Figures 12 to 15). Each headwall panel is designed with care-paired outlets and accessories that locks into place using electro pneumatic brakes, similar to operating room and intensive care booms. This allows for quick turn-times as staff modify the room to match the patient's assessed individual needs without needing to remove any equipment. Current design solutions respond only to physical safety or medical needs, not both. Having flexible emergency rooms would decrease room downtime and ensure that resources are efficiently utilized. Designing rooms with the ability to flex between medical and behavioral health room in the ED will mean that an increased number of patients can be accommodated more efficiently within the same footprint.

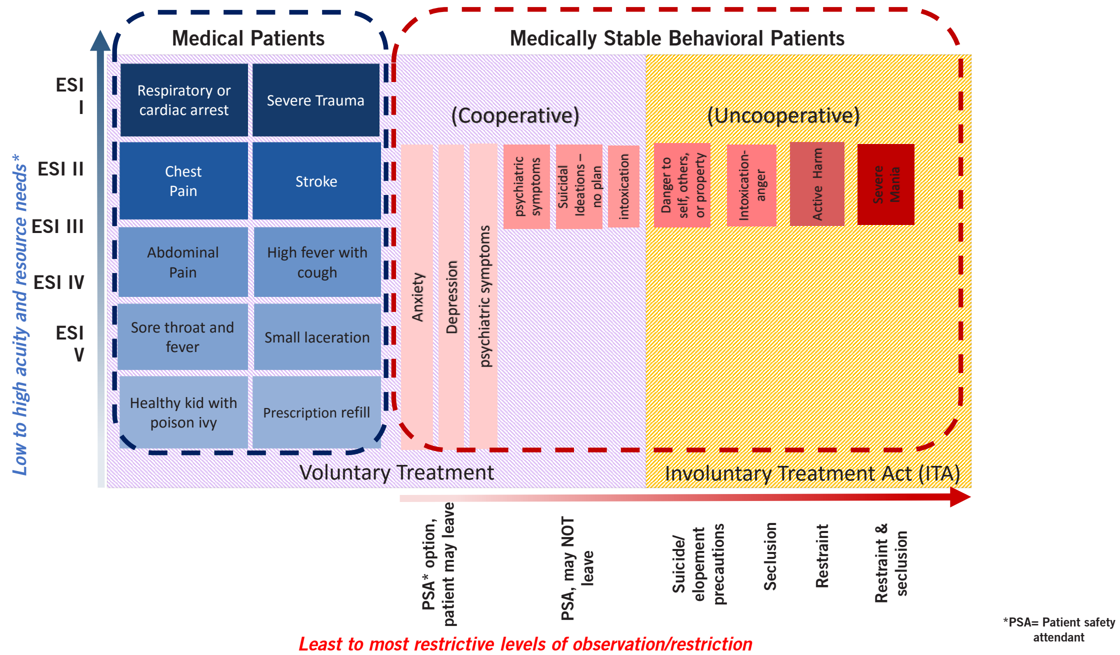
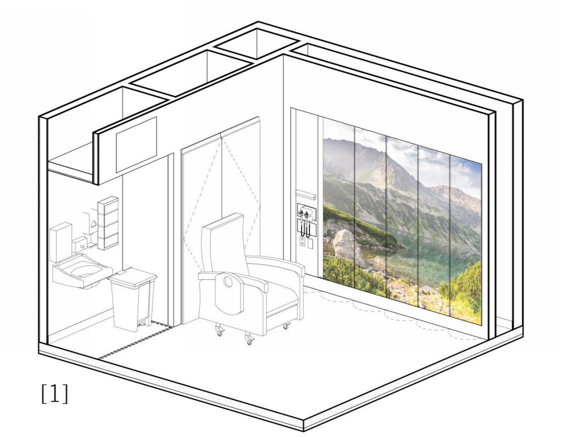
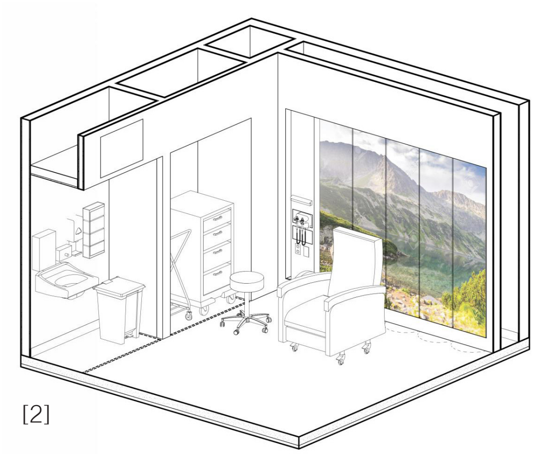


Figure 11: Emergency Severity Index (ESI) chart adn Behavioral Health restriction levels.



[1]

INDEX
[1] ESI 5 (Medication refill) or
ESI 3-5 Low-risk behavioral health
[2] ESI 4 Low acuity patient (Fever)
[3] ESI 3 Medium acuity patient (Abdominal pain)
[4] ESI 2 High acuity patient (Chest pain & Stroke)
[5] ESI 2 High risk behavioral health



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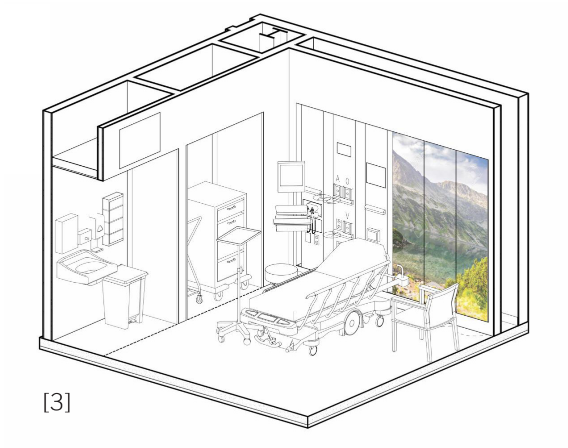

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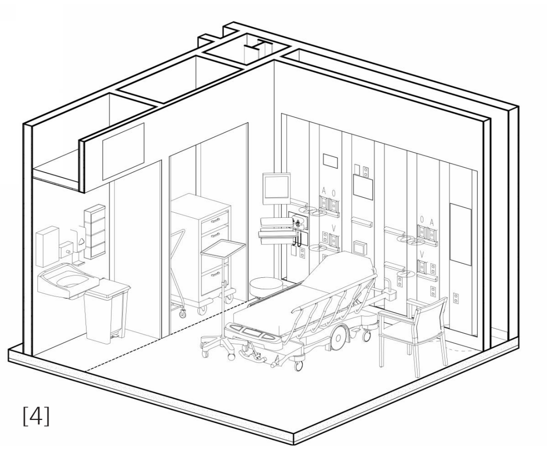

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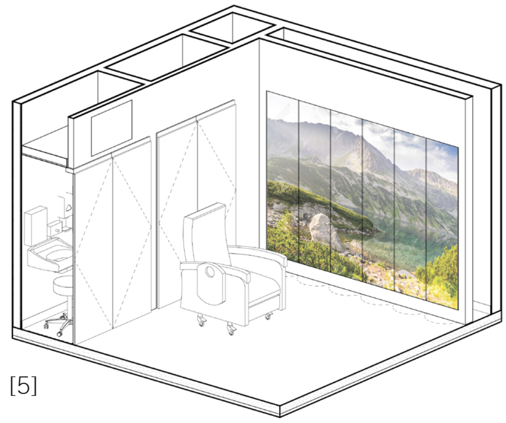

[5]

Figure 12: ESI Scenarios.

3.3 Efficiency

Design of the protectED room goes one step beyond the "universal treatment" room idea. Care modules should become more efficient, as they are able to easily adapt to the changing needs of increasing patient volumes. As the room is repeated within these modules, its' configuration is designed to be identical and is dimensioned such that columns are easily absorbed (Figure 13). With a headwall that can transform from a behavioral health treatment room to a medical treatment room or both, the ED will rarely have a specialty room sitting empty during peak hours.

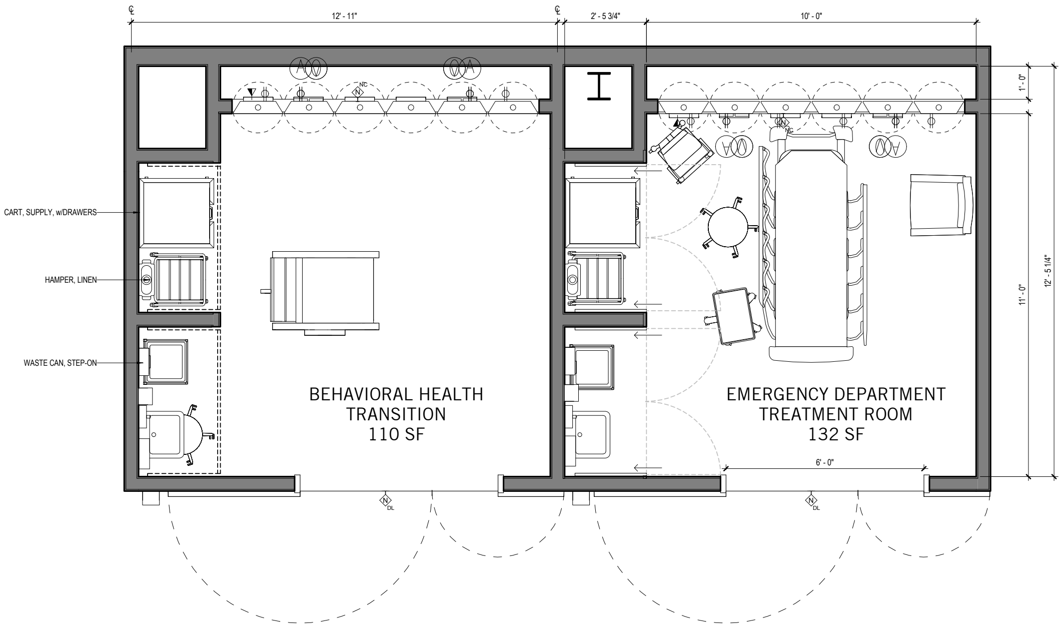

Figure 13: Treatment room floor plan.

3.4 Positive Distraction

The headwall allows for natural landscape images, rendering an entire scene as the headwall panels are rotated. The selection of natural landscape images is supported by multiple studies that have shown decreased stress responses to views of nature. The environmental features can be in the corridors and nurse stations as well, providing increased satisfaction within the work environment. An encased TV can be programmed to shuffle through patient-informed ambient art or naturescapes, while hidden speakers within the ceiling provide audio. A normalized approach to the care of behavioral health patients in the emergency department is essential. Having a dedicated sitting area for patients with a recliner in base recumbent position would be a great place to start, allowing patients to relax. Making a space as warm and inviting as possible, while taking into consideration the flexibility would be the ideal design goal.

3.4 Acoustics

Acoustical treatments that absorb and mitigate sound are applied within the architectural elements, including adjustable non-ligature curtains, furniture, wall surfaces and flooring. Enclosed equipment and hygiene alcoves create secondary sound barriers that help absorb higher noise levels. Ceilings and walls are constructed with additional layers of acoustically enhanced drywall, while the flooring uses an acoustic rubber base to decrease the perceived noise level by 50 percent.

3.5 Lighting

Studies have shown that lighting can contribute to health problems, such as depression, agitation, and sleep; all of which influence the mood of both staff and patients[20]. The protectED room incorporates this knowledge and uses technology to provide programmable or patient-informed lighting choices, as well as control of the light temperature or color. A combination of direct and indirect fixtures provide adequate ambient light for patient exams. All lighting is fully recessed in the hard lid ceiling and shielded with tamper proof covers. Additional task lighting is available on rolling stands. Careful attention to the quality of light, safety, noise control and color facilitates greater interaction between caregivers and patients.

3.6 Materials

Behavioral health spaces require materials that can withstand heavy use and abuse beyond normal wear and tear. Materials must be easily repairable and survive thrown furniture, kicking, scratching and door impacts, while maintaining an ease of cleanliness and germ resistance. The headwall requires molded urethane edges for a durable and smooth, non-ligature seem between panels. All furniture, door handles, sink fixtures, are anti-ligature and free of sharp edges. The hard lid ceiling was designed with tamper-proof lighting and air supply with all access panels outside of the room.

3.7 Furniture

Each room should have a stretcher and/or a comfortable tamperproof recliner, depending on the patient's needs. For medically cleared, behavioral health patients, the stretcher can be removed, decreasing hospital related stressors. A second chair can be brought in for caregivers to have seated talks with the patient.

4.0 CONCLUSION

The protectED room begins to establish important design strategies to benefit behavioral patients and shape future architectural responses to patient acuity, behavioral health needs, and comfort in an emergency room. With increasing medical knowledge, prevalence, and significance of social awareness of behavioral health issues, it is imperative to start designing these spaces with a more therapeutic and holistic attitude that responds to the whole person, in addition to medical treatment needs.

Looking ahead, a continuation of this study would dive deeper into more behavioral health literature reviews coupled with visiting higher acuity level emergency departments. Post occupancy evaluations of behavioral health units would help garner quantitative research goals and further develop design strategies.

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04.
COMPARING AND ADAPTING PITT RIVER SCHOOL TO THE PASSIVE HOUSE STANDARD

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ABSTRACT
This article presents a study of a Pitt River Middle School (built in 2013) and, analyzes how close the project comes to achieving the International Passive House standard and what changes would need to be made to achieve the standard. The article reviews the target metrics associated with the Passive House Standard and processes involved in successful implementation. These processes include overlap of BIM and the Passive House energy modelling process, the impact of thermal bridging and review of specifications for building envelope components. The study finds that the project was designed to achieve annual Energy Use Intensity (EUI) for heating of 48 kwh/m^2 (15.3 kBtu/ft^2), a 40 percent improvement over a baseline according to ASHRAE standard of 82 kwh/m^2 (25.99 kBtu/ft^2). The Passive House standard limits this value to 15 kwh/m^2 (4.8 kBtu/ft^2) an 82 percent improvement over the baseline. Improving the building envelope specification would decrease EUI to 23 kWh/m^2 (7.4 kBtu/ft^2). To achieve the Passive House standard, several design considerations would require a revisit, specifically form factor (compactness), orientation glazing ratio, etc. These criteria need to be considered early in the design process and analyzed in conjunction with other project goals and architectural requirements.

KEYWORDS: Passivhaus; energy efficiency; high performance building; energy modelling; thermal bridging

1.0 INTRODUCTION
1.1 Objectives and Case Study Overview
This article investigates the application of the Passive House standard and how it might be better integrated into the design process. Using a recently built project by the Perkins+Will Vancouver office, Pitt River Middle School (completed in 2013), the research had three aims:

- To establish a project benchmark to see how the project performs relative to the International Passive House standard. This research was conducted after the building was designed and completed (i.e. the building was not designed or built to achieve Passive House standards). The aim of this research was to apply the Passive House lens in retrospect to understand what changes would be necessary for meeting the standard.
- To provide feedback in terms of impact on the design process for projects aiming to achieve the standard, specifically understanding the potential impact on project schedule, and by association potential impact on fee proposals.
- To provide feedback in terms of further training required for design professionals.

Figure 1: Pitt River Middle School.

Pitt River Middle School is a two-story educational facility, located at Port Coquitlam, British Columba, with 5580 m² (62,000 ft²) of conditioned space (Figure 1). It has two wings: an academic wing and an athletic wing. The academic wing consists of classrooms, administrative offices, a library and a workshop. The athletic wing includes a gym, a fitness room, a multipurpose room, a music room and offices.

The project has been recognized for its design excellence, winning a Lieutenant Governor of British Columbia Award in Architecture from the Architectural Institute of British Columbia (AIBC), and a Design Citation Award within the wider Perkins+Will community. It is important to note that any potential recommendations in meeting the Passive House standard would have an impact (positive or negative, depending on how they are treated) on the design and aesthetics of a project, such as thicker walls, eliminated thermal bridges, potentially reduced window areas and reduced north facing clerestory lighting (good for daylighting within the space, but negatively affecting heat loss). All of these factors would have an impact on the design aesthetic in addition to thermal performance.

1.2 Why the Passive House Standard

Commercial, institutional, and residential buildings are responsible for about a third of carbon pollution in the U.S., and about a fifth of carbon pollution in Canada, constituting the largest source of emissions in North America[1,2,3]. Worldwide, buildings account for about a third of energy related emissions, and continue to grow[4]. Over 80 billion square meters (900 billion square feet) will be built and rebuilt in urban areas by 2030, an area roughly equal to 60 percent of the current global building stock[5]. Once these developments are built, their performance is locked in and cannot be improved without costly renovation. The Passive House standard, as suggested by its name, takes a passive approach to improve the thermal performance of the building. Major areas of consideration focus on the building envelope, increased insulation and airtightness of walls, roof and windows, as opposed to active systems that require a constant supply of conditioned air by HVAC systems. This results in a reduction of emissions from buildings under consideration at a low cost, while also improving durability, comfort, and resilience.

This study focuses on the international Passive House (or Passivhaus) standard, as administered by the Passive House Institute in Germany. There are various affiliates in North America that promote, educate and advocate for the standard on a local level (e.g. Passive House Canada, the North American Passive House Network, New York Passive House, etc.). The Passive House Institute US (PHIUS) operates in the U.S. Originally an affiliate of PHI and the international standard to standard, PHIUS has split off in recent years to formulate separate PHIUS+ standards based on U.S. climate zones. This can be confusing for design teams and clients, so it is important to be clear which standard applies.

The Passive House Standard is internationally recognized, performance-based energy standard for both new build and renovation construction projects. It was developed by German and Swedish building scientists and physicists, building on previous energy efficiency concepts in North America and Europe. The focus is on energy conservation and improvement of building envelope. The aim of the rating system is to assist with designing a building in which a comfortable interior climate can be maintained without active heating and cooling systems. It results in buildings that consume roughly 80 percent less heating and cooling energy than conventional buildings while ensuring occupant comfort.

Designing and building a project according to the Passive House standard demands a rigorous methodology. There is an increased focus on the building envelope with the core principles being:

1. Reducing demand
    - Reducing heat loss or gain though superinsulation, reducing air Infiltration and thermal bridges
    - Limiting the overall energy use through a primary energy limit
2. Maximizing gains
    - Capitalizing on solar heat gain and internal gains
3. Ensuring occupant comfort
    - Controlling gains and overheating in the summer
    - Providing fresh air and using a heat/energy recovery ventilator to recover waste heat.
    - Ensuring all thermal comfort criteria are met[6].

Many municipalities are looking into the ways to combat climate change and reduce carbon emissions. For example, the City of Vancouver adopted a Zero Emissions for New Buildings Policy, which came into affect May 2017 for all rezonings. This policy aims to achieve zero emissions for all new buildings by 2030, with stepped

Green House Gas (GHG) and thermal energy demand targets. This policy references the International Passive House standard as a performance benchmark[7].

1.3 Summary of the International Passive House Standard

There are five performance metrics that need to be met for a project to be certified according to the Passive House Standard, as defined by PHI, which are outlined in Table 1[8]. For the purposes of this study, the main focus is on the certification criteria of 15 kWh/ m^2a (4.75kBtu/ft^2 yr) limit to the annual heating energy per area of the building. The same limit is applied for cooling, but there is an additional allowance for cooling depending on the context. The resulting focus of this study is narrow, mainly on the build-ing envelope components. In reality, there are wider issues to be considered when designing to achieve the Passive House standard, including airtightness detailing, mechanical systems design and electrical appliance specifications, accurate measuring of internal gains, all which would all have an impact on achieving the standard.

Table 1: Performance criteria for the internationally recognized Passive House (Passivhaus) Standard, as certified by the Passive House Institute (PHI).

	Performance Metric	Comment
Space Heating & Cooling Demand	15 kWh/m² a (4.8 kBtu/ft²)	A limit to the annual energy consumption per area for heating and cooling the building. For comparison, ASHRAE 90.1-2010 has space heating demand requirement of 85.4 kWh/m² a (27 kBtu/ft² a) for Education Buildings in Vancouver[9]. The cooling demand limit has an additional, climate-dependent allowance for dehumidification.
Max Heat/Cooling Load	10 W/m²	Alternative means of compliance to the Thermal Demand figure. This is a limit on the peak power output of system on the coldest day of the year. Compliance can allow the small heat load to be supplied via the fresh air ventilation system – reducing heating distribution system required.
Primary Energy Demand [Site Energy]	120 kWh/m² a (38.1 kBtu/ft²) [30-60 kWh/m² a] (9.5 - 19 kBtu/ft²)	A conversion/generation factor is applied to the total site energy (including heating, HW, plug loads etc.) to give an overall primary energy demand limit. This limit was set at 120 kWh/m² a (38.1 kBtu/ft²). These limits are being recalibrated with 3 new stepped certification targets to allow for a renewable energy generation – making it easier to achieve in BC where 97 percent of energy comes from renewable sources. The reality is that this limits the EUI of the building to 30-60 kWh/m² a (9.5-19 kBtu/ft²), depending on fuel source. Architecture 2030 Challenge Targets for K12 buildings[10]. 2015 ~ 73 kWh/m² a (23.1 kBtu/ft²) 2020 ~ 37 kWh/m²a (11.7 kBtu/ft²
Airtightness	0.6 ACH@50Pa	The City of Vancouver residential code calls for 3.5 ACH@50Pa. The Zero Emissions Plan (active as of May 2017) requires 2.0 L/s*m² @75 Pa if not complying through achieving Passive House. The average airtightness for large buildings in Canada is approximately 2.15 L/s*m² @75 Pa[11]. Note that there are two differing metrics for airtightness testing: - Relative to volume of air in the building - dividing the airflow by the volume of the building. This gives a result as air changes per hour (ACH or h^{-1}), and results are usually reported at 50Pascals. This is roughly equivalent to a 20mph wind on the four sides of the building. The test report is in ACH (or h^{-1})@50Pa. This is the usual testing protocol for residential and smaller scaled buildings. - Relative to the area of the building envelope - dividing the airflow (V75) by the area of the building enclosure. This gives a result of flow per unit area (L/s·m² or cfm/ft²). Results are reported at 75Pascals (0.3 inch water column (wc)). This higher pressure can be more difficult to achieve (requiring more equipment, etc.). The test result is reported is in L/s·m²@75Pa or cfm/ft²@0.3 in wc. This is typically the testing protocol of commercial or larger scale buildings. For larger buildings (over 1500 m² / 16145 ft²), both values must be reported for facilities seeking certification. The airtightness metric is verified with an onsite pressure test in both pressurized and depressurized states for Passive House certification. Most regulatory airtightness testing require testing in one direction only.
Overheating frequency	(over 25°C) ≤ 10 percent of year	Ensuring minimum overheating due to summer sun and internal heat gains. Must be met for all living areas year-round.

2.0 SUMMARY OF PREDICTED ENERGY PERFORMANCE OF PITT RIVER MIDDLE SCHOOL

Two energy models were developed during the design of the project, which gave an insight into the predicted performance of Pitt River Middle School. These models were examined to determine whether any further energy reduction would be possible by pursuing building envelope performance requirements of the Passive House standard.

2.1 BC Hydro Incentives (August 2011)

The BC Hydro New Construction Program offers funding, resources and technical assistance for projects who use an approved energy study to achieve savings of over 50,000 kWh/a, compared to a baseline case[12]. This is an absolute number (without regard to building area) so the project type and size will determine how easy this is to achieve.

Pitt River Middle school applied for this program, comparing the proposed design and energy conservation measured with a baseline based on ASHRAE 90.1 2004. Under the BC Hydro program, the Design Team proposed a series of Energy Conservation Measures (ECMs), resulted in a 39 percent reduction of energy consumption. From the associated energy study, it was clear that space heating is the most dominant energy end use even after the proposed energy conservation measures are implemented (42 percent of total consumption, as shown in Figure 2). This makes it a viable case for the Passive House approach, which targets space heating reductions by focusing on a high quality thermal envelope.

The result of the proposed ECMs on the space heating demand is outlined in Table 2. The Passive House certification target of 15Wh/m^2a would require an overall maximum space heating demand of 83,700kWh, with an annual cost of $9,039.60 (energy costs of CAD $0.108/kWh were used in the modeling process). Typical ASHRAE compliance level for education buildings in Vancouver is approximately 85 kWh/m^2a.

Table 3 demonstrates proposed ECMs, focusing on the building envelope and their comparable Passive House recommendations, giving an idea where further reductions may be achieved through improvement of the building envelope elements.

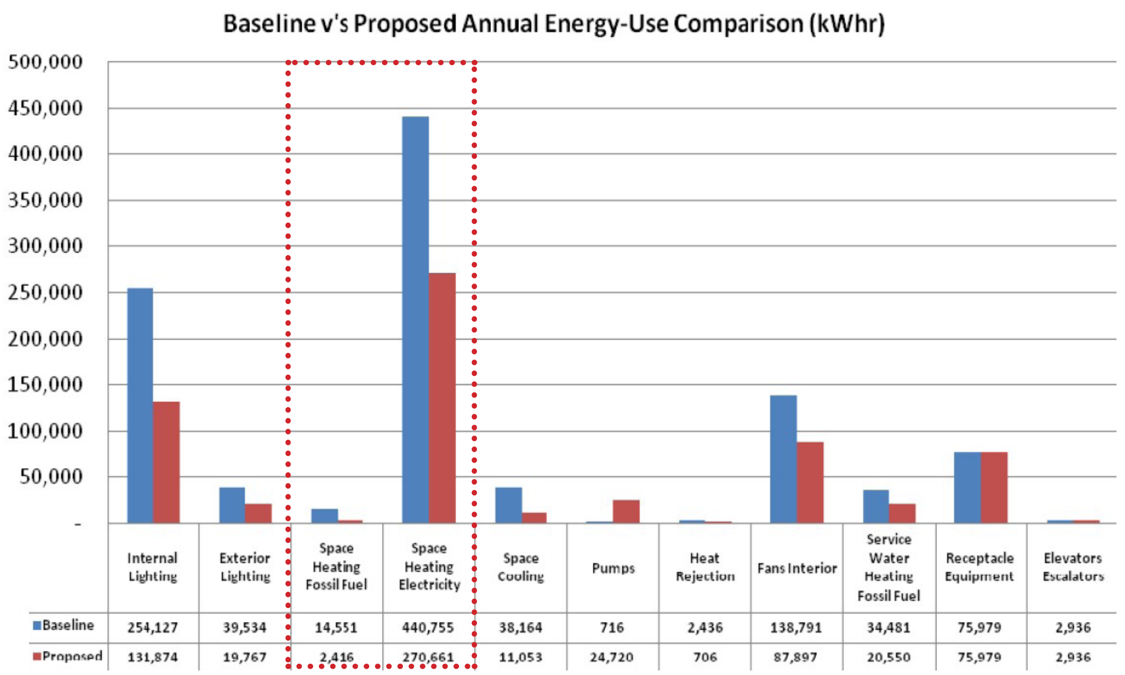


Figure 2: Pitt River Middle School Replacement Project BC Hydro new construction program schematic energy study, indicating space heating as the predominant energy usage.

Table 2: BC Hydro Incentive results compared with Passive House values.

BC Hydro	Baseline	Proposed via BC Hydro	Passive House
Annual Heating Demand	455,306 kWh/a	-273,077 kWh/a	83,700kWh/a
Specific Space Heating Demand	82 kWh/m²a	-49 kWh/m²a	-15 kWh/m²a
Cost (@ CAD $0.108/kWh)	$47,601.54	-$29,231.39	-$9,039.60

Table 3: Assembly performance values of the baseline case (as per ASHRAE90.1 2004), compared to the proposed BC Hydro Incentives and Passive House values. .

BC Hydro	Baseline per ASHRAE 90.1 2004	Proposed	Passive House (recommended)
Roof U-value W/m²K (Btu/h-ft²-°F)	0.360 *(R16)*	0.139 *(R41)*	0.09-0.15 *(R35-R70)*
Wall U-value W/m²K (Btu/h-ft²-°F)	0.475 *(R12)*	0.272 *(R21)*	0.1-0.15 *(R35-R50)*
Floor U-value W/m²K (Btu/h-ft²-°F)	0.296 *(R19)*	0.296 *(R19)*	0.15-0.175 *(R30-R40)*
Overall glazing U-value W/m²K (Btu/h-ft²-°F)	3.24 *(R1.5)*	3.24 *(R1.5)*	0.85 *(R6-8)* (installed including thermal bridges)
Thermal Bridging ψ value (W/mK)	Not accounted for	Not Accounted for	Thermal Bridge Free 0.01
Glazing g-value (SHGC)	0.39 (S,E,W) 0.49 (N)	0.39 (S,E,W) 0.49 (N)	0.5-0.6
Glazing Percentage	40 percent	57 percent	Generally 40-60 percent, varies depending on project. South exposure and solar gain to be optimized while avoiding summer overheating

2.2 LEED Energy Compliance Model (November 2013)

An IES energy model and report was prepared for the purposes of LEED certification in November 2013. This compared the proposed building design with ASHRAE 90.1.2004 to determine energy points earned under LEED Canada NC V1.0. The report was prepared for LEED certification (not to predict actual energy use or costs). The report indicated that the energy use of proposed building design was reduced by 41 percent when compared to the ASHRAE 90.1-2004 baseline building. The combination of energy efficiency measures of this facility results in 38 percent regulated energy cost savings and earns 5 points in the LEED Canada NC V1.0 Energy and Atmosphere Credit 1.

As per the BC Hydro study, space heating offered the highest potential for saving and was the highest energy use both for the baseline and proposed case, as seen in Table 4. The order of magnitude of energy use for heating is the same as for the BC Hydro study.

Important ECMs identified for achieving the proposed savings were:

- Exterior roof with overall 62 percent U-value improvement when compared to baseline case
- Exterior wall with overall 56 percent U-value improvement when compared to baseline case
- High efficiency glazing with overall 49 percent U-value improvement when compared to baseline case
- Reduction of lighting power density when compared with the baseline case
- Occupancy sensors
- Exhaust air heat recovery system
- Variable speed drives on pumps and fans
- Hydronic heating system fed by a central heating plant consisting of three water-source heat pumps with 3.3 COP, versus the baseline case's air source heat pump at 3.20 COP
- Hydronic heating system fed by a central heating plant consisting of two natural gas condensing boilers with 95.3 percent efficiency, versus the baseline case's natural gas boiler at 80 percent efficiency
- Domestic gas-fired condensing boiler with 95.3 percent efficiency, versus the baseline case's gas-fired domestic hot water boiler at 80 percent efficiency
- Demand control ventilation
- Low flow fixtures providing 40 percent service water reduction when compared to the baseline[13].

As a result of these measures, the project would achieve the following LEED NC V1.0 v3 credits:

- Energy & Atmosphere Cr1 – Optimize Energy Performance 5 out of 10 possible
- Energy & Atmosphere Pr2 – Prerequisite gained (reduce cost by 18 percent compared to ASHRAE).

There are synergies in how Passive House can help achieve points under LEED Energy and Atmosphere and Indoor Envoironmental Quality categories. The first Passivhaus public school in North America, the Center for Energy Efficient Design (CEED) in Rocky Mount, Virginia received 33 points, representing 41percent of the total points required for LEED Platinum certification. These points have been rewarded for the energy efficiency and indoor air quality benefits, achieved using the Passive Haus Certification Strategy[14].

The proposed ECMs focus on improvements to the building envelope, as well as an optimized and more efficient mechanical system. Implementing these strategies to recommended Passive House performance levels would give an opportunity for further energy savings, as is examined in the next section.

Post-occupancy energy evaluation was undertaken for the first 18 months, subsequent to the project opening. However, sub data sets of space heating were not available for comparison purposes.

Table 4: LEED baseline and proposed savings compared with Passive House values.

LEED	Baseline	Proposed via LEED	Passive House
Annual Heating Demand	474,455 kWh	251,070 kWh	86,400kWh
Specific Space Heating Demand	82.3 kWh/m²	43.6 kWh/m²	15 kWh/m²
Cost (@ $0.108/kWh)	$51,241.14	$27,115.56	$9,331.20

3.0 TAKING PITT RIVER SCHOOL TO THE PASSIVE HOUSE STANDARD

Passive House projects use an excel based energy modelling software, Passive House Planning Package (PHPP), both as a design tool and submission for third party verification under the certification process. Completing this energy model is time consuming and requires experience.

Part of this research was to explore the use of DesignPH, a SketchUp plugin, as a 3d environment that design team can work in and also understand Passive House metrics. The plugin gives initial results for the specific heating demand metric, and can automatically calculate the shading inputs required for PHPP (which otherwise can be a time consuming manual process). The DesignPH model will not give the final results for certification, it still needs to be exported to PHPP for further inputs and calibration.

This study looked to analyze SketchUp as an interface to connect Revit to PHPP, as shown in Figure 3. However, a potential area of future study is the interface between Revit and PHPP directly. Given that PHPP is an Excel-based tool and Revit has the ability to export and link to Excel (for example, using the spreadsheet link), this might improve interoperability between different software platforms.

The following steps outline the process for Revit – SketchUp (DesignPH) – PHPP data exchange:

1. Open Revit model and delete/purge all elements and worksets that are not required. For the purposes of DesignPH and PHPP, all outside surfaces of the thermal envelope are required, along with any elements that cause shading on windows, e.g. columns outside the thermal envelope, surrounding buildings, etc. Also, internal floor areas are required (without internal walls) to calculate the Treated Floor Area (TFA).
2. Export as .dwg (ACIS solids) for import into SketchUp.
3. SketchUp requires the Design PH Plugin to be installed. Depending on the cleanliness of the model, imported geometry can either be used without further modifications or remodeling over the imported geometry is necessary to create the thermal envelope. This can be achieved by working with groups and layers within SketchUp to separate walls, roofs, glazing, etc. in component parts. Each element is assigned an element grouping (Wall Ambient, Roof, etc.), and assigned U-value. Design PH has a glazing component tool, which can be used to create windows and assign thermal properties to frames and glazing.
4. DesignPH allows export to PHPP (v8 and v9). With larger projects, the SketchUp file ends up with a large number (500+) of surfaces for walls, window frames, etc., which is a problem for PHPP to handle. This requires editing PHPP to add more rows in Excel (not recommended) or simplifying the model further to reduce the number of surfaces.

Figure 3: Modelling processes with the Passive House standard.

There is an opportunity for an improved workflow from Revit (or other BIM platforms used by architects, such as ArchiCad) to PHPP. There is potentially a computational design interface using Dynamo within Revit that could serve to communicate with PHPP directly to streamline the process, especially when it comes to early design stage iterations. It is vital for the success of a Passive House project that the PHPP be used as a design tool and not as a spot check once a design has been finalized.

Figures 4 and 5 show the energy balance of the Pitt River Middle School, as modelled in Design PH (similar to the energy balance graph formulated typically in PHPP). These figures compare the losses to gains, and the remaining segment is the heating demand.

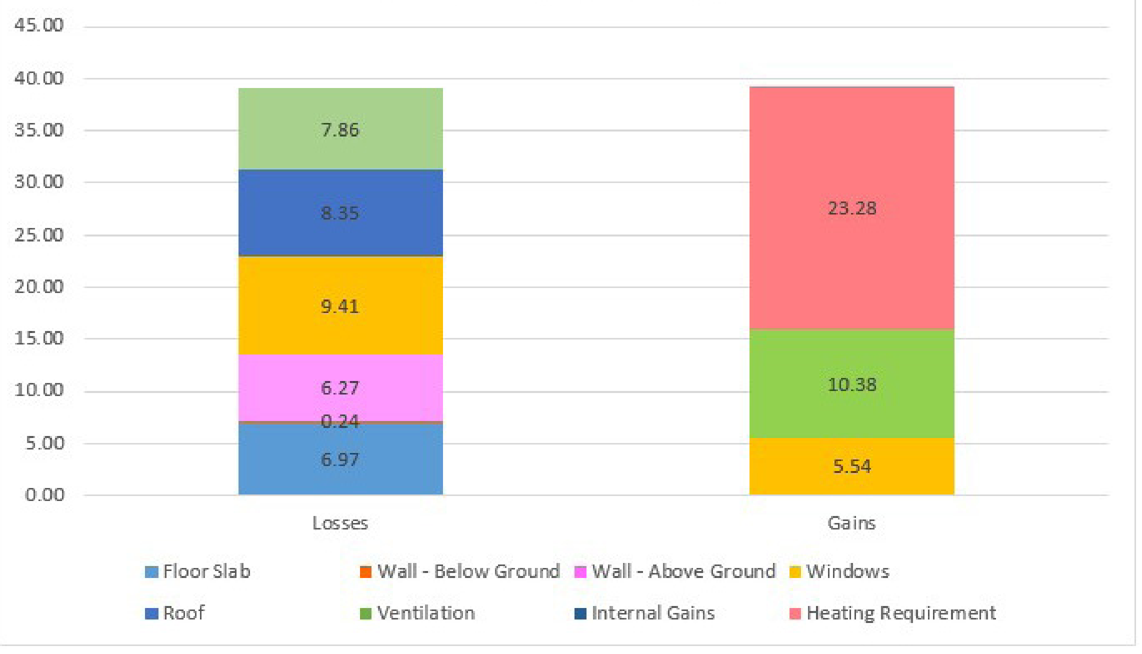
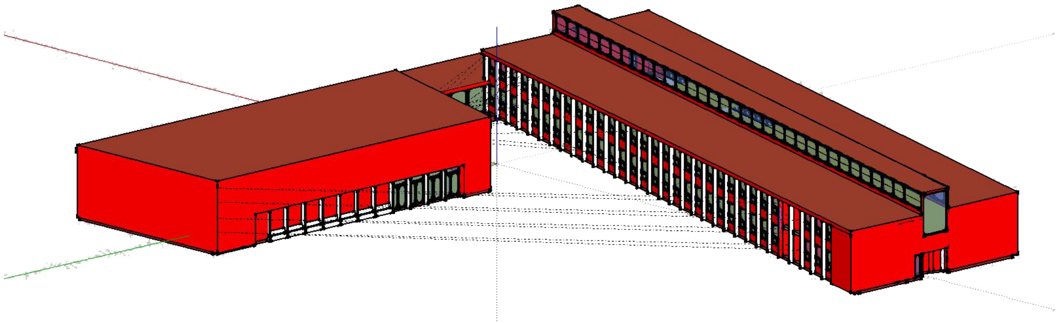


Figure 4: Result of DesignPH modelling – energy balance graph.

CLIMATE: Vancouver
Qh 23 kWh/m²a
TFA 5688 m² (User-defined)
Heat Loss Form Factor 1.91



Losses (kWh/a)		Gains (kWh/a) (Utilization factor: 0.99		Heating Demand (kWh/a) (Q_H)
Transmission (Q_T)	Ventilation (Q_V)	Solar (Q_S)	Internal (Q_I)	
177721.57	44681.50	31524.90	59053.19	132429.32
Specific Annual Heat Demand (q_H) = Q_H /TFA = **23.28 kWh/m²a**				

Figure 5: Energy balance of Pitt River Middle School, as modelled in DesignPH.

Using a TFA of 5687.8 m² (61,223 ft²), as exported from the Revit model, the specific annual heating demand for Pitt River School was calculated as 23.28 kWh/m²a (7.4 kBtu/ft²), compared to the Passive House certification standard of 15 kWh/m²a (4.8 kBtu/ft²), as shown in Figure 6.

While the results indicate that the project lies outside the certification target, with further refinement achieving the standard could potentially be possible. The results, like any other modelling effort, are only as good as the inputs. Potential areas that would negatively affect the calculation include:

- The TFA calculation, on which the Passive House certification standard is based, would require further study. While it compares to the areas used for the BC Hydro and LEED modeling efforts, the area used was imported from Revit without any further verification per Passive House parameters (e.g. all internal walls discounted, stairways not double counted, etc.). As a result, there is a high likelihood the actual TFA is a smaller area, which could increase the specific heat demand.
- Thermal bridging was assumed to follow Passive House best practices (without thermal bridging), therefore having negligible effect on the resulting heat loss. In reality, the details as proposed have a PSI value of greater than 0.01W/mK (0.006 kBtu/hr-ft-F).and therefore would need to be accounted for in the energy model, as discussed in more detail in the later section. This can be assigned within DesignPH. Thermal bridging was not factored into either of the BC Hydro or LEED energy models, and can be a source of considerable heat loss if not taken into consideration. This is explored further in the next section.
- The inputs assumed that the airtightness target of $0.6h^{-1}$ is met and the HRV is at least 75 percent efficient, as measured to the Passive House standard protocol (HRV units tested to the North America protocols are typically found to be less efficient when tested to International Passive House protocols, mainly due to more stringent requirements on the recirculation of air within the unit and limits on electric fan power).
- No surrounding context was modelled, which

could have a large impact on shading and solar gains. This, however, is not likely to be a major issue as there are no significant shading elements to the south of the project.

- Internal gains are modelled using the PHPP default value of 2.1 W/m². In the UK, Passive House school projects have found that this default is too low[15]. In reality, correct internal gains would have to be modelled based on occupancy, usage patterns, equipment and lighting to determine more accurate internal gains.
- Altitude of the project can have an effect on the results and would need to be correctly entered in PHPP.

The 15 kWh/m²a certification target is based on the TFA as calculated per PHPP protocols. Defining this value correctly, along with setting the correct climate data, is one of the first steps when using PHPP to model a Passive House project. For the purposes of this study, the value used was that imported from Revit of 5688 m². This falls between the values used for the BC Hydro energy study (5580 m²) and LEED (5760 m²). Using either of these values gives a q_H value of 21 and 24 kWh/m²a, respectively. The overall heating demand value is still relevant, at 132,429 kWh/a it is still more than 50 percent smaller than that of the optimized BC Hydro and LEED models (273,077 kWh/a and 251,070 kWh/a, respectively). In this study, this was achieved without

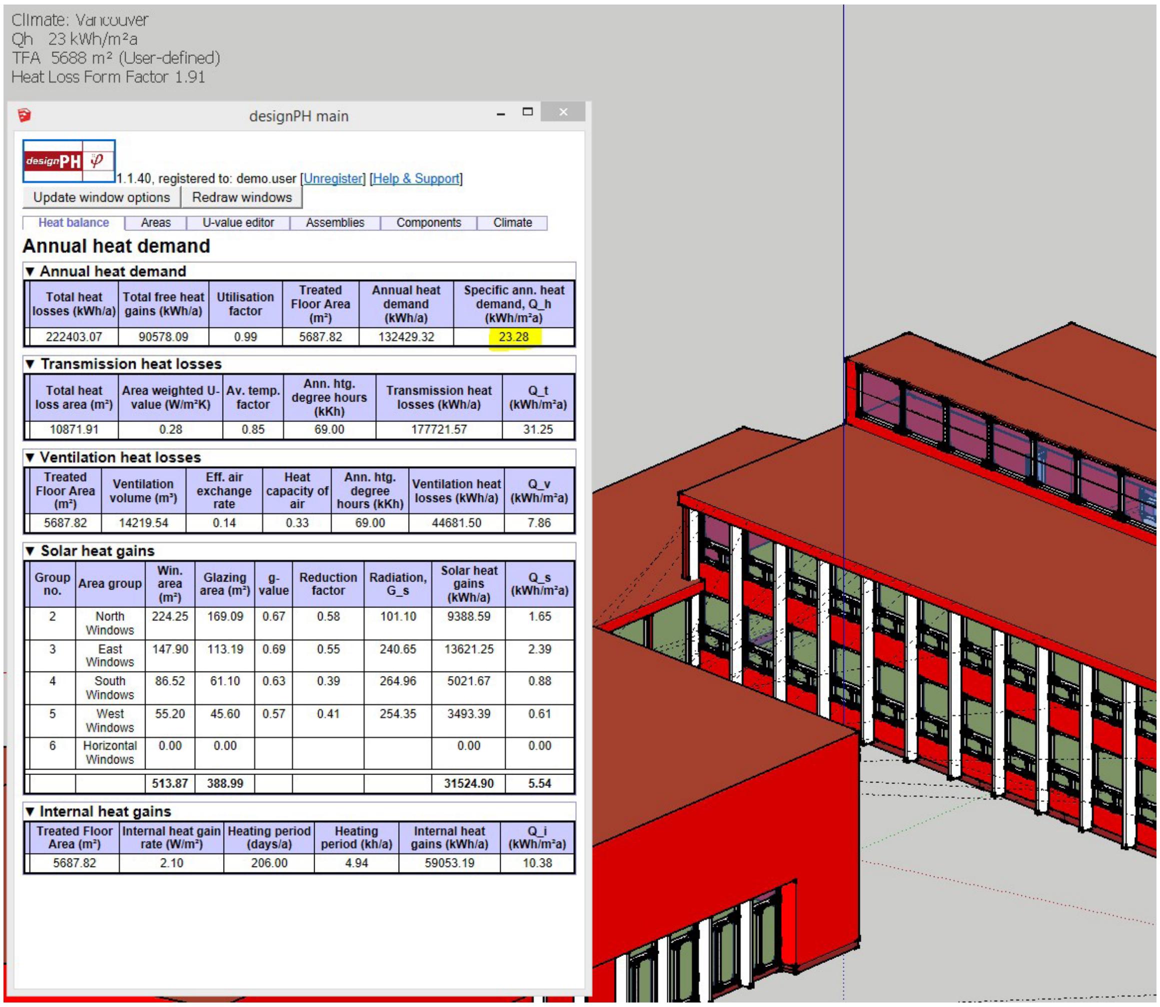


Figure 6: Energy balance of Pitt River Middle School as modelled in DesignPH.

any change to the design, just be assuming a Passive House level of performance for the building envelope elements.

To achieve the additional heat loss savings required (~8 kWh/m²a), these elements would have to be examined in detail and there may also need to be changes in the design (more compact form, glazing ratios, and examination of window energy balance revisited). This is where it is important to seek performance improvements without compromising the architectural design and integrity of the project. Whether these final improvements of 8 kWh/m²a, the most difficult to achieve, are worth any compromise on the design is something for the design team to consider. This can become a source of conflicting ideals if the standard is not considered from the outset. However, having the target established from the start and having everyone on the design team, client and if possible contractor on board and engaged, ensures that it is a shared goal and ambition as opposed to a source of conflict with project aims.

4.0 ANALYSIS OF THE BUILDING ENVELOPE

4.1 Form Factor

Passive House Form Factor quantifies the relationship between the living area of the building and the total amount of surface area. The form factor is calculated by dividing the total heat loss area by the floor area.

The form factor is related to the amount of required insulation in building envelope. If the building form is compact, this reduces surface area and subsequently heat loss, reducing the amount of needed insulation to obtain improved thermal performance. For Pitt River Middle School, the form factor is 1.91. This does not tell us much without comparing it to other similar sized projects. However, this would be an area that could be revisited to see if the design be made more compact to achieve the additional ~8kWh/m²a savings.

While designing the most compact form possible is not always the most architecturally desirable solution for a given project, the effect of creating a less compact form should still be understood by the design team.

4.2 Opaque Elements

Table 5 outlines the properties of opaque elements of the building envelope, and improvement strategies.

Table 5: Properties of opaque elements and improvement strategies.

Element	As Specified / Built	As modelled	Comment
Walls: U-Value (W/m²K)	0.272	0.15	This could have been modelled at a higher level (some Passive House projects achieve 0.1 W/m²K)
Roof: U-Value (W/m²K)	0.139	0.14	The roof as specified and built was within Passive House levels at 0.139
Floor: U-Value (W/m²K)	0.8	0.25	There was 2" of insulation under the ground floor slab. There is scope for improvement here. The U-Value modelled is conservative, 0.25 equates to ~160mm of EPS (λ= 0.04W/mK / R3.6 per inch). The insulation provided in the project was not continuous at perimeter footings, which would result in a thermal bridge (discussed in the next section).

4.3 Glazing

Table 6 lists U-value of the windows in the project. When specifying windows, it is also important to note that generally manufacturers provide only center of glass U-value for a fixed size unit. It is also necessary to obtain and specify a frame U-value, spacer thermal bridge value and if possible the thermal bridge of the installation detail (discussed more in the next section). Individual windows within a project will have different U-values if the sizes vary (this is calculated in PHPP for each window and factored in). PHPP is available in both metric and Imperial units, and care needs to be taken when specifying units to use consistent method. The best performing Passive House windows are generally 0.59-0.75 W/m²K with the recommended install U-value (accounting for the thermal bridge of the connection to the wall) being 0.75 -0.85 W/m²K (0.13-0.15 Btu/hr-sf-°F).

Table 6: U-value of windows.

Element	As Specified / Built	As modelled
Windows: U-value (W/m²K)	1.53 Fixed 1.76 Operable	0.92 (Installed)

Windows were modelled with a Psi install (thermal bridge value as discussed below) of 0.04W/mK. This is a default PHPP value that indicates a thought-out detail, but it can be improved with further attention to fully eliminate thermal bridge (≤ 0.01 W/mK). Left unattended, this thermal bridge at window installation can result in sizeable heat loss (as modelled below). The install U-value modelled in this study (accounting for glass, frame, spacer and installation) is 0.92 W/m²K. This in itself is conservative, typically 0.85 W/m²K is recommended, but there are not as many Passive House level windows available in North America. This higher performance requirement for windows is to ensure heat loss is minimized but also to ensure comfort and hygienic requirements are met. The average temperature internal surface of the glazing and minimum surface temperature is limited to avoid unpleasant cold air descent, radiant heat deprivation and eliminate the risk of condensation and mold growth (PHPP will issue a warning glazing elements are close to or above these thresholds).

There is a large amount of glazing in the project, in particular oriented north. This is good from a daylighting point of view and in Pitt River Middle School results in a very successful corridor spaces lit via north facing clerestory windows, as seen in Figure 1. However, it is not desirable from a heat loss perspective, and the north facing windows results in losses of approximately 24,000 kWh/a (or 4.2 kWh/m²a). Overall, there are 53,550 kWh/a losses (or 9.4 kWh/m²a) compared to 31,525 kWh/a gains (or 5.5 kWh/m²a). Generally, Passive House projects seek to minimize losses and maximize gains. Glazing elements are less efficient than opaque surfaces but are also the only building envelope element which can serve as a source of free heat and result in a net gain contributor.

4.4 Thermal Bridging

Thermal bridges, sometimes referred to as "cold bridges", occur in the building envelope when a material of relatively high conductivity interrupts or penetrates the insulation layer. They provide a path of least resistance for heat to bypass the insulation layer and have a measurable impact on energy efficiency and thermal comfort. As buildings become more insulated, the relative effect of thermal bridging becomes more pronounced.

In addition to being a source of heat loss, the primary reason to avoid thermal bridging is the durability of the building envelope and indoor air quality. Thermal bridging can result in colder surface temperatures on the internal surface of the building envelope. This in turn can lead to warm moist air, hitting a colder surface, with a risk of condensation and mold. In order to ensure human comfort that Passive House requires, internal surface temperatures should be maintained above 17°C (62.6°F). Critical areas (e.g. door thresholds, window frames, etc.) should be kept "condensation risk free" above 12.6°C (54.7°F) the temperature where dew point is likely, by eliminating thermal bridging.

There are a number of different types of thermal bridges, which are outlined below. Typically, the approach in Passive House buildings is to avoid/eliminate thermal bridging by ensuring continuity of insulation. While this takes a bit of consideration in the design stage, it is a simpler and in the long run more cost-effective, in terms of energy loss and building detailing.

Thermal bridges are often unavoidable, particularly where there are other multiple issues to be resolved at a junction (e.g. structure, fire safety). Where they cannot be eliminated, they should be minimized and accounted for in the PHPP energy model.
Thermal bridges can be categorized in a number of ways, but there are two main groups:

- Geometrical thermal bridges occur due to the building form. It may be due to shape alone where the thermal envelope changes shape, such as an external wall corner.
- Construction thermal bridges occur where there is a penetration or gap in the insulation due to the construction.

There are a number of other sub-categories of thermal bridges that are often referenced:

- Repeating thermal bridges are construction-based and follow a regular pattern and are evenly distributed over an area of the building envelope, such as studwork in a wall assembly, cladding attachments, masonry wall ties, etc. These are the only thermal bridges accounted for in ASHRAE 90.1, whereby the R-values of the assemblies are degraded from nominal R-values to effective R-values[16]. This is allowed in

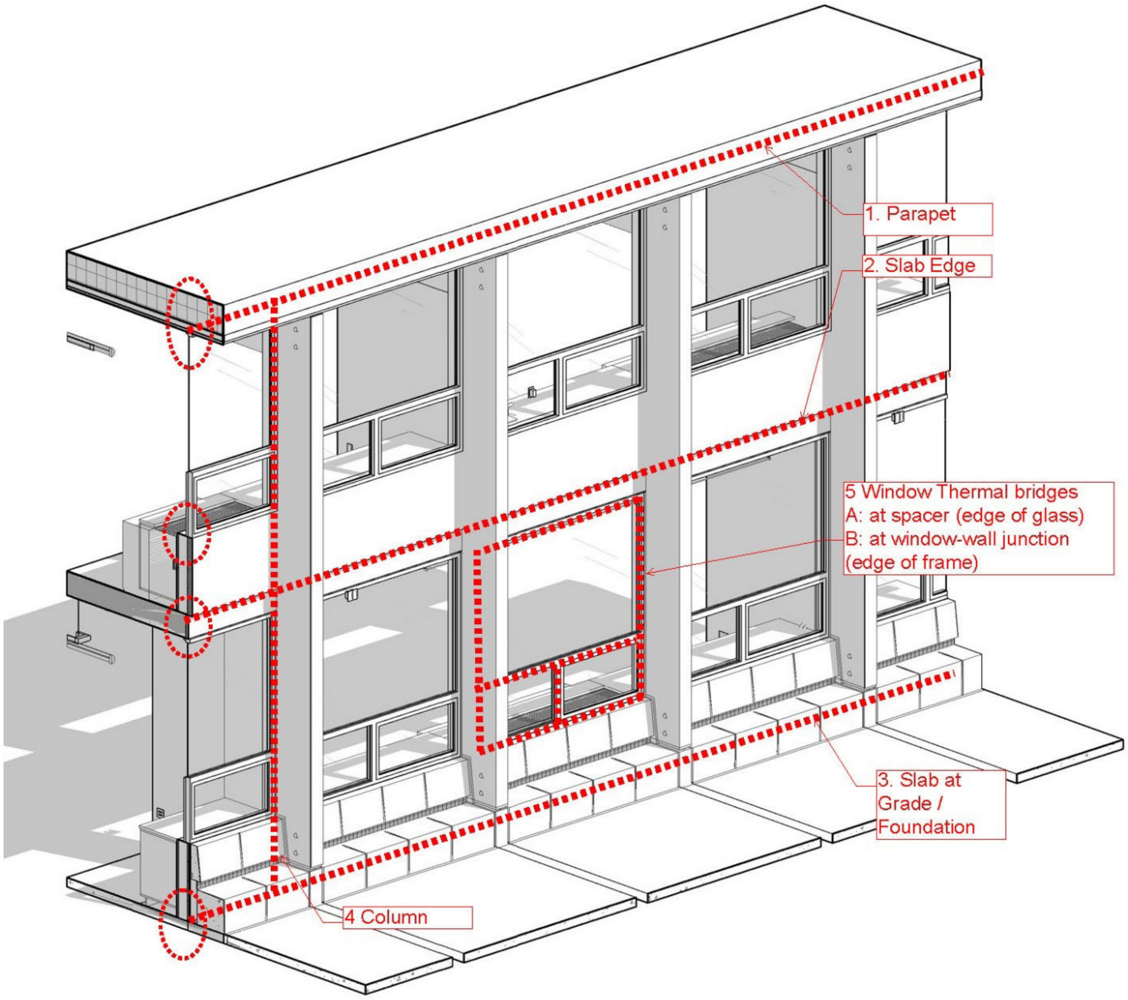


Figure 7: Potential areas of (linear) thermal bridging.

PHPP modelling. Repeating thermal bridges can have a significant effect on heat loss.
- Non-repeating are intermittent and occur at a specific point in the construction. These may be linear thermal bridges or point thermal bridges, as described below.

There are also a number of thermal bridges that may come as a surprise to the design team and may need to be modelled in PHPP, such as curtain wall anchors, rainwater liters and sanitary pipes if uninsulated and penetrating the envelope, any direct venting (e.g. a kitchen extract hood, dryer exhaust), etc.

Figure 7 shows potential thermal bridges for this project. In the instance of the balcony detail thermal bridging was recognized as a potential issue by the design team and was highlighted in the project specifications and detail drawings. Excerpts from specifications are included below:
- Provide thermal isolation where components penetrate or disrupt building insulation. Install gap-filling insulation in shim spaces at perimeter of assembly to maintain continuity of thermal barrier
- Structural Performance: Provide structural thermal break assemblies capable of withstanding the design loads within limits and under conditions indicated.

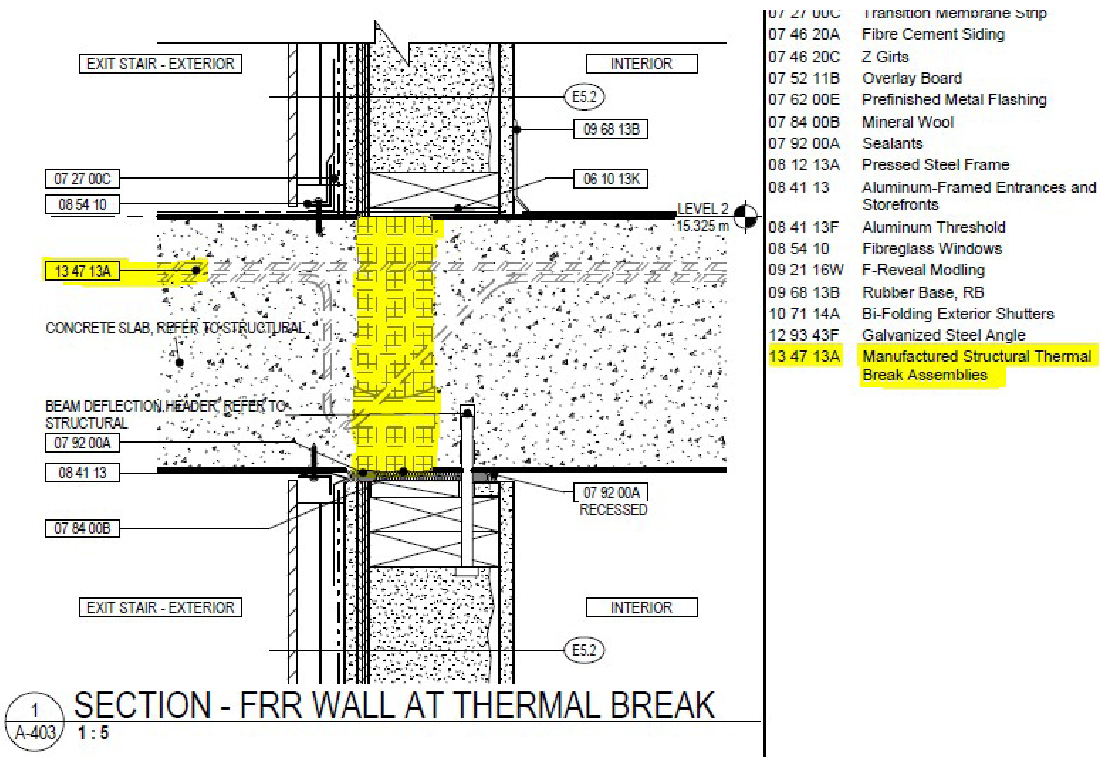


Figure 8: Detail drawing.

- Expanded-Polystyrene Foam Insulation: Manufacturer's standard high density foam with graphite; minimum thermal transmittance (U-factor) of 0.78 W/sq. m x K per 25 mm thickness.

Of note are structural thermal breaks installed at floor slabs, penetrating the envelope to become a balcony slab. Typically, balcony slabs are constructed without the thermal break, and dramatically decrease the effectiveness of assembly. It is important that these measures are not only specified, but also installed correctly. Passive House certification process requires photographic evidence of the thermal break correctly installed to achieve certification. In a Passive House project, all potential thermal bridges need to be identified and calculated and the specification would need to indicate required Psi (ψ) values (described below), and mitigation measures.

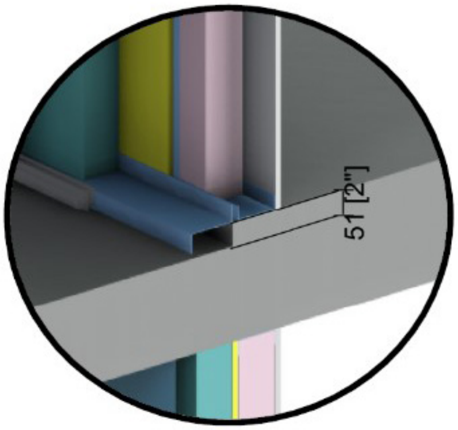
Thermal bridging can have a dramatic effect on the thermal performance of building envelopes[17]. In the example illustrated in Figure 9, the nominal R-value of R-29 (Btu/hr-ft^2-F) wall becomes an effective R-value of R-8.6 due to the thermal bridging of a concrete slab. Installing a thermal break does not completely mitigate the problem and render the detail thermal bridge free, but can restore some of the effectiveness of the insulation, in this example to R-13.6.

In terms of energy loss through thermal bridges, this is assigned a coefficient known as the Psi (ψ) value for linear thermal bridges and a Chi (χ) value for point thermal bridges. Similar to a U-value for elements such as walls, this value indicates the rate of heat flow through the thermal bridge. For a Passive House project to be thermal bridge free, these values should be less than or equal to 0.01W/mK (0.006 kBtu/hr-ft-F). This is achieved through detail design, providing adequate continuous insulation and specifying materials of adequate thermal performance.

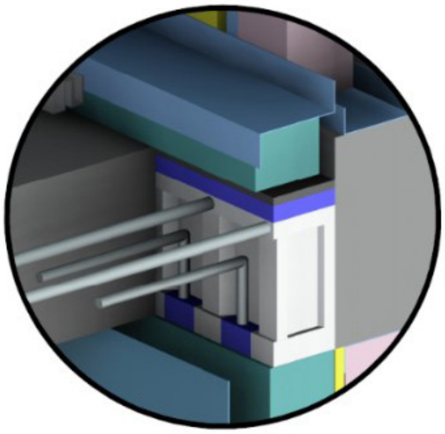
The heat loss effect of a thermal bridge is given by multiplying ψ value by the linear length of the thermal bridge, such as a balcony running around the perimeter of a building. Table 7 illustrates the comparative effect of the potential heat losses of a thermal bridge 200 m long the

Table 7: Comparison of heat losses for different climates, in relation to thermal bridging. This given by is the heating degree hours by the climate data files within PHPP, given in kilo-Kelvin hours per annum (kKh/a). This is 69kKh/a for Vancouver and 93kKh/a for Toronto.

	No thermal break	Thermal break	Passive House
ψ (W/mK)	1.059	0.327	0.01
Heat loss (W/K) = ψ x L	211.8	65.4	2
Annual Demand in Vancouver* HL x 69 (kWh/a)	14,614.2	4,512.6	138
Annual Cost in Vancouver AD x $0.108/kWh	$1,578.3	$487.4	$14.9
Annual Demand in Toronto* HL x 93 (kWh/a)	19,697.4	6,082.2	186
Annual Cost in Toronto AD x $0.108/kWh	$2127.3	$656.9	$20.1



Balcony Stepdown Detail



Thermally Broken Slab Detail
(Isokorb CM20)

Figure 9: The example on the left (no thermal break) has a ψ value of 1.059 W/mK (0.612 kBtu/hr-ft-F) and degrades an R-29.1 h-ft²-°F/Btu (5.15 m²K/W) wall build-up to R-8.6 h-ft²-°F/Btu (1.51 m²K/W). The example on the right with the thermal break installed has a ψ value of 0.329 W/mK (0.189 kBtu/hr-ft-F] and degrades the same wall build-up to R-13.6 h-ft²-°F/Btu (2.40 m²K/W)[17].

perimeter (if the balcony detail ran the full length north and south of the academic wing of Pitt River Middle School, it would be this long). Also noted are the effects of the same detail in a different climate (Toronto), for illustrative purposes.

4.5 Window Installation Thermal Bridge

Part of the study's aims was to examine the process of thermal bridge modelling and calculating PSI (ψ) values. This is a scope of work that is integral to Passive House projects, but not required in typical projects. This was conducted using heat transfer analysis software THERM, developed by Lawrence Berkley National Laboratory. The window sill detail was examined, as seen in Figure 10, with the results shown in Table 8.

Repeating thermal bridges (e.g. studwork in an wall assembly) are generally accounted for in degrading the R-value of the wall. Non-repeating thermal bridges are measured by assigning a thermal bridge loss coefficient. These may be 2D/linear (e..g a length of parapet) or 3D/point thermal bridges (e.g. a steel beam penetration). Using modeling software, such as THERM, the design team can determine the exact heat loss through a detail of a building component. This can be compared to the heat loss that is estimated within an energy model (e.g. PHPP) by using the U-values and areas of the assemblies. This comparison of real versus estimated values gives an adjustment factor to be applied to the detail to account for the thermal bridging effects. This is essentially an accounting principle that compensates for the difference in heat loss between values modelled based on assemblies and the actual heat loss.

For point (3d) thermal bridges, the correction factor is known as the Chi (χ) Value. In Passive House design, these bridges are usually designed out and can be ignored unless they contribute to significant heat losses (in which case they may require specialist thermal bridge modelling, such as for a steel beam penetration).

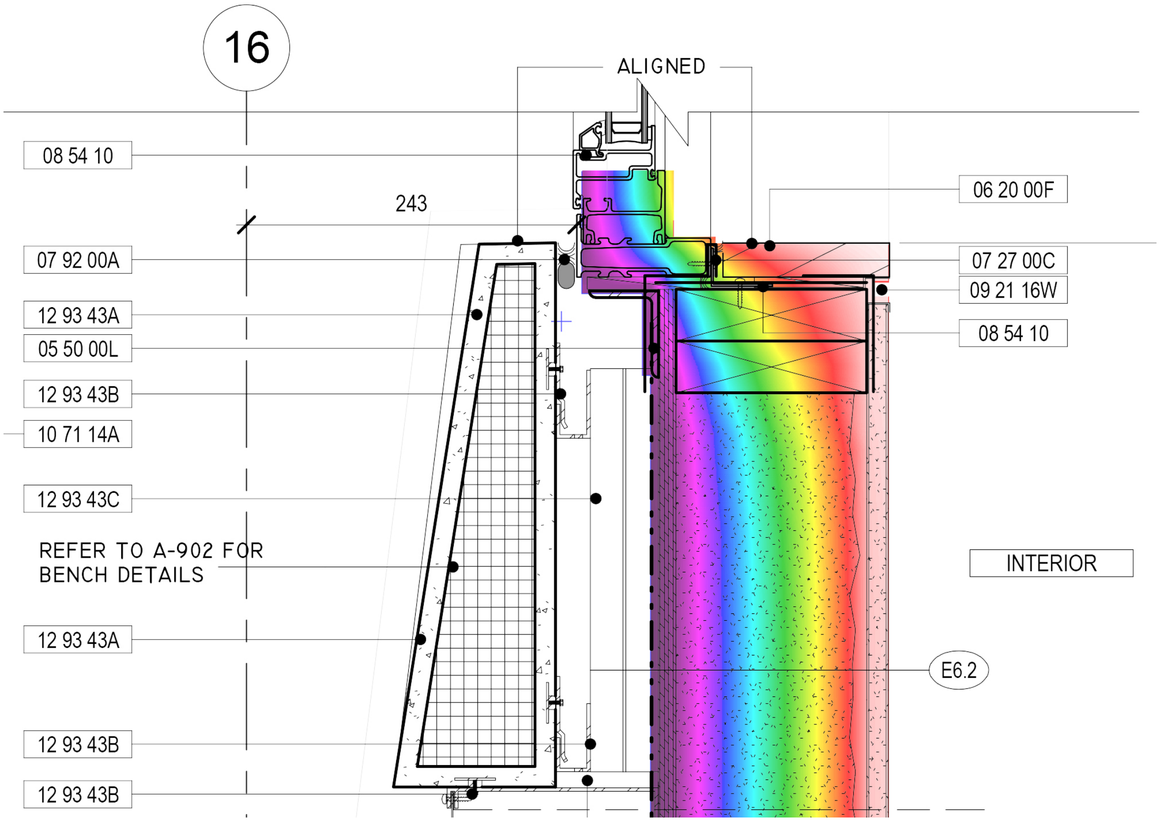


Figure 10: Pitt River typical window sill detail, where the PSI value was calculated using THERM software as 0.129 W/mK.

Table 8: Heat loss and cost of thermal bridging of window installation detail.

		TB total length (m)	ψ value (W/mK)	Total Annual Heat Loss (kWh)ψxLx69	Total Annual Cost @$0.108/kWh
Window Sill	As Built	591	0.129	5260.49	$568.13
	Passive House	591	0.04	1631.16	$176.17

For linear (2d) thermal bridges, this value is known as the PSI (Ψ) value. Multiplying the Ψ value by the linear length (L) of the junction will give the heat loss as a result of thermal bridging for this detail. This can be used as an input for PHPP to give the correct heat loss from thermal bridging. A design without thermal bridging can be defined as $\Psi \leq 0.01$ W/mK (0.006 kBtu/hr-ft-F). It is possible to have a negative PSI value. PHPP uses external dimensions for measuring heat loss. This means that the heat loss at external junctions may be overestimated (accounted for twice). The negative PSI value compensates for this.

For Passive House, U-value of the glazing must account for U-values of the glass (center of pane) and the frame, and the Psi values of the glass spacer. This is not the actual U-value that a window will have in reality, as the installation detail can have a thermal bridging effect and needs to be accounted for. The default in PHPP for a well-designed detail is $\Psi = 0.04$ W/mK (0.023 kBtu/hr-ft-F). The typical Pitt River window detail was modelled in THERM, giving a resultant thermal bridge value of $\Psi = 0.129$ W/mK (0.074 kBtu/hr-ft-F).

A typical classroom window in the project is 2.575 m x 2.350 m, and there are 60 windows in total, giving a total perimeter length of 591 m. The window sill thermal bridge ψ value may differ slightly at the jamb and head due to detailing, but for the purposes of this research was assumed constant. The heat loss (and cost) is reduced by 70 percent by bringing the value to the default 0.04 W/mK.

Assuming that the wall assemblies are optimized to achieve recommended Passive House U-values, it is possible eliminate thermal bridging (ψ value <0.01W/mK). The junction with the wall requires careful detailing in order to eliminate the thermal bridge of window installation. Some basic rules of thumb to improve the ψ value are:

1. Placing window as close to centre of insulation layer as feasible;
2. Over-insulating frame;
3. Avoiding extra framing and blocking at rough opening; and
4. If possible, using non-metal flashing.

5.0 CONCLUSION

This study demonstrates that the recommended Passive House levels of thermal performance are a step beyond existing best practices. This study was limited to examining the role of Design PH as a precursor to PHPP modelling, and discussed the process of calculating thermal bridging. Specifying Passive House levels of performance for the building envelope, assuming an optimized mechanical system specification and layout, will get a project approximately half way there (in this case from 49 kWh/m^{2}a in the BC Hydro Report, 44 kWh/m^{2}a in the LEED Report to ~23 kWh/m^{2}a). The final reduction, in this case ~8 kWh/m^{2}a, is always the hardest to achieve. This shows the importance of setting the target as a goal at a very early stage in the project, as a project cannot be "made" Passive House compliant at the end of schematic design stage or beyond, once important design decisions have been made. It requires careful planning and consideration, as well as engagement of the whole project team.

As was the case with the first LEED projects, the first Passive House projects will have a steep learning curve. The question of identifying and quantifying any required extra cost to achieve the Passive House standard is usually one of the first to be asked. This is closely tied to the impact on schedule. The cost impact can be broken out into:

1. Impact on construction (costs and schedule);
2. Building operation/running costs;
3. Impact to design stage (costs and schedule), such as additional work required by the architect and design team; and
4. Passive House consultancy and certification costs.

While this is outside the scope of what was explored in the context of the study on Pitt River Middle School, further study into this area is being explored by the author and will be the subject of subsequent articles.

In terms of the effect on the design process, there are a number of elements that differ from a traditional project, specifically requiring additional scope of work and sequencing of work. There is more detailing required, particularly in terms of meeting the required performance levels for airtightness and thermal bridging.

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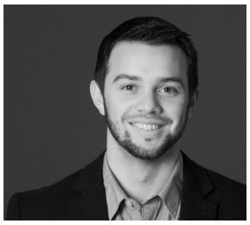

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