

Enhancing the Liveability and Resilience of Multi-Unit Residential Buildings (MURBs)

MURB DESIGN GUIDE

VERSION 1.0, JANUARY 2017

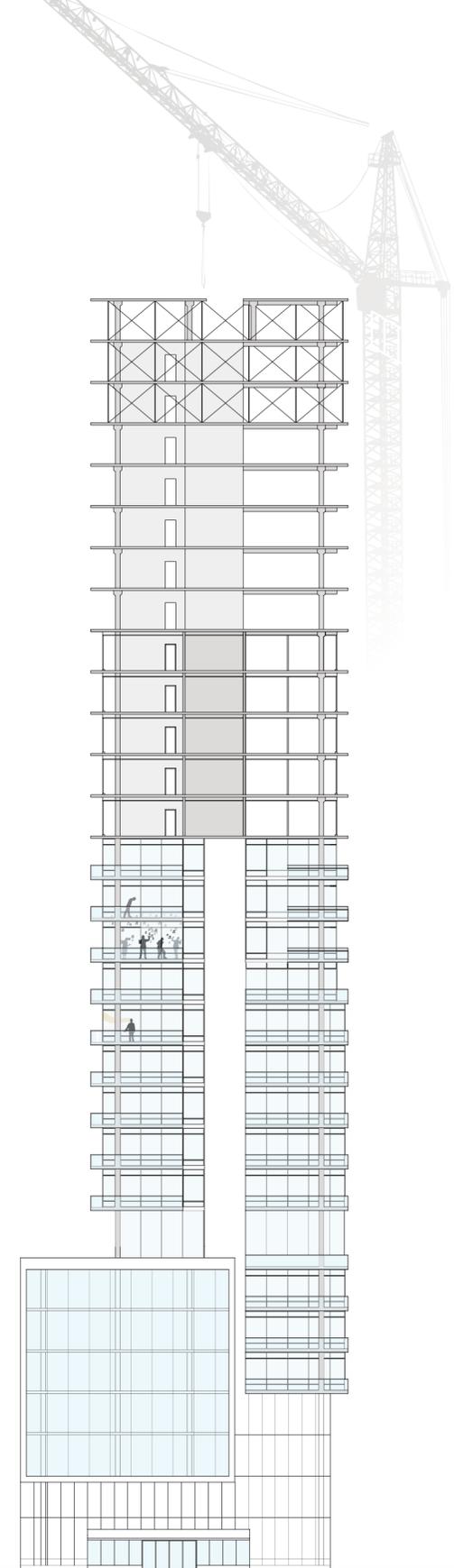
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MURB Design Guide

ACKNOWLEDGEMENTS

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DISCLAIMER

The information presented in this publication is intended to provide guidance to knowledgeable industry professionals experienced in the design of multi-unit residential buildings. It remains the sole responsibility of the designers, constructors and authorities having jurisdiction that all work performed conforms to applicable code and standards, and adheres to sound building science principles. This guide is not a substitute for prudent professional practice and due diligence. References to external organizations, agencies, web sites and publications, and the provision of downloadable reference materials, do not constitute an endorsement of any of these sources of information. While care has been taken to ensure the accuracy of information presented herein, this publication is intended solely as a document of building science and architectural intent. The authors, contributors and sponsors assume no responsibility for consequential loss, errors or omissions resulting from the information contained herein. The views expressed in this guide are those of the authors and do not necessarily represent the views of the contributors and sponsors.

HOW TO USE THIS GUIDE

This publication is intended to serve as a framework guiding the design of multi-unit residential buildings in a Canadian climate, specifically mid-rise and high-rise housing typologies. It is aimed primarily at practising architects and engineers, but it can also be helpful for anyone interested in MURB design. In-depth reference materials may be downloaded to gain further insights beyond what is presented in this Guide.



Key Messages

MULTI-UNIT RESIDENTIAL BUILDING (MURB) DESIGN GUIDE

MURB Design Basics

Liveability – Access to light and air, thermal comfort, accessibility, utility, amenity, privacy, safety and security.

Sustainability/Resilience – Massing, structure, enclosure, flexibility, adaptability, materiality, serviceability.

Civility – street interface, impact on surroundings, indoor/outdoor connectivity, focus on pedestrians.

Building as a System

Passive versus Active Systems – Privilege passive systems to provide primary performance supplemented as minimally as possible by active systems.

Building Systems Integration – Massing, structure, enclosure, flexibility, adaptability, materiality, serviceability.

Inhabitant Choice versus Automated Control – Manual override for all key functions, minimal and simple controls.

Passive Systems Design

Enclosure – Rain control and moisture management, effective thermal resistance, thermal bridging, window-to-wall ratio, airtightness, compartmentalization.

Materials – Durability, useful service life, ecological footprint (embodied energy and environmental impacts), material efficiency (reduce/reuse/recycle), no adverse health effects for inhabitants or workers.

Site & Landscape – Stormwater management, plantings, accessibility, outdoor comfort and amenity.

Active Systems Design

HVAC Systems – Individualized heating, ventilating and air-conditioning for suites, sub-metering.

Renewable Energy – Solar thermal domestic water heating, green power purchasing.

Emergency Power – Combined heat and power (CHP) and/emergency storage.

Commissioning

Commissioning Plan – Owner's project requirements, performance targets, mock-ups, agents/consultants.

Review, Inspection, Testing – Peer review of details and specifications, quality assurance program, field testing.

Operations and Maintenance – Project documents, equipment manuals, warranties, operations and maintenance schedules.

Post-Occupancy Evaluation

Measurement and Verification – Thermography, airtightness testing, energy and water consumption, temperatures and thermal comfort.

Occupant Survey – Comfort, convenience, cleanliness, privacy, etc.

Inhabitant Engagement – Information dissemination, feedback mechanisms, social events/initiatives.

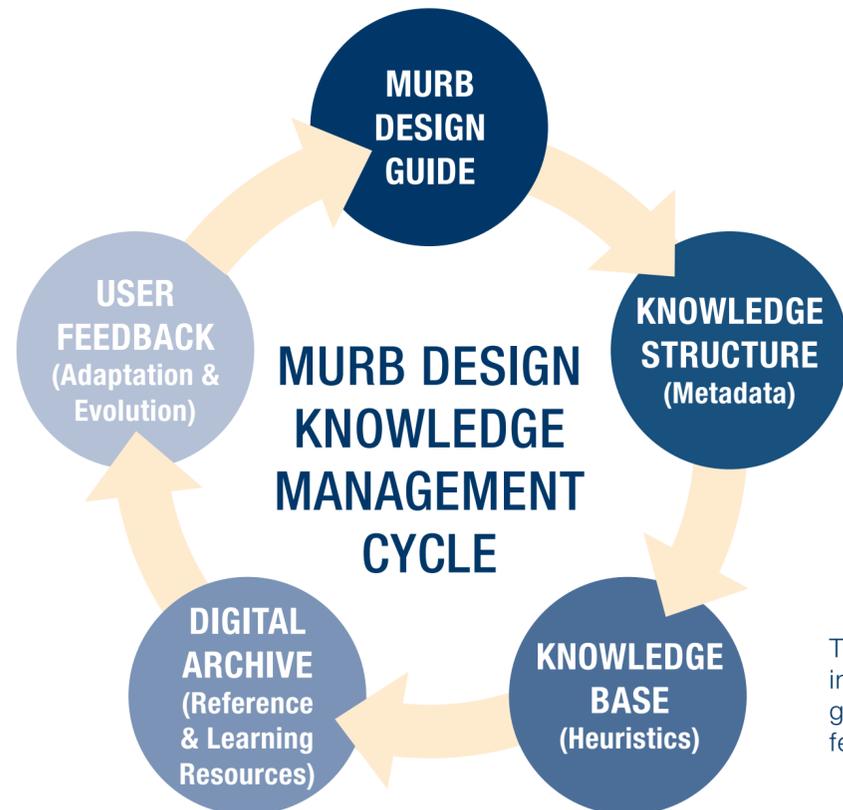
NAVIGATING THIS MURB DESIGN GUIDE

This design guide is aimed at design professionals such as planners, architects and engineers, but may also provide helpful insights to legislators and policy makers wishing to improve the performance of MURBs. It may also serve as an educational resource in professional programs of architecture, planning and urban design.

How to Use This Guide

The approach adopted within this guide is to provide users with a “knowledge map” of the field of performative multi-unit residential building design to help them navigate more integrative solutions. This digital guide document in .pdf format represents a cognitive framework that outlines the key considerations in the development of efficient, comfortable and resilient multi-unit residential buildings in a Canadian context. This guide contains hyperlinks to a downloadable digital archive that contains detailed and in-depth information in the form of journal articles, technical studies, design guides, and literature reviews about specialized topics related to MURBs.

Users are encouraged to take a tour of this entire document and then to selectively access knowledge and information resources according to their needs and interests. Feedback from users is welcome and encouraged.



The initial research project supporting this publication is intended to establish a knowledge base for a MURB design guide that can evolve, adapt and grow based on user feedback and innovation.

Knowledge Map (Metadata) Structure

- Intended primarily as a digital desktop reference document
- Digital guide is structured as a cognitive framework
- Focus is on energy efficiency, comfort and resilience (including durability)
- Knowledge map connects users to external sources of information



Use download icon to access digital archive

Downloadable Digital Archive

- Case Studies
- Technical Reports
- Design Guides
- Journal Papers and Articles
- Best Practices

KNOWLEDGE MAP



DOWNLOADS

MURB Design Guide
Enhancing the Liveability and Resilience of Multi-Unit Residential Buildings (MURBs)

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Rules of Thumb for MURB Design

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- Massing
- Orientation
- Structure
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- Materials
- Access / Streets
- Indoor / Outdoor Connectivity

MURB Design Guides

Toronto Condo Projects

MURB Design Survey

Healthy Communities

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Building Science Basics

Building System Performance

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- Thermal Control
- Thermal Persistence
- Recommended Levels of Thermal Insulation
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- Natural Ventilation

Building Enclosure Design

Thermal Bridging

MURB Energy Efficiency

Daylighting

Natural Ventilation

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- Individual vs. Central HVAC Systems
- Operability and Controls
- HVAC System Energy Sources

MURB Ventilation & Indoor Air Quality

MURB HVAC Technology

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MURB & Resilience

Combine Heat & Power for MURBs

Thermal Autonomy & Passive Survivability in MURBs

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Commissioning

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Post-Occupancy Evaluation of MURBs

Measurement & Verification

Occupant Engagement & Education

MURB Design Guide

OVERVIEW

The recent surge of multi-unit residential building (MURB) developments across many parts of Canada, mostly in the form of condominium or strata projects, is a trend that is forecast to continue well into the foreseeable future. Many cities now seek to intensify development as a strategy in reducing their carbon footprints while capitalizing on existing infrastructure to support growth. Increased population densities generally make for a more walkable city that privileges the pedestrian rather than the automobile, and this is widely acknowledged as contributing to a better quality of urban life. If MURBs are trending to become the dominant form of new housing development in most urban centres across Canada, then it is important that these developments contribute as much to improving the quality of life for their inhabitants as they do for their immediate neighbourhoods and the surrounding city.

This design guide focuses on how to deliver better performing mid-rise and high-rise multi-unit residential buildings. It does not deal with low-rise housing types such as townhouses. The objectives of this guide are to connect architectural design with contemporary building science knowledge in order to:

- **Improve Energy/Water Efficiency and Reduce Carbon Footprint** – Energy and water conservation measures in buildings not only save energy and resources, but may also reduce our greenhouse gas emissions by choosing low carbon energy sources and utilizing green energy intelligently.
- **Promote Inhabitant Comfort and Well Being** – On average Canadians spend about 90% of their time indoors and about half of this time is spent in their dwellings. Thermal comfort and access to light and air, along with views that connect inhabitants with outside life are major determinants of the quality of our indoor environments, and hence our well being.
- **Extend Durability and Service Life** – Buildings are durable goods and housing typically represents the average Canadian's largest investment or rental expenditure. Not only should housing be durable, but it should be reasonable to maintain. Maintenance fees reflect the service life and maintenance requirements of the building, and under extreme circumstances, prematurely deteriorating components can impose unexpected special assessments on condominium and strata owners. In some cases, persistent performance problems can devalue real estate investments.
- **Reduce Peak Electrical Energy Demands** – Electrical grids cannot renew and adapt themselves as quickly as the advance of new building development, especially if the growth in population is accompanied by expanded industrial and institutional facilities that place additional demands on the electrical energy system. It is important that not just housing, but all new buildings, minimize peak electrical energy demands in order to avoid the costly expansion of the electrical energy system.
- **Promote Resilience, Thermal Autonomy and Passive Survivability** – Climate change is causing more frequent and severe weather events around the world. In Canada, this will translate into higher winds, periods of more intense precipitation (rainfall and snowfall), and increased incidences of freezing rain, as well as hotter and more extended heat waves accompanied by drought. Not only must housing be more resilient to withstand the effects of climate change, but it must also provide shelter when the energy grid goes down due to extreme weather events. Housing that is easily susceptible to damage and that cannot passively provide shelter during extended power outages will not only be viewed as being of inferior quality and therefore less desirable, but also more costly to insure and less marketable.

By addressing these issues as opportunities for improving housing design, users of this guide will gain an awareness of the key performance parameters that are vital to sustaining Canada's housing stock.

What Is Performative Building Design?

The predominant approach to the design and construction of buildings across Canada has been “build cheap, maintain expensive.” Notions of best practices guided by building science did not emerge until after World War II, when the widespread departure from traditional materials and methods resulted in modern buildings with numerous performance problems. The management of heat, air and moisture was largely unacceptable and building inhabitants tolerated indoor environments that were often uncomfortable and in some cases unhealthy. Building owners discovered these ‘innovative’ buildings were expensive to operate and maintain, and their durability was much less than their traditional counterparts from the previous era. Across Canada, an entire generation of public housing that exhibits poor performance is a testament to an indifference by building designers towards the application of building science principles that form the basis of this design guide.

Performative building design, sometimes referred to as high performance building design, embodies a process that integrates and optimizes on a life cycle basis all major attributes, including energy conservation, environment, safety, security, durability, accessibility, cost-benefit, productivity, sustainability, functionality, and operational considerations. Performative building design explicitly establishes performance metrics and indicators that can be used to test the proposed building at the design stage, throughout construction, and after it is occupied and operational.

Key performance parameters are related to health, comfort, energy and water efficiency, carbon footprint, durability, accessibility, flexibility/adaptability, affordability and resilience. Professionals who engage performative building design seek to attain or surpass performance thresholds that correspond to the environmental, social and economic aspirations of society as a whole, rather than any individual, organization or interest group. A key consideration in the performative design of housing is intergenerational equity to ensure the housing needs of future generations are not compromised.

Common Performance Problems with MURBS

Multi-unit residential buildings (MURBs) have a number of common performance problems, regardless of whether they are rental apartment buildings, cooperatives, condominiums or strata developments. This guide focuses on mid-rise and high-rise building typologies, but many of the problems encountered in these types of buildings may also be found in other forms of housing. Common performance problems include:

- **Daylighting** – failure to provide sufficient levels of daylighting to promote health, well being and delight;
- **Indoor air quality** – ineffective mechanical and natural ventilation that do not deliver sufficient fresh air and remove contaminated air and moisture caused by cooking, washing and bathing;
- **Thermal comfort** – air leakage, inefficient windows and walls, and thermal bridging at balcony slabs cause occupant discomfort during periods of hot and cold weather;
- **Operating and maintenance costs** – inefficient building enclosures, plumbing fixtures, HVAC and lighting systems inflict high operating costs while non-durable materials and equipment require excessive maintenance and repair;
- **Sound control** – high levels of noise from outside and between suites, and a lack of privacy within suites;
- **Elevator service** – Frequent breakdown of elevators and very slow service during peak periods;
- **Social isolation** – amenities and layout of the building discourage social interaction;
- **Site and landscape** – uninviting site and landscape that are void of human activities and disconnected from the surrounding community;
- **Waste management** – no or poor management of garbage, recycling and composting;
- **Insects, vermin, mold/mildew and dirt/odours** – bad design/construction, deferred maintenance and poor housekeeping lead to problems with cockroaches, mice, fungal growth, dirt, litter and unpleasant odours in the building;
- **Safety** – lack of appropriate security measures inside and outside the building cause safety concerns for occupants and visitors;
- **Adaptability/Flexibility** – building design cannot accommodate multicultural demographics, aging in place, multigenerational households, live-work lifestyles and future adaptive reuse.
- **Accessibility** – site, building and suites are not hospitably accessible by persons with disabilities; and
- **Affordability** – escalations in operating and maintenance costs become challenging to households on low and/or fixed incomes.

Many of these performance problems are directly related to the high carbon and ecological footprints of MURBs, and others are indicators of inadequate levels of resilience, health and safety, and comfort. It is important to note that simply avoiding these problems should not be viewed as necessarily achieving good design.

The Big Picture

RULES OF THUMB FOR MURB DESIGN

This guide begins with a quick review of rules of thumb for MURB design. It is important not to lose sight of the big picture as it relates to architecture, urbanism and making better places to live. While this guide focuses on aspects of performative design that have been long neglected in contemporary multi-unit residential building design, it does not imply these are the only critical aspects deserving the attention of planners, designers and developers.

There are many forces and factors at play in Canada and around the world that are driving a trend towards urbanization and intensification. The Canadian dream of the single family detached home is being displaced by a realization that sprawling, low density suburban developments are simply much less sustainable than compact, high density urban communities. It is being projected that an increasing proportion of the Canadian population will rent apartments rather than own homes, and condominium or strata developments will dominate new homebuyer marketplaces in urban growth regions.

Regardless of the forecast trends, our quality of life is significantly determined by the quality of our housing. The quality of housing and urban design also plays an important role in human health, while its cost relative to incomes has numerous economic implications ranging from international trade competitiveness to the amount of money Canadians and their governments have to invest in healthcare, education, innovation, the environment, arts and culture.

Designing, developing and maintaining high quality housing rank among society's most important and influential investments. These rules of thumb are intended to avoid the big mistakes that make for bad outcomes - they are not a guarantee of good design and housing quality. Hopefully, the MURB design resources that are embodied in this guide can inform better ways to cultivate Canada's housing resources going forward into the 21st century.

RULES OF THUMB FOR MURB DESIGN

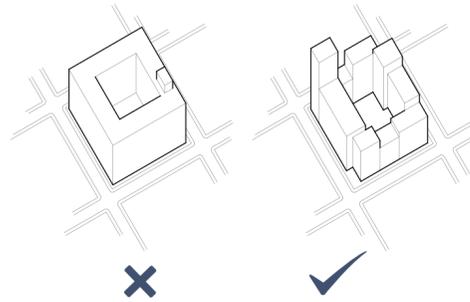
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Scale / Typology Guidelines

PERIMETER BLOCK BUILDINGS

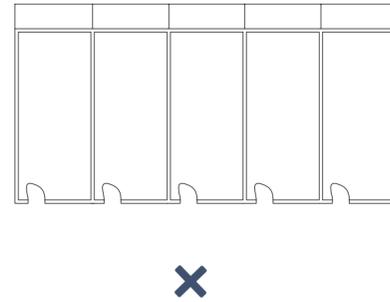
Buildings which take over entire street blocks should have their masses broken up substantially.



EXAMPLE: BARBICAN ESTATE (1960S-80S)
LOCATION: LONDON, ENGLAND
ARCHITECT: CHAMBERLIN, POWELL AND BON

SHOEBOX APARTMENTS

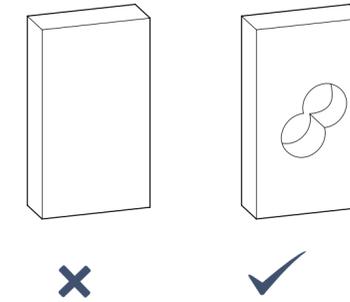
Shoebox apartments, where units are arranged like sardines with the short side facing the exterior, should be avoided.



EXAMPLE: MYRIAD, SYNTAX AND TUNGA (2009)
LOCATION: AMSTERDAM, THE NETHERLANDS
ARCHITECT: DICK VAN GAMEREN

PICTURE LARGE MASSES

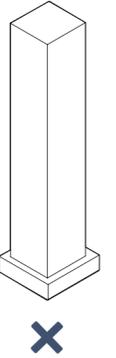
Large masses such as towers may contain breaks in their mid-areas to allow for air and light to enter as well as to create visual interest.



EXAMPLE: MIRADOR BUILDING (2005)
LOCATION: MADRID, SPAIN
ARCHITECT: MVRDV

SINGULAR MONOLITHS

Solitary, singular, monolithic buildings must be carefully designed. Floor plates should be small and the units must be thoughtful and flexible (such as, for example, each unit being a corner unit, and having minimal shear-walls between them for flexibility).

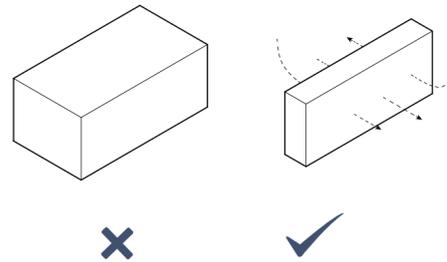


EXAMPLE: ZELLWEGER PARK APARTMENTS (2015)
LOCATION: USTER, SWITZERLAND
ARCHITECT: HERZOG AND DE MEURON

Massing Guidelines

LEAN IS BETTER THAN FAT

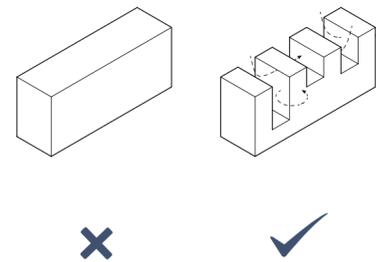
Deep floor plates make it difficult for light and air to penetrate the inner areas of the building. Thinner, leaner floor plates give greater access to the outdoors.



EXAMPLE: HOCHHAUS APARTMENTS (1962)
LOCATION: BREMEN, GERMANY
ARCHITECT: ALVAR AALTO

STAGGER VERTICALLY

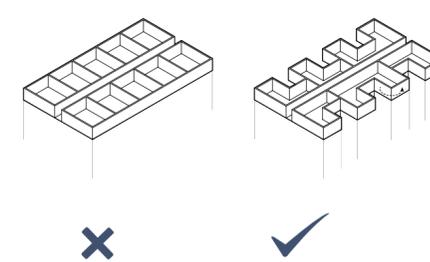
Forms that are varied vertically, rather than flat, allow air and light to reach more areas of the building. Staggering also creates opportunities for a variety of tenant types and uses.



EXAMPLE: ICEBERG PROJECT (2013)
LOCATION: AARHUS, DENMARK
ARCHITECT: JULIEN DE SMEDT

STAGGER HORIZONTALLY

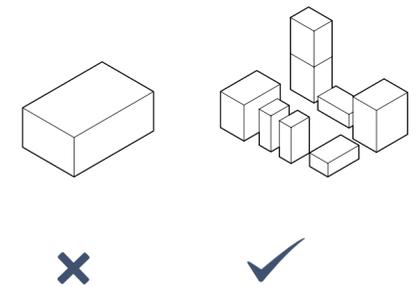
Staggering floor plates horizontally allows for the creation of more corner condition units, which gives tenants more ample access to air and light.



EXAMPLE: PICASSO ON RICHMOND (2015)
LOCATION: TORONTO, CANADA
ARCHITECT: TEEPLE ARCHITECTS

DISTRIBUTE FOOTPRINT

Footprints that are spread out and varied, rather than singular and monolithic, allow for greater access to light and air.



EXAMPLE: THE INTERLACE (2013)
LOCATION: SINGAPORE
ARCHITECT: OMA, OLE SCHEEREN

RULES OF THUMB FOR MURB DESIGN

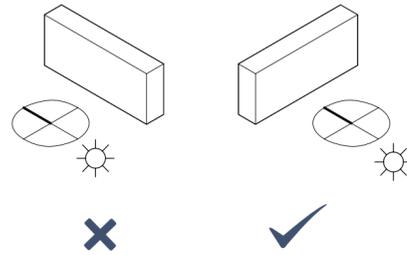
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[MURB Design Survey](#)



Orientation Guidelines

DIRECT LONGER SIDE TOWARDS SOUTH

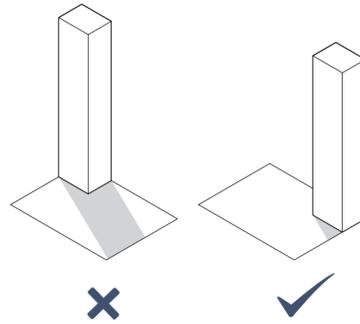
As sunlight radiates largely from the south, orienting the longest side of the building towards the sun gives more tenants access to sunlight.



EXAMPLE: SIAMESE TWIN, 41 APARTMENTS (2008)
 LOCATION: LELYSTAD, NETHERLANDS
 ARCHITECT: AAS ARCHITECTEN

CURATE SHADOWS

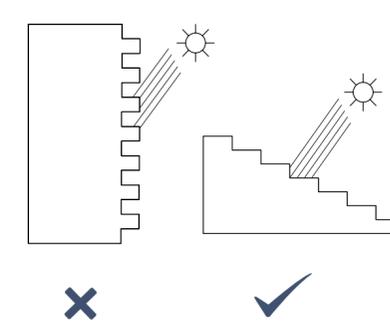
Shadows should be carefully curated to avoid obstructing public areas, green space, and other tenants.



EXAMPLE: CHASSE APARTMENTS (2001)
 LOCATION: BREDA, NETHERLANDS
 ARCHITECT: XAVEER DE GEYTER

SET BACK FOR SUNLIGHT

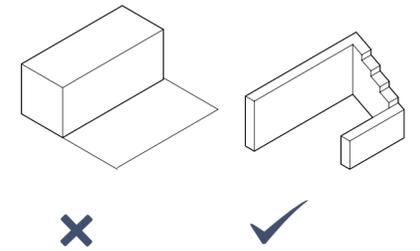
Buildings should thin as they rise vertically to allow for more light to penetrate into the surrounding site.



EXAMPLE: UCLA STUDENT HOUSING (2015)
 LOCATION: LOS ANGELES, CA, USA
 ARCHITECT: LORCAN O'HERLIHY ARCHITECTS

ENCLOSE SPACE

Buildings that enclose space, where site conditions allow, create quiet residential zones of public or semiprivate space. This allows tenants to have quieter, more peaceful living in their units.

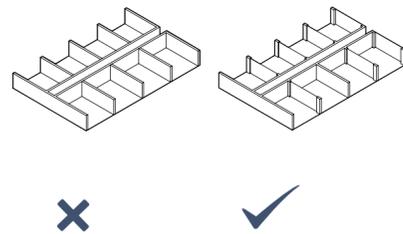


EXAMPLE: PIRAEUS (1994)
 LOCATION: AMSTERDAM, NETHERLANDS
 ARCHITECT: HANS KOLLHOFF, RAPP + RAPP

Structural Guidelines

MINIMIZE SHEAR WALLS

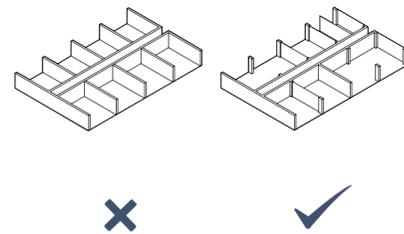
Overuse of shear walls in vertical towers allows for buildings to be built quickly, but at the cost of removing flexibility for tenants. By minimizing shear walls, buildings have the opportunity to be customized and therefore to last longer.



EXAMPLE: HEARST HEADQUARTERS, (2006)
 LOCATION: NEW YORK, NY, USA
 ARCHITECT: FOSTER + PARTERS
 DETAILS: THE DIAGRID SUPPORT STRUCTURE ENABLES A 20% SAVING OF STEEL. THE TOWER WAS BUILT TO 85% OF RECYCLED STEEL.

FLEXIBLE UNITS

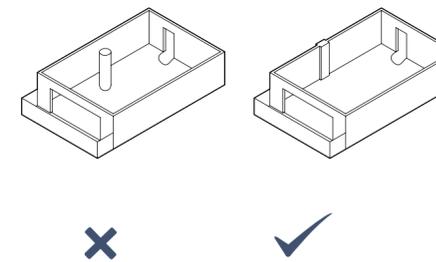
Thoughtfully curated column and beam placement, and favouring column systems over shear wall systems, allow for floor plates and units to be flexible over time, and give tenants the ability to customize their living spaces.



EXAMPLE: DNB NOR HQ (2008)
 LOCATION: OSLO, NORWAY
 ARCHITECT: MVRDV
 DETAILS: THE PIXELATED DESIGN ALLOWS FOR THIS RESPONSE TO BE HIGHLY FLEXIBLE AND EFFICIENT.

INTEGRATE COLUMNS

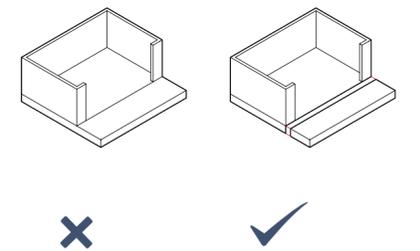
Columns should be integrated into walls and other living structural and dividing elements, rather than encroaching on tenant space.



EXAMPLE: SKYBRIDGE (2012)
 LOCATION: CHICAGO, ILLINOIS
 ARCHITECT: PERKINS + WILL

THERMALLY BREAK BALCONIES

Balconies should be built using thermal break technology, or using a separate structural system where possible, to allow for more efficient insulation and less energy expenditure on heating.



EXAMPLE: ISOKORB® BY SCHÖCK - STRUCTURAL THERMAL BREAK ELIMINATES HEAT TRANSFER ACROSS CANTILEVERED REINFORCED CONCRETE BALCONY SLABS.

RULES OF THUMB FOR MURB DESIGN

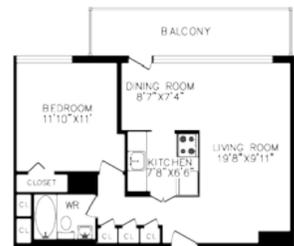
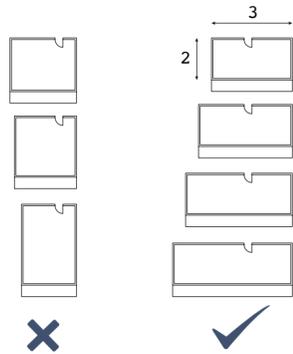
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Unit Guidelines

MINIMUM 2x3 ASPECT RATIO

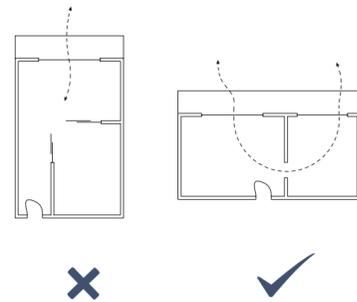
Units that have a longer aspect ratio, with the longer side facing the exterior of the building, give tenants greater access to air and light.



EXAMPLE: EXAMPLE OF A SHALLOW DEPTH SUITE LAYOUT PROVIDING AMPLE ACCESS TO LIGHT AND AIR.

WINDOW IN BEDROOM

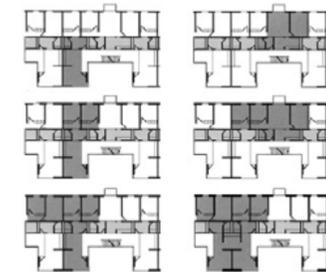
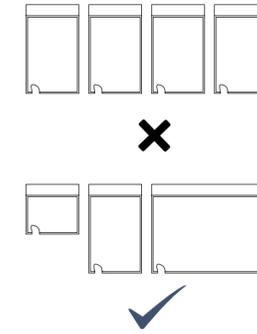
Units that have an opening to the outside, rather than a glass partition to the living room, provide a humane sleeping space. Remember: no mechanical ventilation system could ever replace a true window to let in fresh air and light.



EXAMPLE: LARGE OPERABLE WINDOWS IN BEDROOMS MAKE THEM MORE LIVEABLE. PUNCHED WINDOWS MAKE THE BUILDING MORE ENERGY EFFICIENT. [1990S APARTMENT BUILDING, PORTLAND, OREGON]

VARIETY / FLEXIBILITY

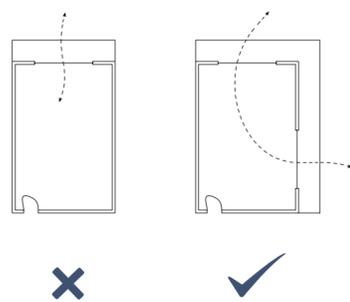
A building with a variety of suite sizes and uses in mind, that caters to diverse tenants, is preferable to a building that caters only to investors preferring single-user smaller units. Flexible units, such as ones that can grow over time, expand into each other, or be subdivided, and more forward-thinking than inflexible units.



EXAMPLE: ÜBERBAUUNG HELLMUTSTRASSE (1991) LOCATION: ZÜRICH, SWITZERLAND ARCHITECT: ADP ARCHITEKTUR UND PLANUNG

CORNER CONDITIONS

The most superior units typically exist at a corner condition. This occurs at a literal corner of a building, or it may be imitated through the design layout of the unit. Corners receive better cross-ventilation and light access so they create preferable living conditions.

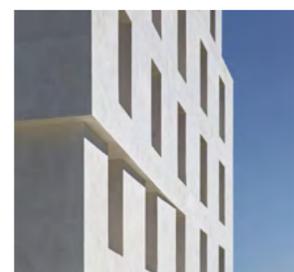
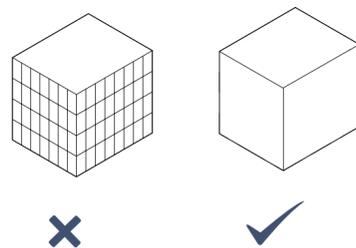


EXAMPLE: CONTINUUM APARTMENTS (2015) LOCATION: BOSTON, MASSACHUSETTS ARCHITECT: SAMUELS & ASSOCIATES

Material Guidelines

MINIMIZE GLASS

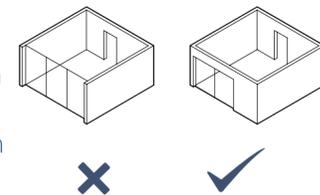
Materials with insulative properties should be favoured over glass curtain walls. This gives buildings insulating properties even in power failures and allows for lower expenditures on energy. Windows should be thoughtful, curated openings.



EXAMPLE: ARDEKO (2013) LOCATION: BOULOGNE-BILLANCOURT, FRANCE ARCHITECT: BAUMSCHLAGER EBERLE

UTILIZE THERMAL MASS

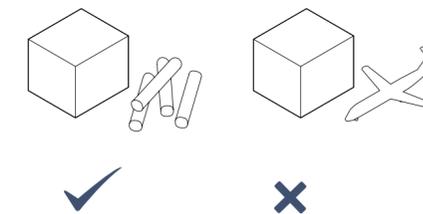
Thermal masses allow for buildings to self-regulate temperature, and makes them retain heat in winter and keep cool in the summer. Thermal masses should be located such that they can absorb heat energy from the sun during winter and where possible be hidden by overhangs from higher sun angles in the summer.



EXAMPLE: KOP VAN OOST (2009) LOCATION: GRONINGEN, NETHERLANDS ARCHITECT: MECANOO ARCHITECTS

SOURCE LOCALLY

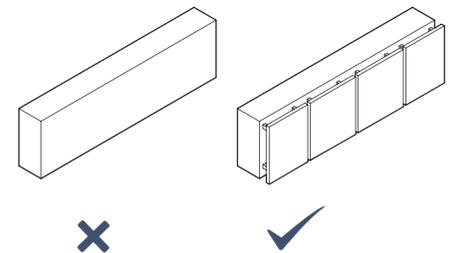
Use locally-sourced materials to expend less energy on construction.



EXAMPLE: HIGH RISE APARTMENT LOCATION: ALMERE, NETHERLANDS ARCHITECT: THOMAS MAYER DETAILS: FACADE COVERED WITH NATURAL SLATE

USE RAIN SCREENS

Cladding solutions such as rain screens allow for facades to shed water more efficiently and contribute to a longer building life.



EXAMPLE: 60 RICHMOND STREET E CO-OP HOUSING (2010) LOCATION: TORONTO, CANADA ARCHITECT: TEEPLE ARCHITECTS

RULES OF THUMB FOR MURB DESIGN

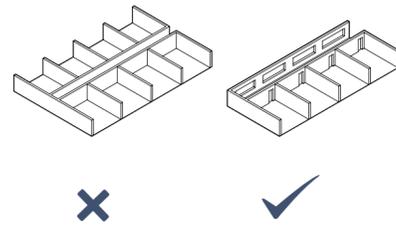
Click on the download icon for more information about:
Healthy Communities



Access / Street Guidelines

SINGLE-LOAD WHERE POSSIBLE

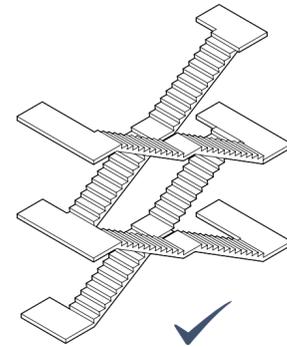
Even in cold-climates, single-loaded corridors provide far superior access to sunshine and greater tenant satisfaction.



EXAMPLE: RENAISSANCE BARCELONA FIRA HOTEL (2012)
LOCATION: BARCELONA, SPAIN
ARCHITECT: ATELIERS JEAN NOUVEL, RIBAS & RIBAS ARQUITECTOS
DETAILS: HIS TYPE OF CONSTRUCTION ALSO HAS A GAP BETWEEN ITS ELEMENTS, ELABORATELY GREENED AND ALLOWING FOR THE PASSAGE OF AIR

COMBINE STAIR USES

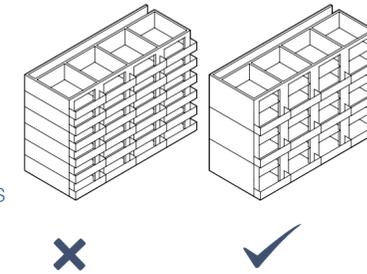
Creative combinations of elements can make spectacular design solutions. For instance, using balconies as part of the emergency egress system created a well-connected midrise in the example below. In addition, dual means of egress can be achieved using a scissor stair.



EXAMPLE: 20 NIAGARA
LOCATION: TORONTO, CANADA
ARCHITECT: PETER CLEWES

SKIP-STOP PLANS

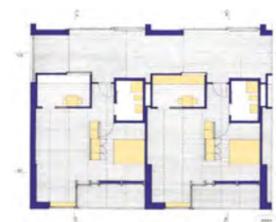
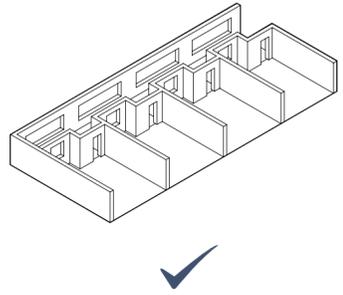
Skip-stop plans allow for highly efficient access to air and light. With the access corridor (and elevator stops) located on every other floor, non-access levels have larger floor space. In addition, double-height balconies allows sunlight to penetrate very deeply into the building.



EXAMPLE: KANCHANJUNGA APARTMENTS (1983)
LOCATION: MUMBAI, INDIA
ARCHITECT: CHARLES CORREA

ELIMINATE BACKSIDE

In creating openings in the backs of units in single-loaded plans, windows and staggering may be added to unit entrances to create ownership of corridor space as well as allowing for additional sunlight and air circulation.

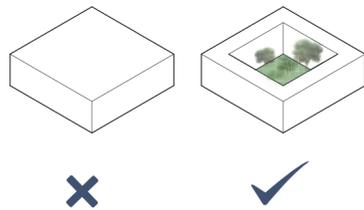


EXAMPLE: CASA DI RIPOSO PER ANZIANI A COIRA (1999)
LOCATION: COIRA, SWITZERLAND
ARCHITECT: PETER ZUMTHOR

Indoor-Outdoor Connectivity Guidelines

GREEN COURTYARDS

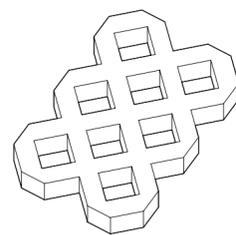
Cold-climate countries such as Sweden and Denmark frequently make use of green courtyards as a means of providing access to natural space for tenants to view from their units. In addition, the sheltering effect of the courtyard allows for it to be utilized during cold months.



EXAMPLE: VIVAZZ MIERES SOCIAL HOUSING (2010)
LOCATION: ASTURIAS, SPAIN
ARCHITECT: ZIGZAG ARQUITECTURA

PERMEABLE PAVING

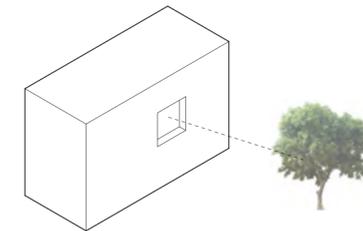
Paving surrounding buildings should be permeable wherever possible to allow for the earth below to absorb rainwater.



EXAMPLE: BENNY FARM (2002)
LOCATION: MONTRÉAL, CANADA
ARCHITECT: SAIA BARBARESE TOPOUZANOV ARCHITECTES

CURATED WINDOWS

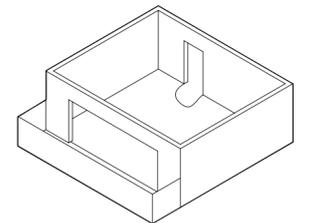
Windows should be curated for the best views of green space for sun orientation.



EXAMPLE: 214 SÜDPARK (2012)
LOCATION: BASEL, SWITZERLAND
ARCHITECT: HERZOG & DE MEURON

SEMI-BALCONIES

In cold climates, semi-balcony solutions allow for tenants to make use of balcony space even during colder months.



EXAMPLE:
LOCATION:
ARCHITECT: KLASS LOTHER

THE BUILDING AS A SYSTEM

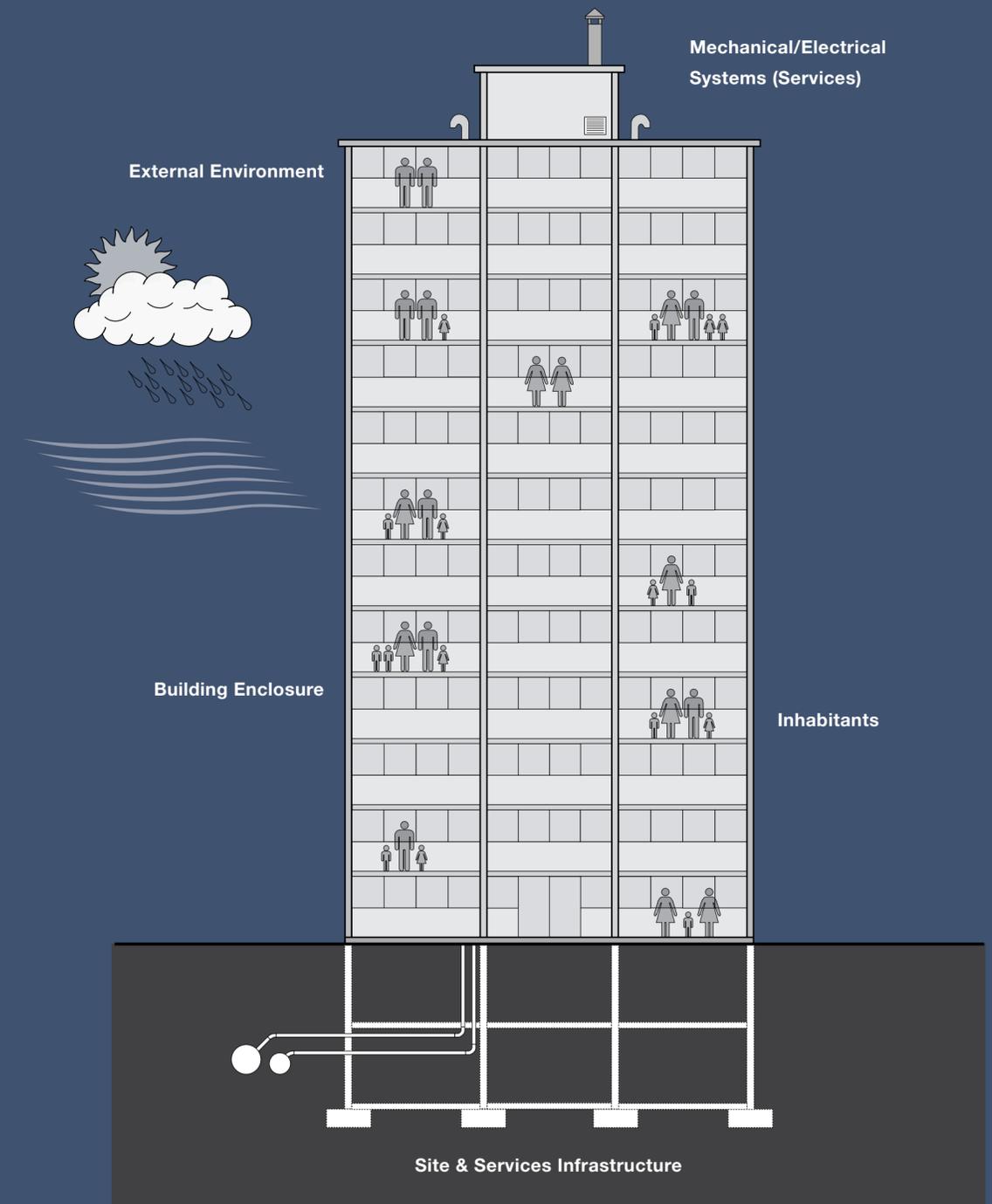
The integrative design of multi-unit residential buildings requires to understand and appreciate the building as a system concept. The idea of the building as a system springs from modern systems theory and the application of building science principles to building behaviour and performance.

The building as a system concept is a relatively new development in building science. It resulted directly from the introduction of a systems approach to building science practice, starting in the 1960s. As innovation increasingly became the means to achieving new forms of architectural expression in the 20th century, analysis and review of building failures indicated that traditional approaches to design were inadequate. This was due to inappropriate adaptations of successful past precedents, or an unknowingly narrow analysis at the building component level for radical departures from technical norms. In both cases the interactive behaviour among elements of the whole system was not considered.

The building as a system approach requires designers to explicitly and consciously consider the interactions between the primary elements comprising the system:

- The **building enclosure** (building envelope system);
- The **inhabitants** (humans and/or animals and/or plants, etc.);
- The **building services** (mechanical/electrical systems);
- The **site** (with its landscape and services infrastructure); and
- The **external environment** (weather and micro-climate).

Design that harmonizes these elements is the key to well performing buildings.



The building as a system model drives interdisciplinary and integrative design.

THE BUILDING AS A SYSTEM

Click on the download icon for more information about:
Building Science Basics



Passive Versus Active Systems

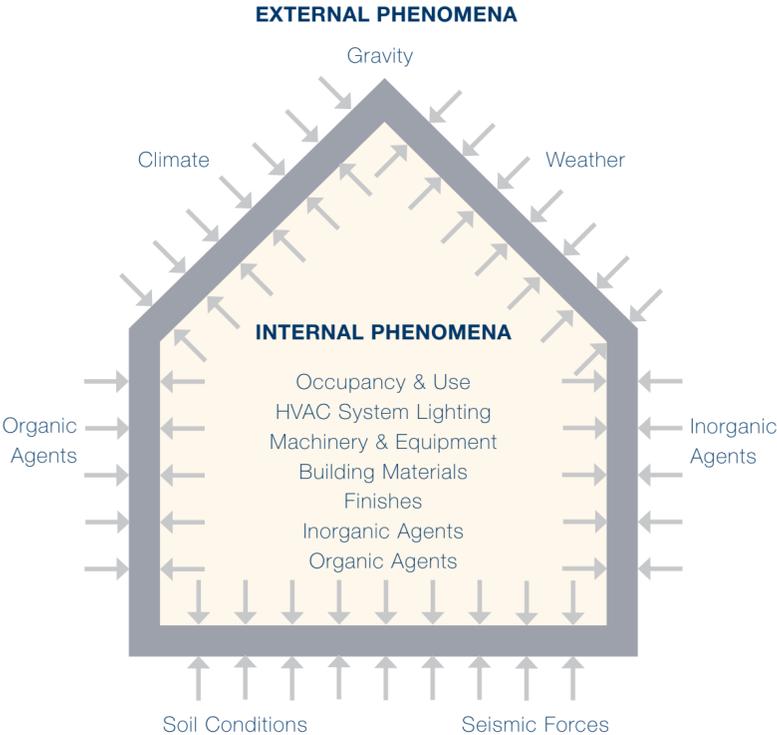
In order to be able to prioritize critical parameters in building design and devote resources accordingly, it is necessary to appreciate the dynamic between passive and active system. With the exception of the most simple buildings, practically all buildings consist of both passive and active systems which ideally complement each other to achieve functionality and a desired condition of environmental control.

Environmental control, or moderation of the indoor environment, is achieved through passive and active means. The passive means are provided by the building enclosure (comfort, daylighting, natural ventilation) while the active means are provided by building services (HVAC, lighting, controls). In light of a low carbon economy and climate change adaptation, the passive and active system roles may be defined as follows.

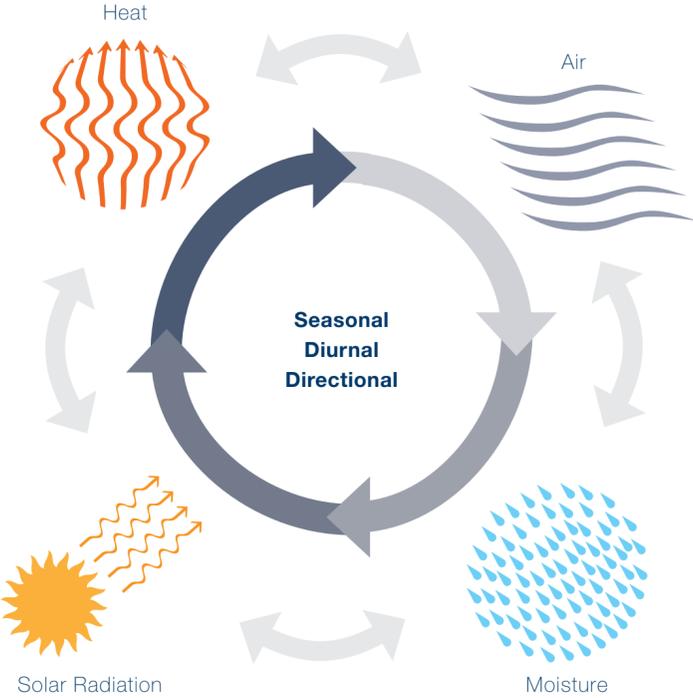
Passive Role – To moderate the environment for the safety, health, well being and delight of the occupants without the appreciable consumption of non-renewable energy over the useful life of the building.

Active Role – To supplement the passive systems to the extent that is required to achieve the desired level of environmental control and functionality, preferably by means of renewable energy, or with a minimal input of non-renewable energy.

Building enclosures determine the level of thermal comfort that may be achieved indoors, and they also influence the peak energy demand, magnitude and intensity of space heating and cooling loads. The thermal efficiency of the enclosure, including the opaque elements, fenestration and airtightness, directly impact the quality of the indoor environment because only the enclosure can moderate the effects of heat, air, moisture and solar radiation.



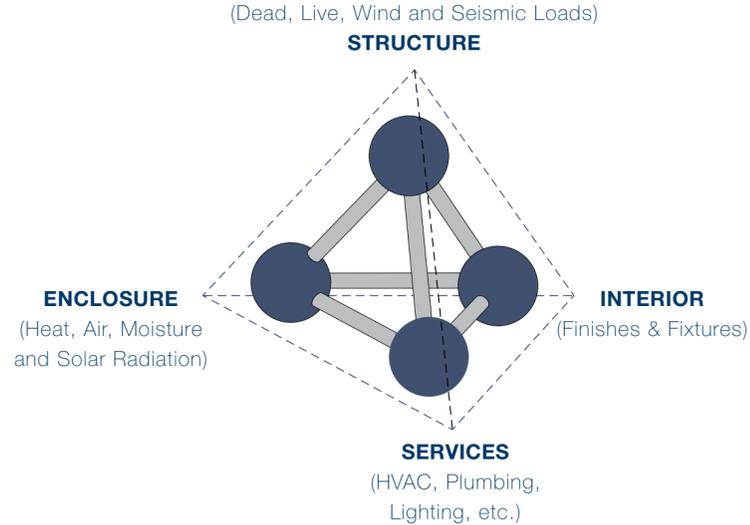
The building enclosure does all the heavy lifting when it comes to environmental control. If it is not appropriately designed, it abdicates its role to active systems and the result becomes what is termed "a high cholesterol building."



Active systems cannot manage the physical phenomena to which buildings are exposed. Only building enclosures (passive systems) can moderate the effects of heat, air, moisture and solar radiation. Passive systems continue to provide persistent performance after all active systems fail.

Building Systems Integration

A common purpose of building science is to achieve building system integration, not by-trial-and-error over many generations of building precedents, but each and every time a building is being designed and built. This implies defining a level of performance and a means of assuring compliance.



Four primary subsystems are involved in building systems integration and require interdisciplinary coordination.

Optimizing performance goes beyond compatibility between the structure, enclosure, interior and services. It involves the assessment of economic, social and environmental parameters so that performance targets are attained affordably within the skill capacity of the industry. This means innovation may be defined as achieving better performance and higher quality at less cost over the life cycle of a building or facility, notwithstanding higher initial costs. And the most potential for innovation involves building enclosure design and improving the efficiency and resilience of passive systems.

PASSIVE SYSTEMS DESIGN

Click on the download icon for more information about:
Building System Performance



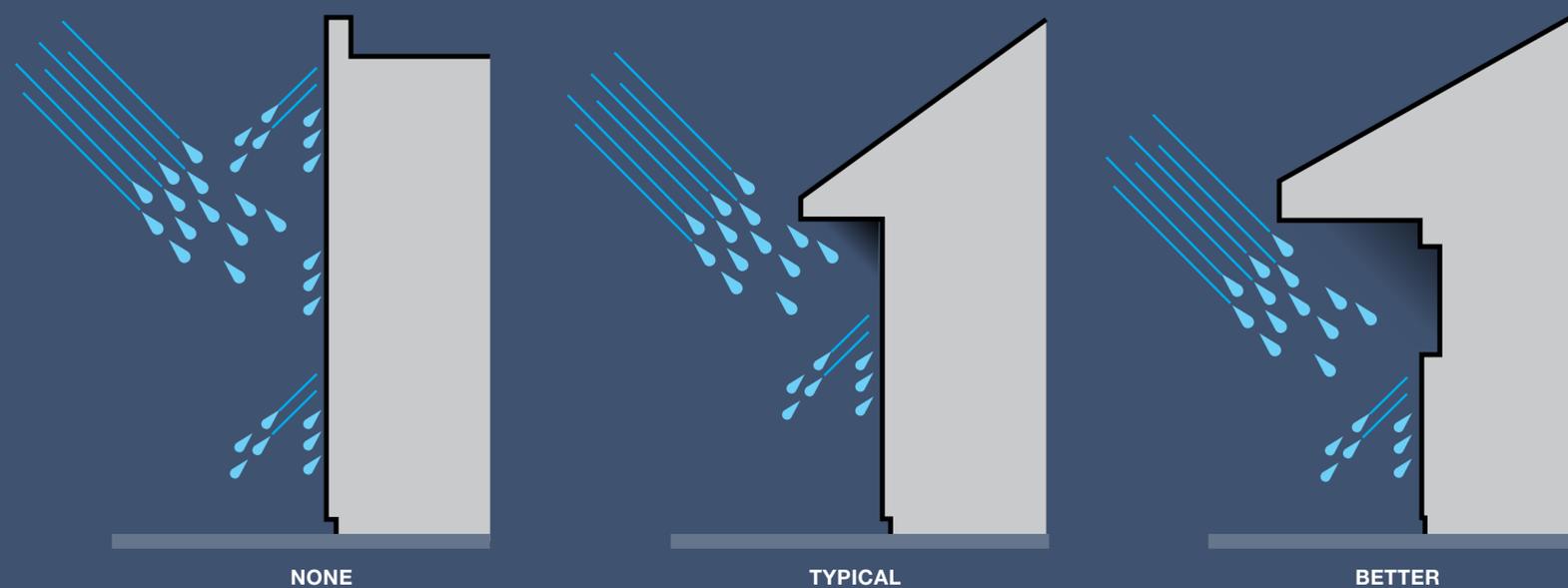
Passive systems design begins with building form and orientation, and for mid-rise and high-rise housing typologies, the layout and arrangement of suites. Enclosure design responds to this organization of suites according to solar orientation and within the context of climate and weather. Enclosures must manage precipitation, heat, air and moisture to deliver durability, efficiency and comfort while providing views and access to light and air. In increasingly critical consideration is for enclosures to be more resilient in view of climate change and provide secure shelter through extreme weather events. This part of the MURB Design Guide highlights these critical considerations and provides links to downloadable knowledge resources for readers who wish to access more in-depth information.

Rain Control, Air Leakage and Moisture Management

Building enclosures are the first line of defense against extreme weather events and for this reason it is important to address issues of rain control, air leakage and moisture management in architectural design.

Rain control involves the design of the enclosure to manage rain penetration. Contemporary building science advocates an approach to rain control that is termed the 4-Ds, which stands for:

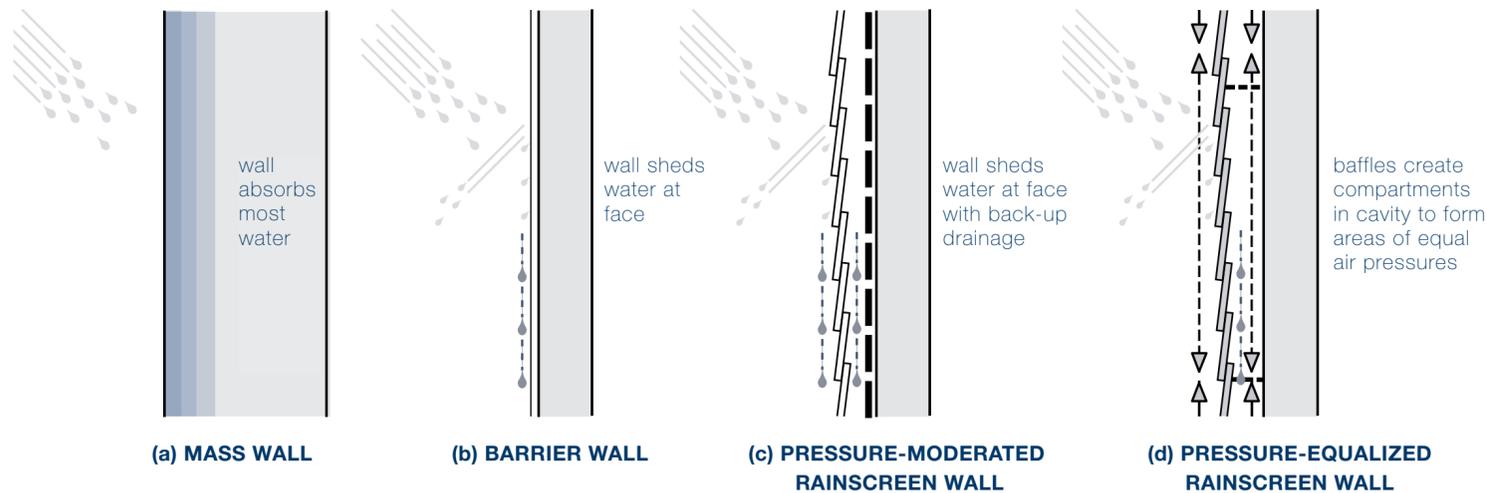
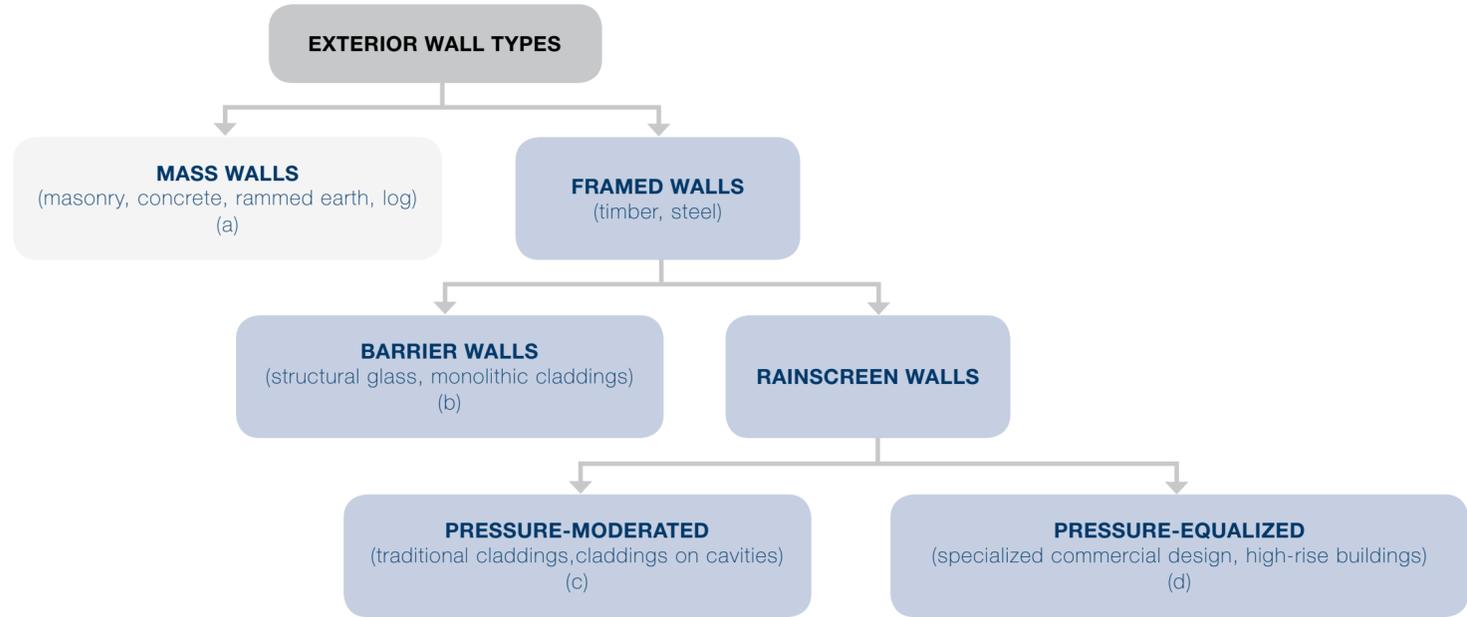
- keeping as much precipitation away from the exterior wall enclosure as practically possible;
- draining away any water that does strike and/or penetrate the cladding;
- providing sufficient ventilation to evaporate residual moisture and arranging materials for gradual drying by diffusion; and
- selecting materials that can withstand periodic wetting without deterioration over the service life of the enclosure.



Deflection strategies in the form of overhangs and recessed windows are among the most effective means of reducing rainfall exposure. Since most facades in modern architecture offer none or little deflection, it is important to emphasize drainage, drying and durability in enclosure design.

PASSIVE SYSTEMS DESIGN

Click on the download icon for more information about:
Building Enclosure Design

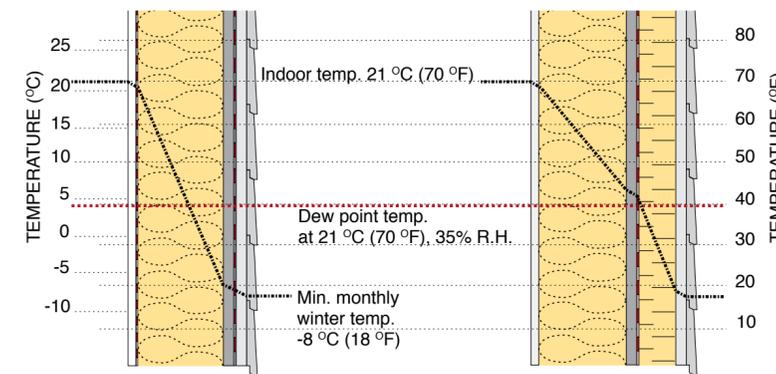


The typology for exterior walls based on moisture management strategies reveals four basic types. The mass wall and barrier wall do not provide acceptable performance by contemporary standards, leaving the pressure-moderated and pressure-equalized rainscreen types as being the only practical and effective alternatives from a building science perspective

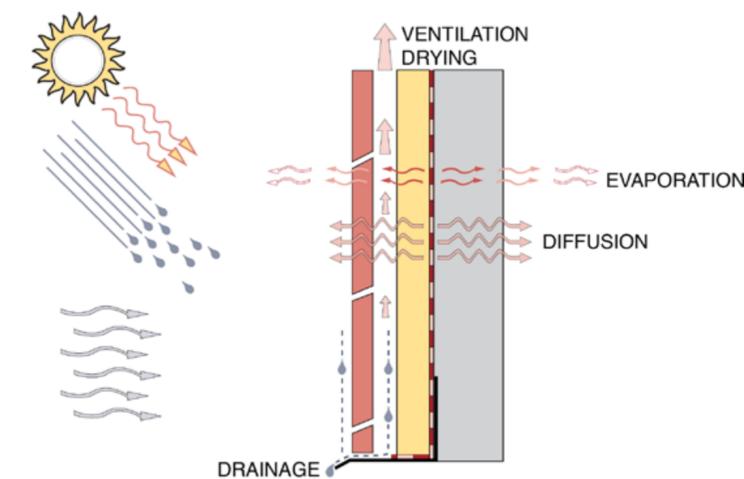
In practical terms, drained and ventilated facades provide acceptable rain control. For most climatic regions, pressure moderated rainscreens adequately control rain for exterior walls, but in very tall buildings and for extreme exposures to wind-driven rain, a pressure equalized rainscreen is recommended. Water resistive barriers and flashings must be carefully integrated to manage rainfall penetration, especially in open joint cladding systems.

Air leakage is controlled through the provision of a continuous, structurally supported air barrier system. Attention to detailing at transitions between materials, components and assemblies is essential. It is important to delineate clearly which trade is responsible for continuity at each transition, such as the wall/roof junction. Air barriers control air leakage that can lead to moisture problems due to condensation, and it also conserves energy by reducing infiltration.

Moisture management involves the selection and arrangement of materials to minimize moisture build up in walls and roofs, and to promote drying. Prudent enclosure design begins by acknowledging that materials and workmanship are imperfect. This reality can be countered by providing multiple measures for managing moisture inside of building enclosures.



Providing continuous insulation outboard of the structure not only improves thermal performance, but reduces the potential for condensation inside of cavities by elevating the cavity surface temperatures above the dewpoint of the indoor air.



Vapour permeable air barriers can control air leakage and manage moisture in enclosures by allowing two-way drying. Building science research indicates the required level of vapour permeability is based on climate zone. Climate change adaptation means vapour barriers at the inside face of wall assemblies should be avoided in all but the most extreme cold climate zones.

Continuous insulation outboard of the building structure addresses the demand for higher levels of thermal performance, but also helps manage moisture migration due to air leakage. It is often not practical to install all of the insulation needed to meet code requirements for energy efficiency outboard of wall and roof assemblies. One way of dealing with this challenge is to insulate the cavity in addition to providing continuous outboard insulation. However, this will require designers to account for a higher potential for condensation inside of cavities.

Except for extremely cold climate zones, the latest building research involving hygrothermal analysis and corroborated by laboratory testing, indicates that air barrier materials should be vapour permeable, to some degree, in order to promote two-way drying when both cavity and outboard insulation is provided. This will become an increasingly critical consideration as climate change unfolds. Modern buildings have a useful life of about 100 years or more. During this time, summers can be expected to become warmer and wetter and building enclosures will begin to accumulate moisture on a seasonal basis unless two-way drying is deployed.

PASSIVE SYSTEMS DESIGN

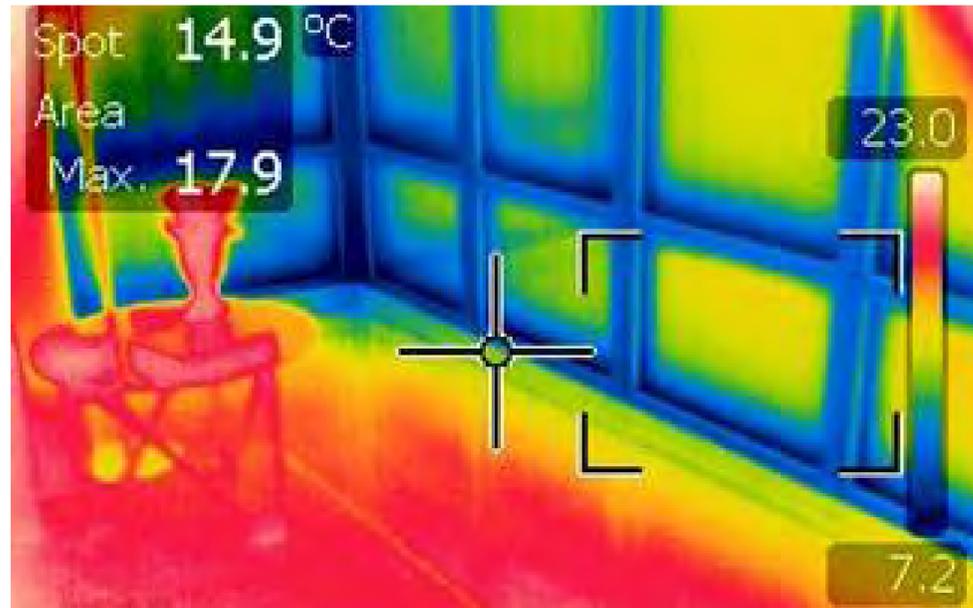
Click on the download icon for more information about:
Thermal Bridging



Thermal Control

While designing for rain control, air leakage and moisture management, it is necessary to provide adequate thermal control for occupant comfort and energy efficiency. This means providing adequate levels of thermal insulation for walls, roofs, floors over unheated spaces, and in basements. The thermal efficiency of windows is even more critical because glazing typically represents the weak link in the building enclosure, especially if the amount exceeds 50% of the gross exterior wall area. As noted earlier, air leakage control is both a moisture and thermal control measure that must be integrated with thermal control to achieve energy efficiency, comfort and durability.

Thermal bridging is now recognized as degrading the overall thermal effectiveness of enclosures. In the past, building codes prescribed the minimum amount of thermal control required in buildings, but this only referred to the amount of insulation that was provided. Recent studies have quantified just how significantly thermal bridging reduces the effective thermal resistance of walls, roofs and windows. Practical solutions have been developed and are both readily available and affordable.

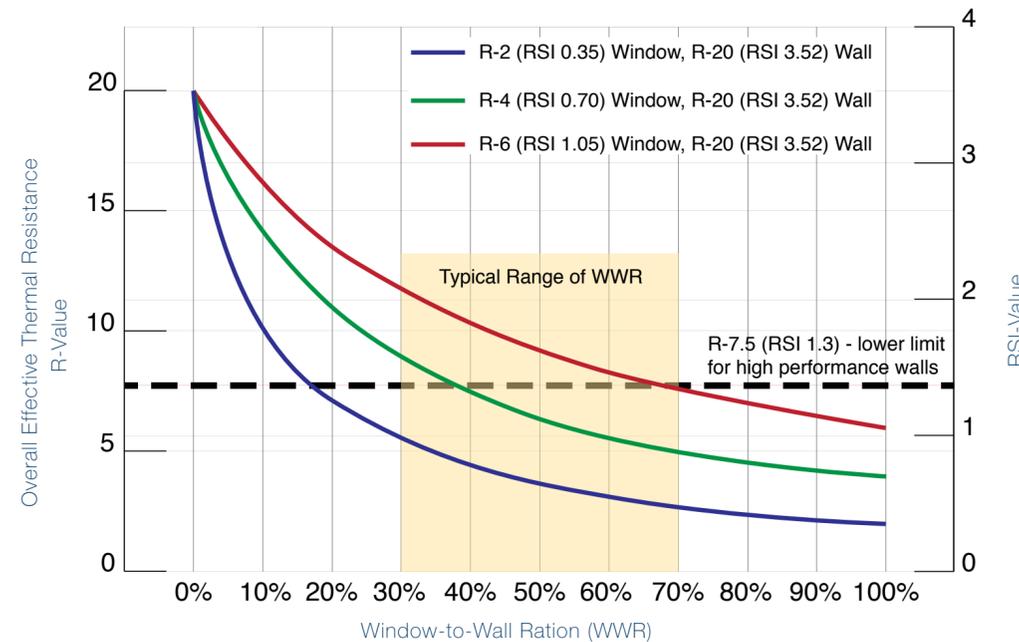


Thermography reveals thermal bridging in building enclosures causing discomfort at the outer perimeter of floor-to-ceiling glazing. Recent research has indicated that shelf angles, girts and fasteners can reduce the effective thermal resistance of walls by 50% or more. Inefficient windows cause occupant discomfort during very cold and hot weather.

Thermal Persistence

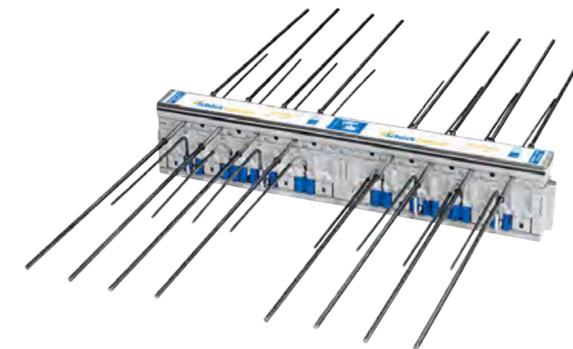
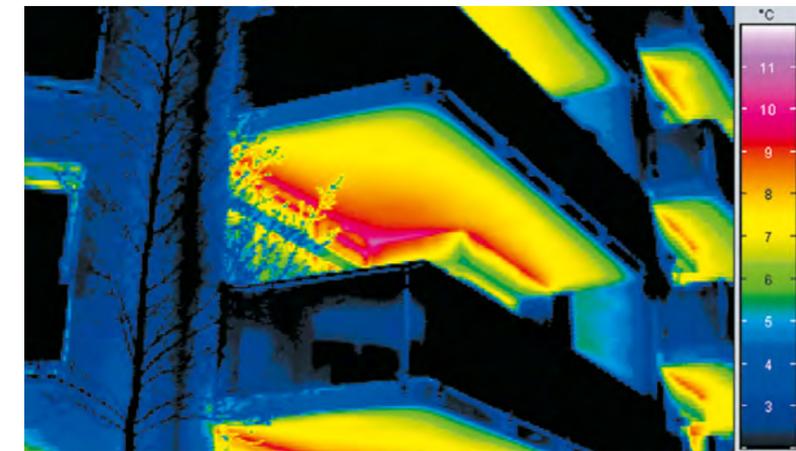
Another related consideration is the thermal persistence of insulation materials across a range of temperatures and moisture contents. Not all insulation materials retain their rated thermal resistance values at very low outdoor temperatures, and most batt and blown or loose-fill insulation products can have their thermal insulating properties reduced when they become wet. Climate change forecasts predict that extreme weather events can be expected to increase in frequency and severity in the future. It is advisable to select insulation materials that can maintain their effectiveness under a broad range of environmental conditions.

Influence of Window-to-Wall Ratio (WWR) The thermal efficiency of the enclosure is largely determined by the thermal effectiveness of exterior walls, which are strongly influenced by the window-to-wall ratio - the area of the windows as a fraction of the gross exterior wall area. Selecting high efficiency windows and limiting the window-to-wall ratio are more cost effective than adding more insulation. For multi-unit residential buildings, the typical range of window-to-wall ratios is between 30% to 70%, however, there are many glass condo towers that have been constructed that exceed an 80% window-to-wall ratio.



For the typical range of window areas, practically no amount of insulation will compensate for low thermal efficiency windows. The amount and thermal efficiency of windows limit the overall effective thermal resistance of exterior walls. High performance windows allow for larger glazed areas without compromising thermal efficiency.

Balcony thermal breaks can enhance occupant comfort and energy efficiency for cantilevered concrete balcony slabs. Typically, balcony slabs are constructed without thermal breaks because these are a relatively new and innovative building technology. Today, thermal breaks are becoming increasingly affordable and straightforward to integrate in conventional construction practices.



Above: Thermography reveals that a great deal of heat loss and gain occurs where balcony slabs penetrate exterior walls.

Left: A modular section of a balcony thermal break assembly.

Below: Balcony thermal break technology is proven, widely available and increasingly affordable.

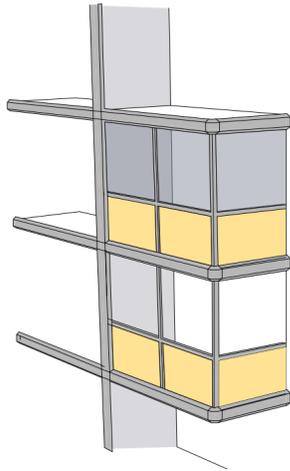


PASSIVE SYSTEMS DESIGN

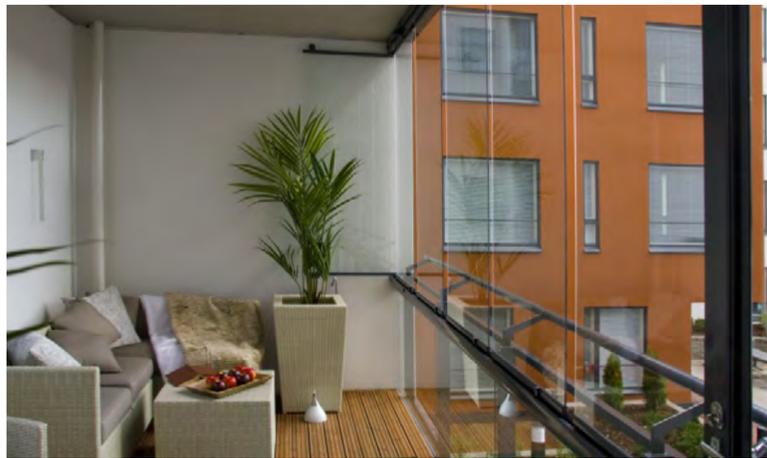
Click on the download icon for more information about:
MURB Energy Efficiency



Balcony enclosures not only provide a more comfortable and habitable space, but they also enhance thermal performance as well as provide protection against airborne projectiles.



Enclosed balconies contribute to the resilience of multi-unit residential buildings by providing a buffer zone against the outdoor climate and potentially a place of refuge in the event of fire.



Contemporary balcony enclosure systems transform balconies into spaces that can be kept dry and comfortable for most of the year.

Balcony enclosures can be added to almost existing buildings, but they may prove difficult to integrate technically and aesthetically. If a MURB design envisages the future addition of balcony enclosures, it is helpful to design the balconies to more easily accommodate such retrofits.

Recommended Levels of Thermal Insulation

Building codes prescribe minimum levels of thermal insulation for walls, windows and roofs as well as windows, skylights and glazing. It is also permissible under today's codes to tradeoff these minimum prescriptive levels by using more efficient heating, ventilating and air-conditioning systems, as well as more efficient lights and appliances. When the thermal efficiency of the building enclosure has been compromised by these tradeoffs, the result is referred to as a "high cholesterol building" because its energy diet relies on unhealthy energy choices instead of passive and renewable energy.

High performance multi-unit residential buildings should conform to the minimum levels of effective thermal efficiency listed in the table below. It is important that these are effective thermal resistance and conductance values that take into account thermal bridging effects.

The energy performance of multi-unit residential buildings is largely determined by the thermal effectiveness of the building enclosure but the effectiveness and efficiency of ventilation systems must also be addressed in design. Energy or heat recovery from exhaust air and the delivery of outside air to each suite on a demand controlled basis are critical to conserving energy while providing acceptable indoor air quality. Efficient lighting and appliances also play a role in MURB energy efficiency, but are far less critical because they do not impact comfort or resilience, and they can be easily and inexpensively retrofit, unlike building enclosures and ventilation systems.

Enclosure Component Assembly	Climate Zones 4 & 5		Climate Zones 6 & 7	
	Effective R-Value	Effective RSI-Value	Effective R-Value	Effective RSI-Value
Roofs	30	5.28	40	7.04
Exposed Walls	20	3.52	25	4.40
Exposed Floors	30	5.28	30	5.28
Foundation Walls	10	1.76	15	2.62
Slab-on-Grade	5	0.88	10	1.76
Windows*	R-4.0 (U-0.25)	0.70 (USI 1.43)	R-5.0 (U-0.20)	0.88 (USI 1.14)
Airtightness (Whole Building)	Maximum 2 L/s.m ² @75 Pa (0.4 cfm/sf @1.57 psf) when tested to ASTM E779.			

* Select low SHGC and high VT glazing – provide South and West exposures with external shading devices for WWR > 40%.

The minimum recommended levels of thermal efficiency for building enclosure components in ASHRAE climate zones 4 & 5 and 6 & 7 are based on resilience criteria related to peak heating and cooling energy demands, thermal autonomy and passive survivability.

Important Note: The effective R-values for Climate Zones 4 & 5 and 6 & 7 allow for considerable design freedom in selecting window-to-wall ratios that may range from 40% to 80%. One of the advantages of providing high effective R-values for MURB enclosure components, besides greater flexibility in window apertures, is that the difference in performance between climate zones is relatively negligible due to the extremely low space heating and cooling energy demands, assuming energy or heat recovery for ventilation air.

The energy performance of multi-unit residential buildings is largely determined by the thermal effectiveness of the building enclosure but the effectiveness and efficiency of ventilation systems must also be addressed in design. Energy or heat recovery from exhaust air and the delivery of outside air to each suite on a demand controlled basis are critical to conserving energy while providing acceptable indoor air quality. Efficient lighting and appliances also play a role in MURB energy efficiency, but are far less critical because they do not impact comfort or resilience, and they can be easily and inexpensively retrofit, unlike building enclosures and ventilation systems.

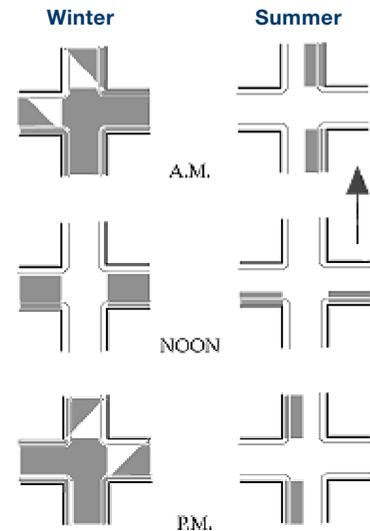
PASSIVE SYSTEMS DESIGN

Daylighting

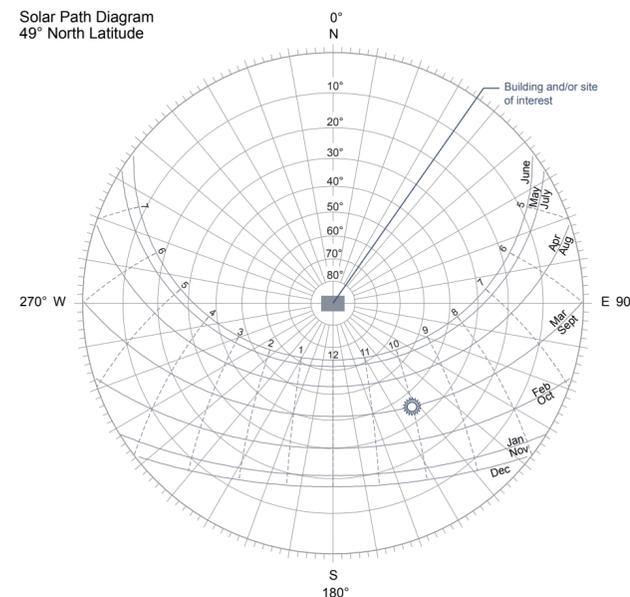
The typical suite in a multi-unit residential building offers fewer degrees of freedom for environmental control than single family detached housing in terms of access to light and air. Daylighting not only conserves energy, but it can also provide passive solar gains. Contemporary research indicates daylighting is important to human health and well being and from an aesthetic perspective, most people prefer well daylit spaces. Providing access to daylight is democratic because for those who do not prefer high levels of daylight, curtains, blinds and/or shutters may be deployed to obtain desirable lighting conditions indoors. The same freedom of choice is not available to inhabitants of suites with insufficient daylight.

Daylighting design involves the form of the building and its solar orientation. While planning and zoning regulations often restrict building orientations and how they face the street, it is important to appreciate how in large new MURB developments the orientation of the internal streets and buildings has a significant influence on solar access.

A simple design aid for planning solar access is the solar path diagram as depicted below. Opportunities for solar access are readily apparent in this projection of the solar path. Looking at the solar path diagram for 49° North latitude, it is apparent that direct solar penetration of the north facade of a building only occurs in the early morning and late evening hours during the summer months. The remainder of the year, no direct sunlight will penetrate the north-facing suites. Due to the low sun altitude angle at sunrise and sunset, the potential for direct solar penetration during the summer may not be realized if surrounding trees and buildings block the sun. As urban areas become intensified, solar access becomes a very important consideration in planning and design.

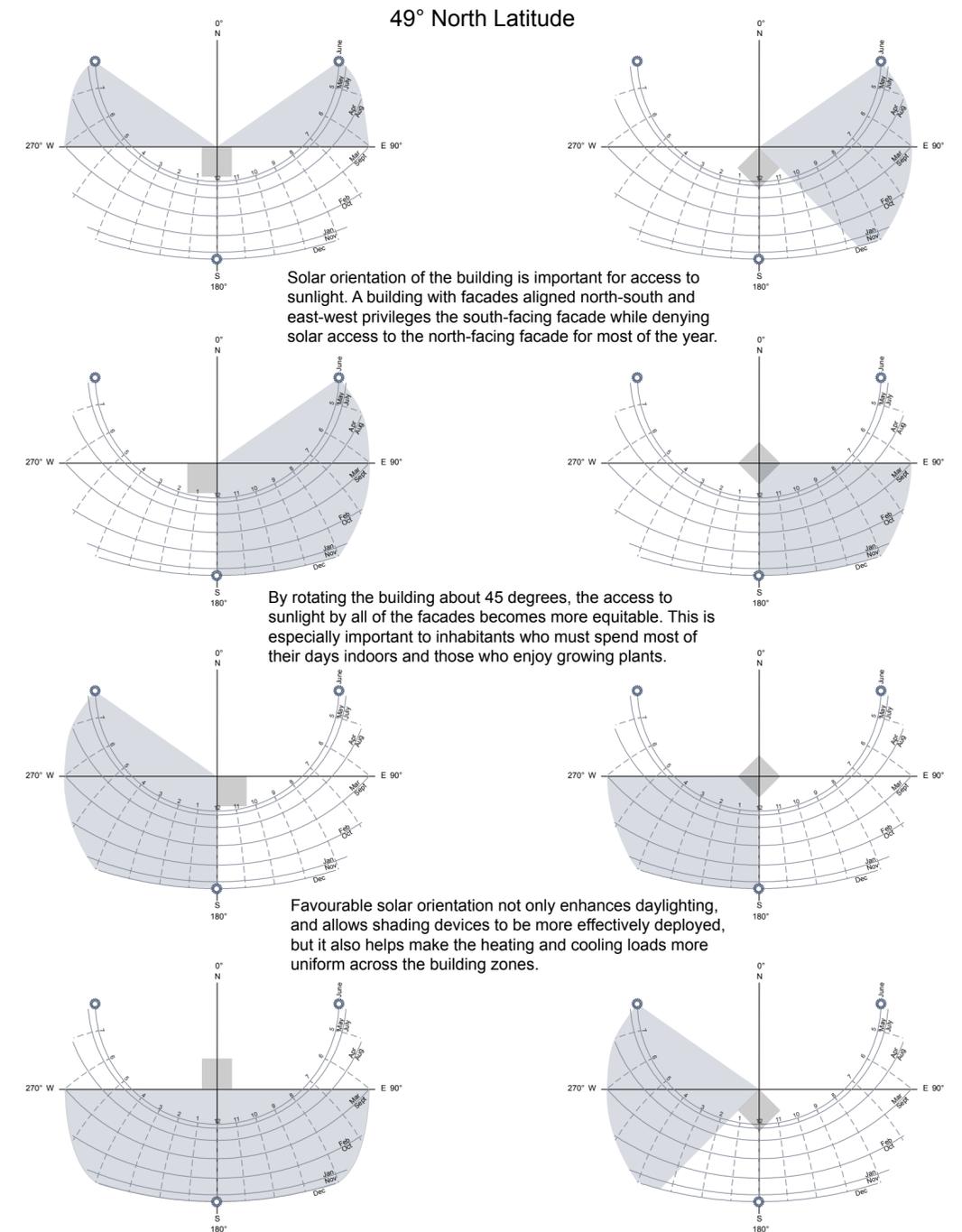


Professor Ralph L. Knowles in his work on the Solar Envelope demonstrated how for a north-south oriented grid (left), streets bearing east-west are likely to be particularly uncomfortable: dark and cold in winter, bright and hot in summer. Shadow patterns in streets laid out on the diagonal (Spanish Grid - right) show that all streets have some winter sun and summer shade, making them generally more comfortable than streets laid out on a north-south oriented grid. Similarly, the orientation of MURB facades significantly influences solar access.



Sunpath diagrams, widely available online for any latitude, are useful in planning solar access for MURBs. The solar path for the 21st day of each month indicates the azimuth and altitude angles for the sun and this information can be conveniently applied at the schematic design stage.

Buildings that are rotated approximately 45° with respect to north-south provide much more equitable solar access and the heat gains (cooling loads) over all solar orientations of suites are much more uniform than buildings whose principal faces are oriented north-south and east-west. While the south facade is greatly privileged to receive generous daylight and passive solar gains in winter, the north facade only sees a glimpse of the sun early and late in the day over the summer months.



Solar orientation of the building is important for access to sunlight. A building with facades aligned north-south and east-west privileges the south-facing facade while denying solar access to the north-facing facade for most of the year.

By rotating the building about 45 degrees, the access to sunlight by all of the facades becomes more equitable. This is especially important to inhabitants who must spend most of their days indoors and those who enjoy growing plants.

Favourable solar orientation not only enhances daylighting, and allows shading devices to be more effectively deployed, but it also helps make the heating and cooling loads more uniform across the building zones.

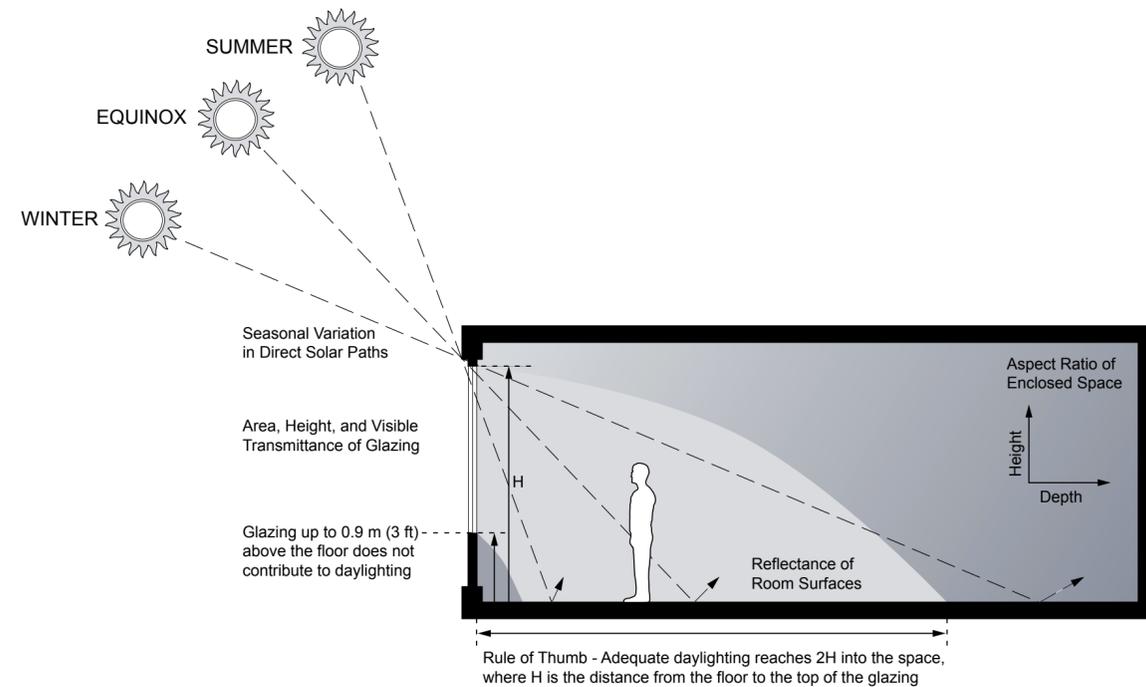
A number of sophisticated software tools are available for modelling solar access and daylighting, but the solar path offers a rapid assessment of basic building shape and orientation strategies to arrive at feasible candidates to which the more sophisticated tools can then be applied. Above, the more equitable access to daylighting across the four facades due to a 45-degree rotation of a building may be determined by entirely graphical methods.

PASSIVE SYSTEMS DESIGN

Click on the download icon for more information about:
Daylighting

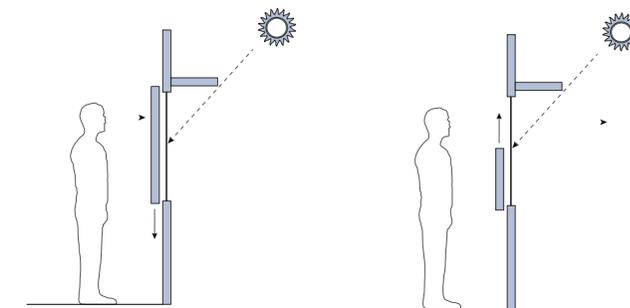
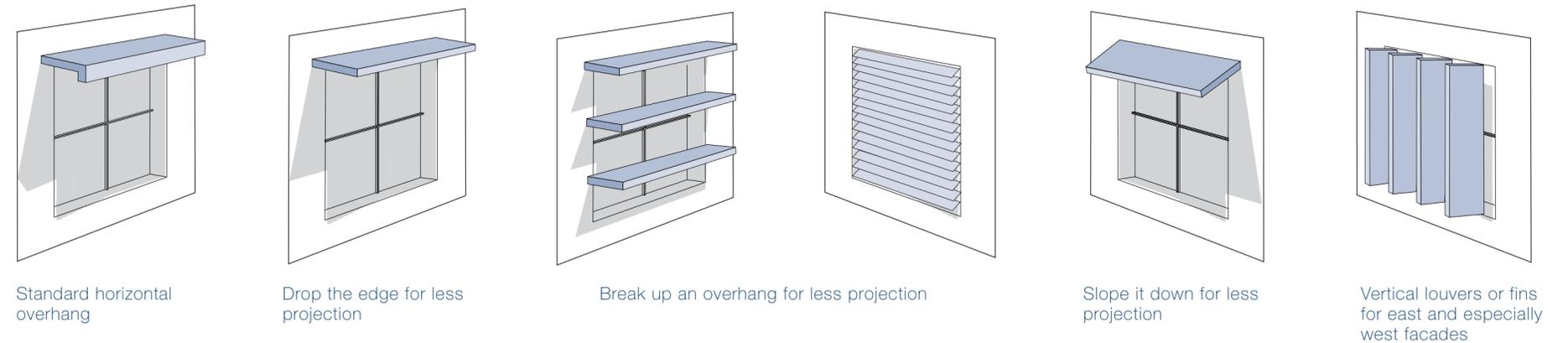


Once the orientation and form of the building has been established, it is important to consider daylighting of the principal rooms (living, dining, kitchen, bedroom, bathroom). Ideally, operable windows are provided to every principal room to afford views and access to light and air. But where this is not feasible, the minimum acceptable daylighting should be provided to rooms that are occupied during daytime hours, such as the living, dining and bedroom areas. The size and in particular the height of the windows above the floor are critical parameters affecting daylighting design.



The rule of thumb for daylighting indicates that increasing the height of windows improves the amount of daylight penetration. For typical multi-unit residential building floor-to-floor heights, room depths in excess of 5 m (~16 feet) are not recommended if adequate daylighting is desired.

In addition to providing adequate daylighting, it is also to control against glare and discomfort due to overheating. External and internal shading devices are essential to providing comfort and energy efficiency.



Above: External shading devices are uncommon in most multi-unit residential buildings except for those having cantilevered balconies. The advantage of external shading devices is that they intercept the direct solar gains before they enter the building, unlike internal shading devices.

Left: There are a number of internal shading alternatives available today that allow for control of daylight, shading against excessive solar gains, and maintenance of views.

Climate change is generating a significant increase in the frequency and severity of extreme weather events. High winds can result in damaged or broken windows from airborne projectiles. An approach to combining shading, privacy and protection that is gaining in popularity is the provision of adjustable louvers or shutters.



In addition to providing shading and privacy, external louvers and shutters also offer protection against wind-borne projectiles during extreme weather events.

As noted previously and worthwhile repeating, daylighting and natural ventilation must be harmonized through proper fenestration design. The selection of glazing systems that are energy efficient, allow for generous ventilation openings and are sufficiently high to admit daylight further into the suite must be accommodated within a window-to-wall ratio that does not compromise the thermal efficiency of individual suites and the MURB as a whole.

PASSIVE SYSTEMS DESIGN

Click on the download icon for more information about:
Natural Ventilation



Natural Ventilation

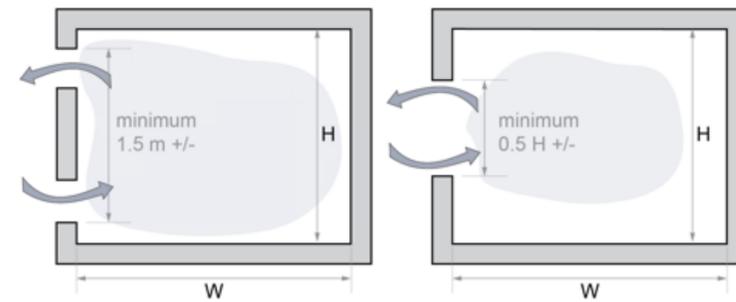
Access to light and air are among the most important considerations in housing design. It is estimated that urban dwellers spend approximately 90% of their time indoors, and this explains the importance of daylighting and natural ventilation to human well being. Unlike mechanical ventilation, which delivers outside air and exhausts stale, moist and contaminated indoor air through fans and ductwork, natural ventilation relies on wind and buoyancy effects (stack pressures) to move air through openings typically located in windows and doors.

The vast majority of MURBs comprise suites with single aspect facades due to the predominance of the double-loaded corridor typology in apartment design. Corner suites have exterior facades on two aspects and it may be possible for suites located on the uppermost storey to be fitted with skylights or roof monitors. The rules of thumb for natural ventilation should be considered along with daylighting parameters in order to harmonize these critical passive systems in terms of the suite aspect ratio of floor plate depth to room height.

Natural Ventilation Rules of Thumb

Single Sided Ventilation

- W (depth) < 2.5 H
- Separate high/low windows more effective than a single opening
- Opening size not less than 5% of floor area (10% with screens)



Cross Ventilation

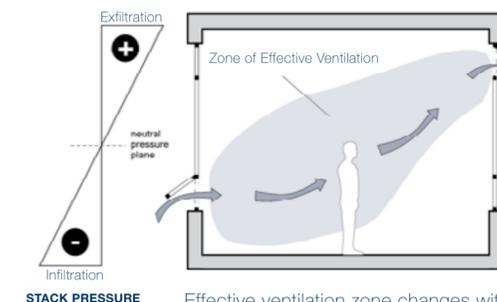
- W (depth) < 5 H
- Separate high/low windows more effective than a single opening
- Opening size, not less than 5% of floor area (10% with screens)



Single-sided natural ventilation strategies require generous window opening areas serving rooms that have relatively shallow floor depths. Safety restrictions for maximum window opening dimensions translate into the need to provide a large number of operable window units. Where cross ventilation is possible, deeper floor plates are permissible. In all cases distribute window openings across the face of the facade to the greatest extent possible.

Stack Pressure Driven Ventilation

- Functions under stack pressures
- Requires intentional openings high and low, preferably on opposite sides of the space

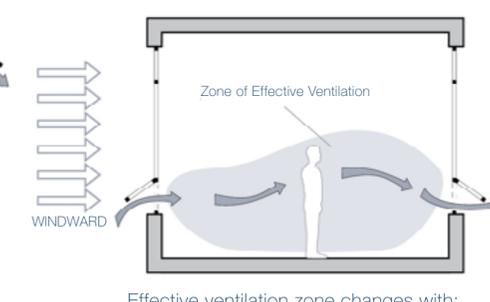


Effective ventilation zone changes with:

- indoor/outdoor temperature difference
- height difference between intentional openings
- size and location of intentional openings
- geometry of the space

Wind Driven Ventilation

- Functions under wind pressures
- Requires intentional openings on opposite sides of the space

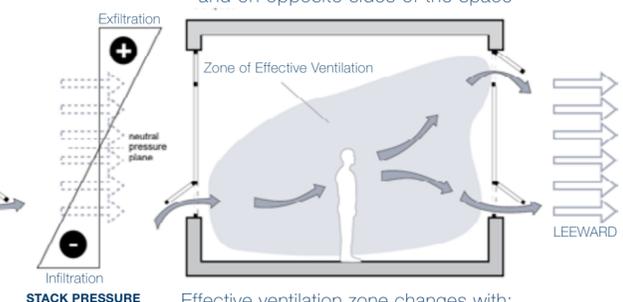


Effective ventilation zone changes with:

- wind speed and direction
- size and location of intentional openings
- geometry of the space

Combined Ventilation

- Functions under a combination of wind and stack pressures
- Requires intentional openings high and low, and on opposite sides of the space



Effective ventilation zone changes with:

- wind speed and direction
- indoor/outdoor temperature difference
- height difference between intentional openings
- size and location of intentional openings
- geometry of the space

MURB suites with opposed double aspect facades represent a higher standard of design for liveability, but are also typically associated with much higher cost housing. The design of fenestration for natural ventilation and daylighting that delivers highly effective passive systems is much easier in suites with double aspect facades, and usually this type of suite layout is easier to achieve in mid-rise rather than high-rise MURB typologies.

Synopsis

Passive systems act as environmental separators that mediate between the indoor and outdoor environmental conditions and together they manage heat, air, moisture, daylighting and natural ventilation. In low energy building design, passive systems are privileged over active systems that are only minimally capable of supplementing passive behaviour. For millennia, architecture involved the creation of passive systems that provided shelter, comfort and delight. It was only for a brief period of history, roughly from the time of the Industrial Revolution until the latter part of the 20th century, that passive systems were abandoned in favour of brute force active systems that failed to deliver on their promise. This failure reflects the phenomenological hierarchy between passive and active systems. Enclosures provide separation between the indoors and outdoors, while active systems can only ever moderate what enclosures cannot manage to separate. Active systems can never completely compensate for poorly performing enclosures because they can never strengthen the weakest link in the chain. However, active systems do play an important supporting role in multi-unit residential buildings and no matter how energy efficient MURBs are designed, there will always be a requirement to provide effective mechanical ventilation to to each suite.

ACTIVE SYSTEMS DESIGN

This part of the MURB Design Guide focuses on heating, ventilating and air-conditioning (HVAC) systems fully recognizing that especially for high-rise MURBs, elevators are an essential active system component. The same importance can be ascribed to pumps that deliver water to the upper storeys of MURBs. Underground parking beneath the building requires automated access doors and security features such as lighting and surveillance cameras, as well as a means of mechanically ventilating the parking space when emissions levels from automobiles exceed safe limits. Finally, the intercom and security systems for the building are vital to the amenity and security of the inhabitants.

It is important to appreciate that unlike single family detached housing, MURBs cannot fully function for extended periods of time without active systems. Rather than looking at the essential active systems that cannot be offset by passive systems, this Guide examines HVAC systems design in the context of buildings where the need for active heating, ventilating and air-conditioning has been significantly reduced through the design of high performance enclosures (i.e., the PassiveMURB).

HVAC System Considerations

Recent research indicates that high performance enclosure design can enhance the thermal autonomy of MURBs. Thermal autonomy is the fraction of time during a typical year when the building does not require any active heating or cooling to maintain comfortable indoor conditions. Peak space heating and cooling loads are also reduced by high performance enclosures and as noted in Passive Systems Design, a coordinated ensemble of passive measures can almost eliminate the need for active systems for a majority of the time. Given this highly passive building context, HVAC system design includes the following important considerations.

- **Centralized Versus Decentralized Systems** – While it often makes sense to centralize domestic water heating in MURBs, decentralized approaches to heating, ventilating and air-conditioning systems may be more effective and responsive to individual preferences.
- **Accessibility, Operability and Lifecycle** – The useful service life of HVAC systems is much shorter than what we normally witness for structures and enclosures. Planning HVAC systems so that vital components are accessible, especially for routine maintenance and cleaning, is an important design consideration. Major equipment and components will have to be removed and replaced eventually so this unavoidable process of renewal should be economical and minimally disruptive.
- **Effectiveness** – Thermal comfort is affected by the effectiveness of space heating and cooling systems although high performance enclosures diminish the need for “brute force” HVAC systems and allow much greater flexibility. However, indoor air quality remains largely dependent on ventilation system effectiveness and properly designed active mechanical ventilation systems are essential in MURBs.
- **Operability and Controls** – Straightforward controls for the HVAC system that permit people to choose their comfort settings have been demonstrated to improve inhabitant satisfaction. It also provides households with manageable choices for energy conservation. Some building systems will always require some form of centralized control and monitoring and practical trade-offs are inevitable.
- **Feedback and Submetering** – When building inhabitants are provided with feedback about their energy and water use, and this is reinforced through submetering, the majority outcome is behaviour that promotes resource conservation. Deploying appropriate technology to inform inhabitants about the consequences of their energy and water use behaviour becomes more important as buildings strive to become more efficient.
- **Energy Choice** – Canada’s move to a low carbon economy will involve making energy choices for our buildings. Multiple energy sources serving a building provide redundancy that enhances resilience. The shift towards net zero energy and carbon neutral buildings will have to reconcile reliable energy sources for emergency power system measures that will become increasingly important as the frequency and severity of extreme weather events increase due to climate change.

ACTIVE SYSTEMS DESIGN

Click on the download icon for more information about:
[MURB Ventilation & Indoor Air Quality](#)



Mechanical Ventilation Strategies

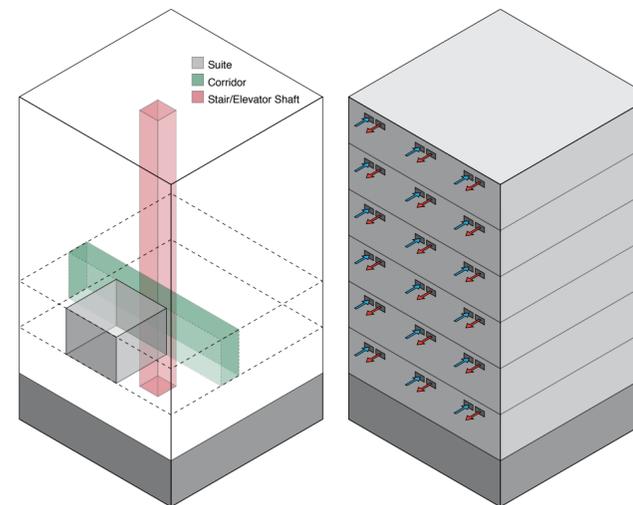
The design of HVAC systems for MURBs begins with the development of an appropriate mechanical ventilation strategy. Natural ventilation is a passive strategy that does not always provide acceptable indoor air quality and/or thermal comfort. Mechanical ventilation is essential during many times of the year when natural ventilation is ineffective. In addition to ventilation, it is also necessary to properly exhaust kitchen range hoods and clothes dryers to minimize the contamination of the indoor air.

There are basically two fundamental mechanical ventilation strategies for MURBs. The most prevalent strategy is the pressurized corridor system depicted in the accompanying figure. As the excerpted caption explains, this approach does not perform as intended. Most of the outside air is not delivered to the suites and ends up migrating through elevator shafts and stairwells where it leaks out of the building. Not only is it costly to condition this outside air, but the exhaust and make-up air units run constantly rather than variably responding to demand for ventilation by the inhabitants. It is also difficult to incorporate energy or heat recovery for this type of approach to mechanical ventilation.



Ventilation in multi-unit residential buildings is typically provided by a pressurized corridor system. This method uses a common make-up air unit to provide air to the corridors of each floor and create a positively pressurized space. The intent of the design is for the air from the corridors to pass through the suites to the exterior driven by this pressure difference and the use of exhaust fans. Though this system design is pervasive throughout North America there is considerable evidence that the ventilation design does not perform as intended, resulting in poor indoor air quality and occupant comfort complaints. [Source: James Montgomery and Lorne Ricketts, *Air Quality in Multi-Unit Residential Buildings*, RDH Technical Bulletin No. 009, August 2015.]

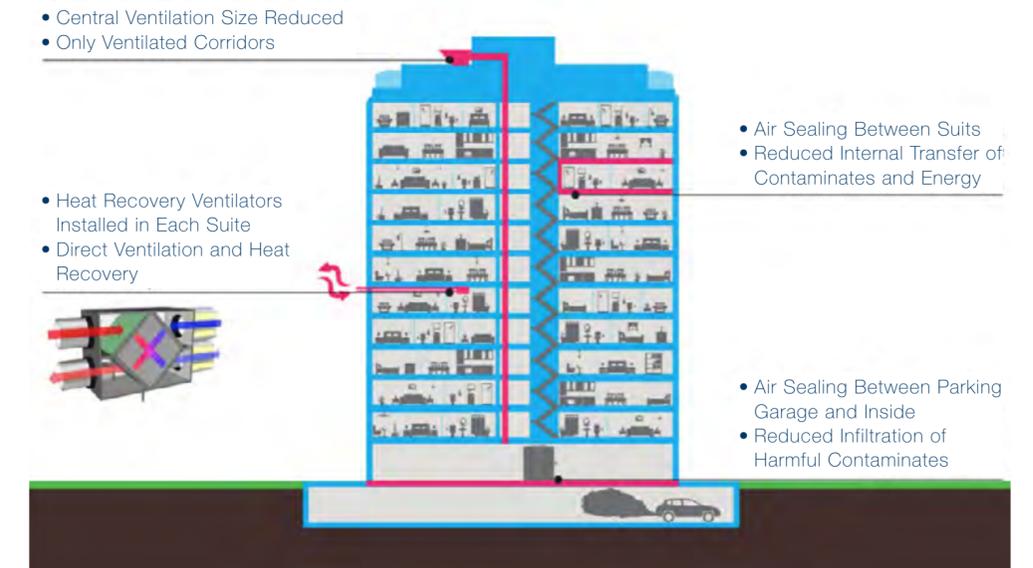
The second strategy for mechanical ventilation is direct ventilation with energy or heat recovery. It is usually deployed along with several other measures to improve ventilation system effectiveness, indoor air quality and energy efficiency. Compartmentalization of the suites and isolation of the suites from underground parking by air sealing eliminate the transfer of odours and contaminants. Energy or heat recovery ventilators are installed in each suite to directly provide ventilation that is controlled by the occupants. The central ventilation system serving the corridors and common elements is significantly downsized to further save energy.



Stack effect driven airflows in tall buildings compromise smoke control and fire safety, adversely affect indoor air quality and comfort as well as increase operating costs for space conditioning energy. By isolating the units from each other and from corridors, shafts, elevators and stairwells, stack effect driven interior airflows can be controlled (left figure). By delivering ventilation individually to each suite across the exterior walls, the ventilation system performance is not compromised by stack or wind pressure inside the building (right figure).

Two key concepts for ventilation systems design in MURBS reveal the need for integration and coordination between architecture and engineering. The first concept is compartmentalization where individual suites are completely separated from air, smoke and fire movement between adjacent suites, corridors and stair or elevator shafts. Each suite, corridor and shaft is compartmentalized. The second concept is that ventilation is provided to each individual suite across exterior walls, not across interior pressure boundaries such as floors or demising walls. Failure to observe the principles underlying these two concepts explains the poor performance of so many MURBs that failed to compartmentalize suites and deployed corridor pressurization systems.

Measures to enhance ventilation system effectiveness and improve indoor air quality are well documented in recent studies and publications. Isolating garbage, recycling and composting areas from the air in the building is a critical best practice in MURBs. The figure below summarizes a sensible approach to saving energy and improving indoor air quality.



Indoor air quality within a building is determined by a number of factors. Ventilation system effectiveness combined with the elimination of odour and contaminant transfers are major considerations in design. The proper venting of range hoods and clothes dryers is another critical measure that can be implemented. Special care must be exercised to ensure sources of exhausted air do not contaminate the intake of outside air, and do not vent into adjacent balcony spaces thus compromising the enjoyment of neighbours. [Source: James Montgomery and Lorne Ricketts, *Air Quality in Multi-Unit Residential Buildings*, RDH Technical Bulletin No. 009, August 2015.]

From an architectural perspective, direct ventilation strategies require the concealment of ductwork and may necessitate increased floor to ceiling heights. Puncturing the facade with intake and exhaust grilles may also impact the aesthetics of the building, but observing physics takes precedence. Common outside air and exhaust shafts with fire dampers at ductwork penetrations are among the approaches found in international precedents, but the number of suites served and the height of the building become critical factors. Regardless of the strategy selected, there is no substitute for proper and rigorous engineering in the design, installation and commissioning of mechanical ventilation systems for MURBs.

ACTIVE SYSTEMS DESIGN

Click on the download icon for more information about:
MURB HVAC Technology

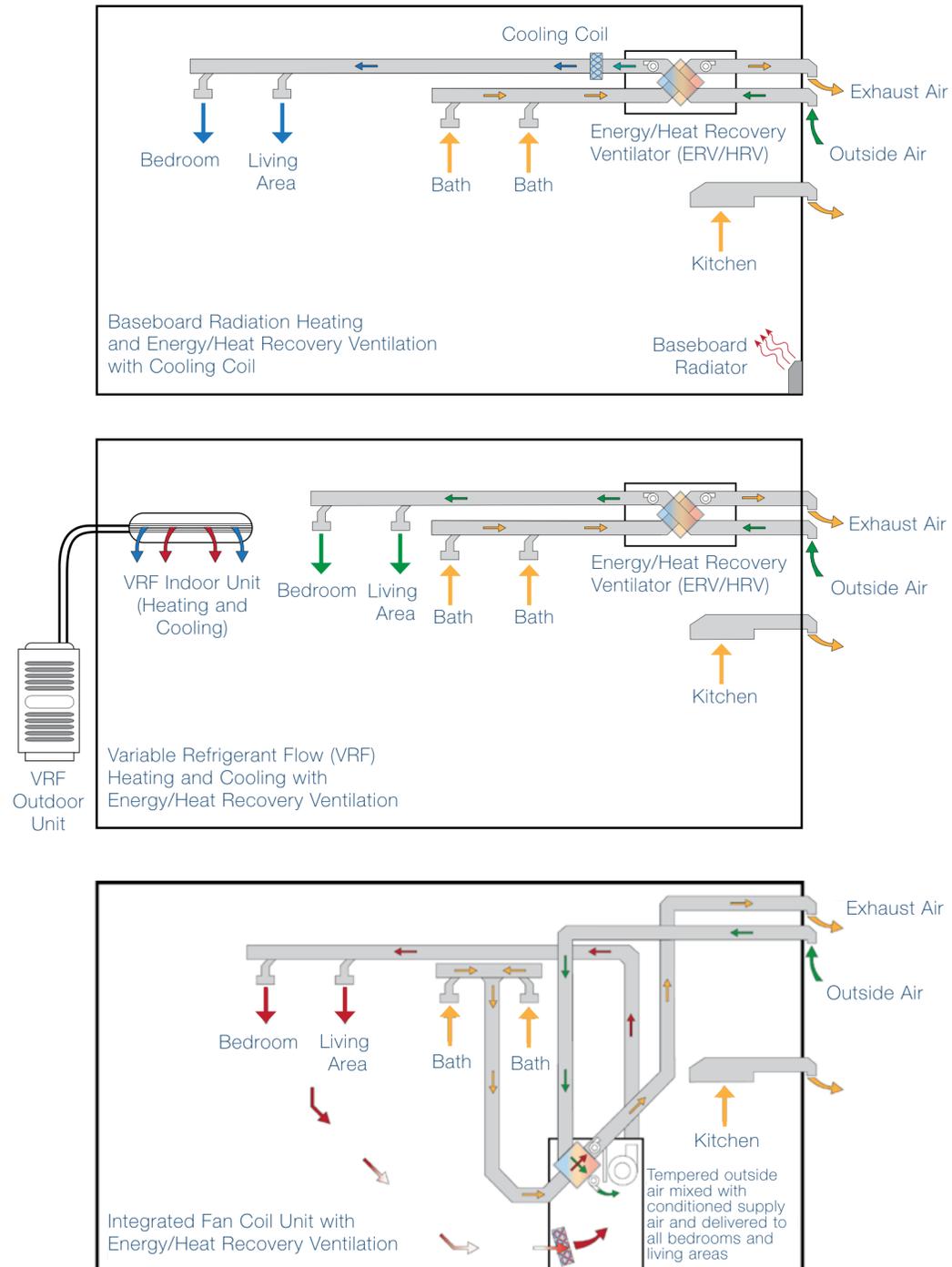


Individual Versus Central HVAC Systems

Traditionally, Canadian apartment buildings (MURBs) were outfitted with a central hot water heating system. Air-conditioning (space cooling) was virtually non-existent and ventilation was provided by operable windows in each of the principal rooms. It was not uncommon for a single thermostat to control the heating for an entire building, typically operated by the landlord or caretaker. Both the building enclosures and heating systems were highly inefficient but this was financially tolerable due to relatively modest energy prices up until the 1970s. Less tolerable were the thermal comfort conditions and indoor air quality. Gradually, building energy efficiency improved and occupants demanded greater control of their household environments. With the trend towards strata or condominium apartment living, inhabitants prefer to individually control heating, ventilating and air-conditioning.

Centralized systems are typically confined to domestic water heating, space heating and chilled water for cooling. In many buildings, mechanical ventilation is also centralized with bathrooms connected to an exhaust system while hallways are pressurized with outside air. It is now feasible to provide each individual suite with all of these services, but there remains a dominant trend towards centralized domestic water heating due to advantages pertaining to economics and efficiency. However, as the efficiency of the building enclosure improves, the amount of space heating and cooling energy correspondingly decreases and minimally obtrusive HVAC systems can supplement the passive enclosure system to deliver acceptable comfort and indoor air quality.

Schematics for three types of HVAC systems suitable for low energy MURBs are depicted in the figures that follow. The captions provide concise explanations about their functionality.



In suites with low space heating and cooling demands, electric baseboard heaters and a cooling coil served by a centralized chilled water supply and integrated with an energy or heat recovery ventilator can effectively condition and ventilate the space. The ERV/HRV must be sized to compensate for the cooling coil pressure drop, and the cooling coil and HRV condensate drainage can be combined into a single drain. An outdoor make-up air unit can be interlocked with the range hood where a high capacity unit is installed in an airtight enclosure.

Where individualized control in different areas of a suite is desired, variable refrigerant flow heat pump technology allows multiple indoor units to be served by a single outdoor unit. This approach allows for the submetering of electrical plug loads along with space heating and cooling energy. The ERV/HRV is purely for ventilation and may be operated independent of space heating and/or cooling demands.

HVAC equipment manufacturers offer a diversity of fan coil units with integrated ERV/HRV technology that effectively manages heating, cooling and ventilation. This approach requires a centralized supply of hot and chilled water serving the fan coil and requires special measures for the submetering of space heating and cooling energy use.

ACTIVE SYSTEMS DESIGN

Operability and Controls

The health, safety, security and comfort of building inhabitants are among the chief reasons we make buildings, in particular housing. It is often observed that automobiles come with better HVAC systems than houses in terms of their functionality and operability. There is also a misconception that controls alone will make for better HVAC system operability. In MURBs, inhabitant operation and control is important because apartment living offers fewer degrees of freedom for environmental control than single family detached housing in terms of access to light and air.

It is generally acknowledged that providing a separate component or piece of equipment for each HVAC function listed in the table below provides the best performance. Uni-functional equipment delivers a discrete function that responds to a particular physical phenomenon (e.g., heat, air, moisture), hence its performance can be optimized. Multi-functional equipment inherently compromises performance because it cannot prioritize all of these functions as effectively. This dysfunctionality is directly related to the configuration of components and controls in multi-functional HVAC systems. Integrated, multi-functional HVAC systems for MURBs are available, but it is important to check that the components and controls enable the discrete operation of each of the individual components.

Basic HVAC Function	Component or Equipment	Types of Control(s)
Make it Hotter	Heating	Thermostat
Make it Colder	Cooling	
Increase Humidity	Humidifier	Humidistat
Decrease Humidity	Dehumidifier or Cooling	
Provide Fresh Air	Fans (e.g., Energy or Heat Recovery Ventilator, Make-Up Air Unit)	Switch (Manual, Timer, Occupancy Sensor, Humidistat, VOC Sensor)
Filter Air and Remove Pollutants	Fans with Air Filters (e.g., Energy or Heat Recovery Ventilator), Exhaust Fan, Range Hood	
Prime Directive: Environmental conditions in a space should be controlled by sensors in the space acting on equipment associated only with that space.		

The most common approaches to HVAC systems in MURBs involve 2-pipe vertical fan coil units for heating and cooling combined with corridor pressurization systems for ventilation air. Kitchen range hoods and bathroom exhaust fans are provided to remove moisture, odours and contaminants. Typically there is no energy or heat recovery associated with these ventilation functions. Since the corridor pressurization system relies on air passing under the hallway doors serving each suite, very little outside air is actually delivered to the occupied space and most inhabitants rely on operable windows for fresh air. The poorly performing enclosure with large glazed areas having low thermal resistance, combined with thermal bridging across the balcony slab, create conditions that challenge thermostats and heating/cooling equipment alike to maintain uniform, acceptable comfort conditions during extreme weather periods (i.e., summer and winter).

It is important to appreciate that “the temperature that defines comfort is not the air temperature, but something called the operative temperature. The operative temperature is a combination of the air temperature, the weighted average of all surface temperatures of a space (defined by the mean radiant temperature, MRT), and air velocity. At low air velocity, the operative temperature is the simple average of the MRT and air temperature.” Thermostats are only able to detect the sensible temperature in the immediate vicinity where they are located - they are blind to surface temperatures (MRT) and the amount of humidity in the air. That is why it is important to design high performance enclosures because the high effective thermal resistance values of walls, windows and roofs and absence of thermal bridging, combined with high levels of airtightness, result in an even, well tempered indoor environment. This enhances the effectiveness of the thermostat at measuring the effective temperature in the space, and the ability of the heating/cooling equipment to maintain acceptable comfort conditions.

Controls are only as good as the HVAC components they serve. Assuming that every reasonable effort has been made to discretely provide for every basic HVAC function, the following best practices for inhabitant operation and control are recommended.

- **Keep It Simple** – Provide simple controls with manual override. Programmable and smart controls can frustrate unsophisticated users that simply want to make an adjustment or turn on equipment. Timer controls are ideal for bathrooms. Sensors for occupancy or VOCs are normally not required. Normally, a thermostat for heating/cooling and a ventilation system control are all that is needed in a typical MURB suite.
- **Proper Location** – Locate controls such as thermostats and humidistats where they are exposed to average environmental conditions and in plain view of the inhabitants. Controls that are located near high sources of heat or humidity will not reflect average conditions and may result in discomfort.
- **Clear Documentation** – For facilities managers and caretaking staff - keep printed and digital copies of operating instructions available for inhabitants because sometimes these are lost, thrown out or misplaced. Where the manufacturer's operating instructions are unclear, consider developing an in-house, simplified set of instructions.
- **Periodic Maintenance** – Replacing filters and cleaning the cores of energy or heat recovery ventilators represent required periodic maintenance. Protocols for demonstrating proper procedures to inhabitants are the most effective means of ensuring maintenance is properly performed. Online videos are an economical and effective means of demonstrating periodic maintenance procedures.

The operation and control of HVAC systems by inhabitants in MURBs should be made as simple as possible. They should understand how to properly maintain their system and be aware when it is not functioning properly and how to obtain corrective service. Most importantly, they should appreciate that virtually all comfort problems stem from poorly performing building enclosures, not from their HVAC systems and controls.

ACTIVE SYSTEMS DESIGN

HVAC System Energy Sources

Heating and cooling of MURBs can be accomplished with a number of energy sources, but mechanical ventilation relies on electricity to power fans. The move towards a low carbon economy will encourage new buildings to be designed to operate entirely on renewable energy sources. But there will also be situations where MURB owners may wish to pick HVAC systems that are fuel-flexible, allowing for a migratory path to renewable energy sources in the future. It is important to differentiate an energy source from technology that converts that energy into heating, cooling or ventilation.

Energy Source	Application	Ecological Footprint*
Fuel Oil	<ul style="list-style-type: none"> • Heating • Combined Heat and Power 	Very High
Natural Gas / Propane	<ul style="list-style-type: none"> • Heating • Cooling • Combined Heat and Power 	High
Conventional Electricity (Multiple sources including fossil fuels and nuclear fission)	<ul style="list-style-type: none"> • Heating • Cooling • Ventilation 	Low to High, depending on the mix of energy sources used to generate electricity
Hydroelectricity	<ul style="list-style-type: none"> • Heating • Cooling • Ventilation 	Low to High, depending on development path taken to flood watershed and construct dams
Green Electrical Power (Solar & Wind)	<ul style="list-style-type: none"> • Heating • Cooling • Ventilation 	Negligible to Low, depending on displacement of indigenous species and effects on migratory paths
Solar Thermal	<ul style="list-style-type: none"> • Heating • Cooling 	Negligible
Biomass	<ul style="list-style-type: none"> • Heating • Cooling • Combined Heat and Power 	Negligible to Low, depending on sources, means of harvesting, transportation and distribution, and combustion technology
Geothermal (Ground source heat pumps)	<ul style="list-style-type: none"> • Heating • Cooling 	Negligible to Low, depending on type of ground loops or boreholes and source of electrical energy

* Ecological Footprint: Includes all environmental risks and impacts such as degradation, reduction of biodiversity, toxicity, greenhouse gas emissions, spills, etc.

Electricity is the most versatile energy source for heating, cooling and ventilation and it can be derived from a number of sources including the combustion of fossil fuels and nuclear fission. Fossil fuels emit greenhouse gases and tend to have much higher ecological footprints associated with them than most forms of electricity. But in many remote locations, fuel oil and propane, as well as wood pellets, are practical alternatives that are easy to transport and store. With most MURB developments taking place in urbanized parts of Canada, almost every energy source is available for consideration by designers.

High performance enclosures that passively manage heating and cooling, daylight and natural ventilation represent the most cost effective means of conserving energy and permitting a higher degree of freedom in energy choices. As the operating energy demands of a building decrease, so do the economic and environmental impacts associated with energy. Thermal storage of both heat and cold are additional means of conserving electrical grid generating capacity. Peak energy demands can be reduced by storing heat energy in thermal mass, or making and storing ice, using electricity during off-peak times. Passive techniques such as passive solar heating and natural ventilation harness renewable energy sources and can help further offset the amount of purchased energy needed to power MURBs.

The future trend in HVAC system energy choices will be towards renewable energy that is carbon neutral and exerts a negligible ecological footprint. Designers of new MURBs, and those involved in the deep retrofit of existing MURBs, should either select systems that run on renewable energy sources, or ensure their HVAC systems represent a migratory path to clean energy sources in the future.

THERMAL COMFORT

Occupant thermal comfort near exterior walls can be compromised in multi-unit residential buildings because of the impact of **cold walls and windows, cold floors and ceilings**, and **exposure to direct solar radiation**. This section explores the significance of discomfort, provides an overview of thermal comfort concepts, and provides design strategies for improving occupant thermal comfort. It also provides links to user-friendly tools that can be used to predict comfort as a function of design.

Thermal Comfort Defined

Thermal comfort is often defined as *“that condition of mind which expresses satisfaction with the thermal environment and is assessed by subjective evaluation.”*¹ But for practical purposes, thermal comfort is understood to be achieved if two conditions are met:

1. The overall heat loss from our skin and respiration balances our metabolic rate; and
2. There is no local discomfort (e.g., cold feet or warm head).

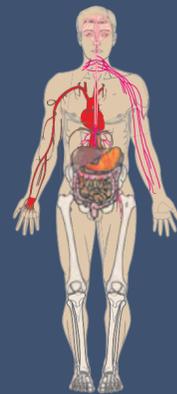
¹ASHRAE. 2013. ANSI/ASHRAE Standard 55-2013. Atlanta: American Society of Heating, Refrigerating and Air-Conditioning Engineers, Inc.



The outer perimeter near the windows of floor-to-ceiling glazed condominiums, like the unit depicted in this photograph, can become a source of discomfort during extremely cold and hot weather.

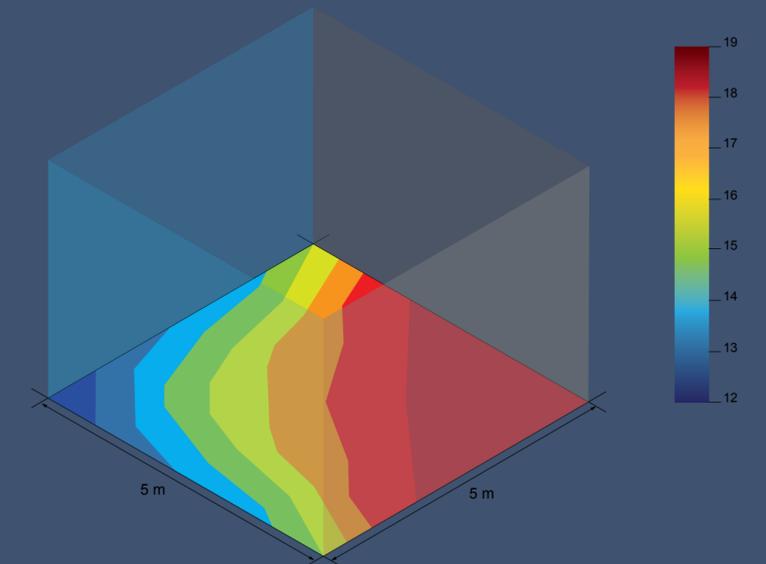
Factors Affecting Thermal Comfort

There are six key factors affecting human perceptions of thermal comfort.



- **Air Temperature** – This is the temperature of the air surrounding the body as measured by a simple thermometer.
- **Radiant Temperature** – Thermal radiation is the heat that radiates from a warm object. Radiant heat may be present if there are heat sources in an environment. Radiant temperature has a greater influence than air temperature on how humans lose or gain heat to the environment. Examples of radiant heat sources include the sun and an open fire.
- **Air Velocity** – The speed of air moving across the skin is an important factor in thermal comfort. Still or stagnant air in indoor environments that are artificially heated may cause people to feel stuffy. It may also lead to a build-up in odour. Small air movements in cool or cold environments may be perceived as a draught as people are particularly sensitive to these movements.
- **Humidity** – Relative humidity is the ratio between the actual amount of water vapour in the air and the maximum amount of water vapour that the air can hold at that air temperature. Very high relative humidity above 80% prevents the evaporation of sweat from the skin, which is the main means of heat reduction in humans.
- **Clothing** – Thermal comfort is very much dependent on the insulating effect of clothing on the wearer. Clothing is both a potential cause of thermal discomfort as well as a control for it humans adapt to the climate by adding or removing layers.
- **Activity Level (Metabolism)** – Physical activity produces body heat and the more heat humans produce, the more heat needs to be lost to avoid overheating. The impact of metabolic rate on thermal comfort is critical.

Perceptions of thermal comfort are determined by a complex number of interrelated factors. Research indicates that weight, age, fitness level and sex can all have an impact on perceptions of comfort eliciting different perceptions among people, even if other factors such as air temperature, radiant temperature, humidity, air velocity and clothing level are all constant.



MURB suites with fully glazed exterior walls on the corner can experience highly uncomfortable operative temperatures during extreme cold weather over the evening hours coinciding with the time when inhabitants would like to enjoy the space. In this analysis for Toronto extreme winter weather and typical full-height window wall enclosure, uncomfortable operative temperatures are indicated for about three quarters of the room floor area.

MURB suites with fully glazed exterior walls on the corner can experience highly uncomfortable operative temperatures during extreme cold weather over the evening hours coinciding with the time when inhabitants would like to enjoy the space. In this analysis for Toronto extreme winter weather and typical full-height window wall enclosure, uncomfortable operative temperatures are indicated for about three quarters of the room floor area.

It is important to appreciate that *“the temperature that defines comfort is not the air temperature, but something called the operative temperature. The operative temperature is a combination of the air temperature, the weighted average of all surface temperatures of a space (defined by the mean radiant temperature, MRT), and air velocity. At low air velocity, the operative temperature is the simple average of the MRT and air temperature.”*²

² John Straube. 2011. The Perfect HVAC. Building Science Insight - 022, Building Science Corporation, July 2009 (Revised June 2011).

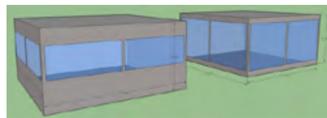
THERMAL COMFORT

Discomfort from Wall and Window Surfaces

The first condition for thermal comfort depends on four indoor environmental conditions: air temperature, average surface temperature, humidity, and airspeed. All of these are affected by enclosure design. But in particular, a little-known fact is that our operative (sensed) temperature is about half affected by surrounding surface temperatures and half by air temperature. In contrast, buildings are heated and cooled based on measured air temperature (using thermostats) only. This means that very cold or very warm surfaces can cause significant occupant discomfort. This problem is exacerbated by poorly insulated walls and windows, which do not maintain comfortable interior surface temperatures in winter and summer. As a general rule, the closer an occupant is to cold or warm surfaces, the less comfortable they will be. The effect of these surfaces depends on how well the occupant's body "sees" the surfaces. Accordingly, the most uncomfortable locations tend to be near large windows – particularly in corners where windows cover both surfaces.

In order to better appreciate discomfort from wall and window surfaces, some thermal comfort modelling was performed. Consider a 5 by 5 meter room in a Vancouver condominium on a cold day (-15°C) that has an indoor air temperature of 21°C. For these conditions, the following scenarios were investigated:

- A corner unit and a middle unit;
- 40% window-to-wall area ratio (WWR) and 80% WWR; and
- Double-glazed low-e windows and a unit with triple-glazed low-e windows.



Models of rooms in a corner condo units with 40% WWR (left) and 80% WWR (right).

Since the difference between indoor and outdoor temperatures is greatest in the winter, winter conditions are best for illustrating the importance of a high performance enclosure (including moderately-sized high-performance windows and a well-insulated wall with minimized thermal bridges). The simulation results show that large glazed areas – especially if they are relatively poorly insulated (e.g., code minimum) cause a considerable cooling effect for occupants near the windows. Two sets of results are presented: first, the operative (or sensed) temperature by an occupant and second, the required air temperature to increase the operative temperature to 21°C.

Table 1 shows the operative temperature in these four different corner unit spaces. Because of the proximity to cold surfaces (10°C for the double-glazing and 15°C for the triple glazing), the glazed corner of the units feels coldest. Notably, the unit having 40% WWR with double-glazing has similar comfort levels as the 80% WWR with triple-glazing. The triple-glazed unit with 40% WWR would feel the warmest, but not significantly warmer than the triple-glazed unit with 80% WWR. High performance glazing is critical to thermal comfort in MURBs and provides enhanced design freedom over fenestration strategies.

Table 1. Operative (sensed) temperature in a 5 by 5 meter corner room (plan view). All temperatures are in Celsius and all distances are from the interior surface of the exterior walls to the center of each 1 square meter grid.

Table 2 shows the required air temperature to achieve an operative temperature of 21°C. The interpretation of these tables values, for example, is that in the case of the double-glazed 80% WWR unit, the occupant would need to elevate the air temperature to 25.6°C to remain comfortable.

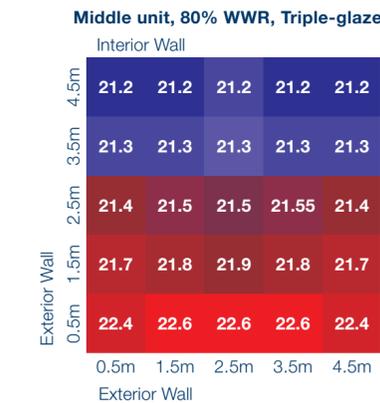
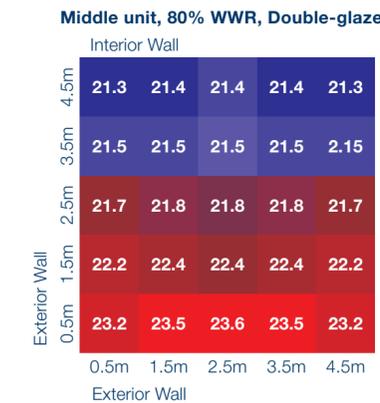
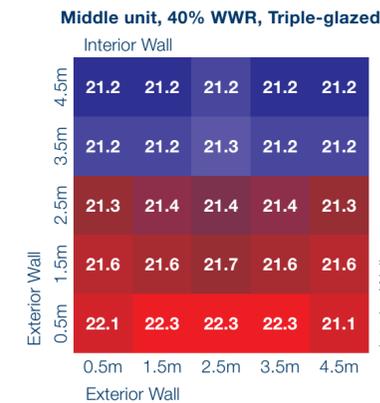
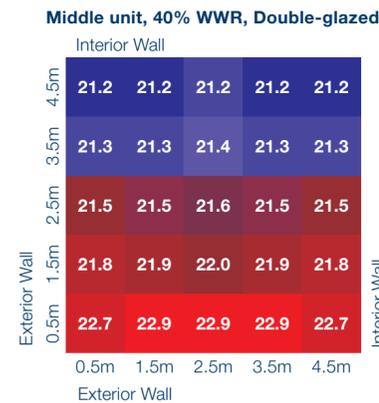
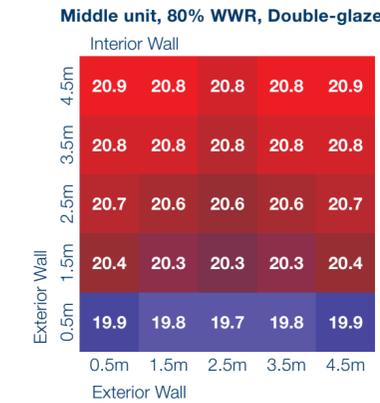
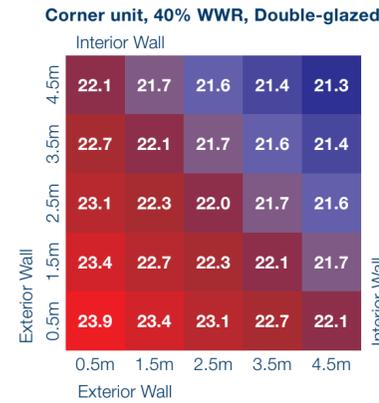
Table 2. Required air temperature to compensate for cooler mean radiant temperatures to achieve an operative temperature of 21°C in typical corner units (plan view).

Table 3 shows the operative temperature in the four middle unit cases. Similar to the corner units, the middle unit having 40% WWR with double-glazing has similar comfort levels as the 80% WWR with triple-glazing. Once again, the triple-glazing provides almost identical levels of thermal comfort for the 40% WWR and 80% WWR cases, indicating that high performance glazing is key to thermal comfort and permits greater design freedom over fenestration strategies.

Table 3. Operative (sensed) temperature in a 5 by 5 meter middle room (plan view).

Table 4 shows the required air temperature to achieve an operative temperature of 21°C in the middle units. The double-glazed unit with 80% WWR requires the biggest increase in air temperature of 1.8°C to maintain a comfortable operative temperature in the room.

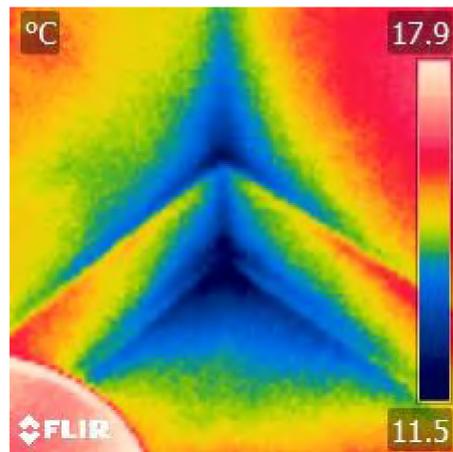
Table 4. Required air temperature to compensate for cooler mean radiant temperatures to achieve an operative temperature of 21°C in typical middle units (plan view).



THERMAL COMFORT

Discomfort from Floors

Beyond the direct impact on discomfort from poorly insulated facades, a frequent cause of discomfort in MURBs is cold floors. Even if an occupant's overall comfort is satisfied, local discomfort can be very problematic. Two confounding causes of this are thermal bridging through floor slabs – particularly near the perimeter of spaces – and highly conductive floor finishes (e.g., ceramic tile). A continuous concrete slab can cause floor temperatures around the perimeter to be well under 10°C and the distance from the wall below 20°C can exceed 0.5 m (1.6 ft). In a typical 3 by 3 meter corner bedroom, this means that about one-third of the room not comfortable.



Thermography indicating thermal bridging caused by a concrete slab. The corner of the floor and at the joints is about 12°C.



Example of an uncomfortable condominium bedroom, where the occupants complained of cold windows and floors.

In contrast to commercial buildings where occupants normally wear socks and shoes, residential building occupants frequently have bare feet. The recommended floor temperatures for common floor finishes are provided in Table 5. Regardless of cold floors caused by thermal bridging across the enclosure, the lower temperature limit of the surface ranges noted in Table 5 is well above typical floor temperatures in MURBs having concrete floors, except for softwood and textile-based floor finishes.

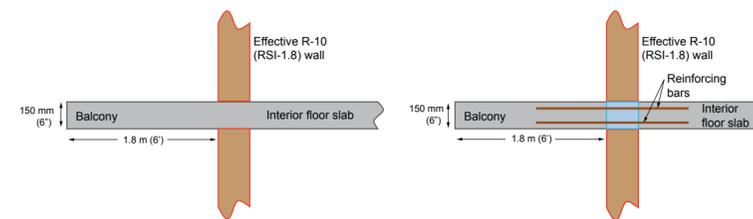
Textiles (carpets, rugs) 21-28°C	Pine Floor 22.5-28°C	Oak Floor 24-28°C	Linoleum 24-28°C	Concrete/Ceramic Tile 26-28.5°C

Table 5. Recommended surface temperature ranges for floors of various materials.

Practically speaking, MURBs with concrete floors will feel uncomfortable to the touch with bare or stocking feet unless a warm finish, such as carpeting, rugs or softwood flooring, is installed. Alternatively, radiant in-floor heating systems will raise floor temperatures to well within the comfort range thus permitting any type of floor finish.

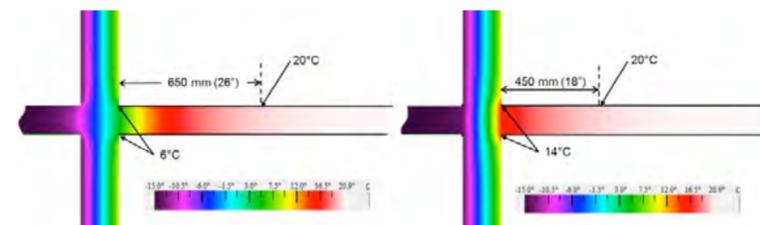
⁴American Society of Heating Refrigerating and Air Conditioning Engineers (ASHRAE) (2013). Handbook - Fundamentals. Atlanta, GA.

To illustrate the impact of balconies with a continuous (thermally unbroken) slab under the same Vancouver conditions as before (outdoor temperature of -15°C and indoor air temperature of 21°C), THERM software was used to assess the impact of a continuous concrete balcony slab and a thermally broken balcony, using simplified wall assemblies as depicted in the figure below.



Section view of two balcony configurations: Continuous balcony without thermal break (left) and balcony with thermal break (right).

The results of this example simulation are depicted in the figures below, and illustrate that a continuous concrete slab leads to cold and uncomfortable floors. A thermally broken slab significantly reduces the depth that the coldness penetrates into the unit.



Temperature profile of an uninsulated continuous balcony slab. Under winter (-15°C) conditions, the floor against the wall is 6°C and the outer 650 mm (26") of the floor is at 20°C or less.

Temperature profile of a thermally broken balcony slab. Under winter (-15°C) conditions, the floor against the wall is 14°C and the outer 450 mm (18") of the floor is at 20°C or less.

While occupants are not in direct contact with cold ceiling slabs, there are still comfort implications associated with cold ceilings since human heads are particularly sensitive to cold or warm surfaces.

The space heating and cooling energy savings from thermally broken balconies (or no balconies at all and exterior insulation over the slab edge) are modest at 5 to 10%. But the impact on occupant comfort and useable space alone is critical. Further risk of condensation from cold floor slabs and other thermal bridging (e.g., window frames - see photograph) is also problematic.

In addition to thermally broken balconies, local thermal discomfort of bare feet can be further mitigated with less conductive floor finishes, such as wood or carpet, around the perimeter. Design considerations should also include indoor air quality (e.g., dust accumulation and off-gassing of synthetic materials of carpets) and ensuring adequate exposed thermal mass to absorb direct incident solar gains.



Frost and condensation build-up on the mullion of a window (left) and around the frame of a glass door (right). Moisture from the interior condenses on surfaces that are so cold due to thermal bridging that frost accumulates. Mold has started growing at the bottom of the window mullion and water will damage the window sill.

³Ge, H., V. R. McClung and S. Zhang. 2013. "Impact of balcony thermal bridges on the overall thermal performance of multi-unit residential buildings: A case study." Energy and Buildings 60: 163-173.

THERMAL COMFORT

Click on the download icon for more information about:
Thermal Comfort in Housing



Discomfort from Solar Radiation

Direct solar radiation on an occupant in a room can have a profound impact on thermal comfort and is not typically considered during design; nor is it compensated in heating and cooling controls. As a rule of thumb, every 100 W/m² of solar energy intensity will increase the temperature sensed by an occupant in a sunlit space by 1°C. For example, a clear sunny day will impose about 800 W/m² on surfaces exposed to the direct sunlight, hence the sensed temperature would be about 8°C higher than the air temperature (e.g., an occupant in a room with an air temperature of 21°C who is exposed to direct sunlight would feel like an occupant in a room receiving no sunlight with an air temperature of about 29°C). While this increase in sensed temperature could be very desirable in winter, it is typically not acceptable to lower the thermostat accordingly because the benefit of direct solar radiation would only impact occupants near the façade during sunny periods. The CBE Thermal Comfort Tool, discussed later on, provides a user-friendly interface for understanding the impact of solar radiation on comfort.

Design solutions for improving thermal comfort implications of solar radiation include balconies or other fixed exterior shading devices. Particularly for near-south facing facades, balconies and other horizontal surfaces above windows are very effective at blocking direct solar radiation in the summer. Horizontal surfaces are not nearly as effective at blocking the sun on east and west-facing facades, however, vertical side-fins can be used to control solar radiation.

⁶Ge, H., V. R. McClung and S. Zhang. 2013. "Impact of balcony thermal bridges on the overall thermal performance of multi-unit residential buildings: A case study." *Energy and Buildings* 60: 163-173.



Example of side fins to protect occupants from direct solar radiation on an east-facing facade.



Example of sun-exposed living spaces.

Light-colored solar shades with a low openness factor or venetian blinds can empower occupants to control and reduce direct solar radiation. The Performance Shading Advisor tool discussed below can be used to select ideal shade properties. Glazing with a low to medium solar transmittance directly reduces the warming effect of solar radiation, though offers no seasonal flexibility, in contrast to moveable shading devices.

Synopsis

Thermal comfort is becoming an issue in multi-unit residential buildings with window-wall enclosures because entirely glazed facades are not only thermally inefficient, but over time they tend to become leaky, admitting both moisture and air. This means that over time they will become more uncomfortable unless they are retrofitted at considerable expense.

High performance enclosures that avoid thermal bridging and control air leakage are the first line of defence for thermal comfort. The selection of appropriate window-to-wall ratios and provision of shading devices is the next strategy to avoid thermal and visual discomfort situations. Suitable floor coverings that do not rapidly conduct heat to and from the feet can make a significant contribution to enhancing comfort. Finally, dedicated ventilation systems with energy or heat recovery will temper ventilation air so that it does not feel cold and drafty in winter. Thermal comfort is easily achievable in multi-unit residential buildings if the factors causing discomfort are appropriately addressed in design. The need for some level of inhabitant education is unavoidable because the operation of HVAC systems, adjustment of shading devices and the opening or closing of windows, as well as dressing appropriately for the season, are all common sense measures that help mediate the comfort conditions in housing.

THERMAL COMFORT

Occupant Comfort Software Tools

Several online tools for evaluating thermal and visual comfort are available to support design decisions. They are briefly described below.

CBE Thermal Comfort Tool

URL: <http://comfort.cbe.berkeley.edu/>

This tool allows users to evaluate whether conditions are comfortable based on four indoor environmental variables (air temperature, mean radiant temperature, relative humidity, and air speed) and personal variables (clothing level and metabolic rate).

Glazing and Winter Comfort Tool

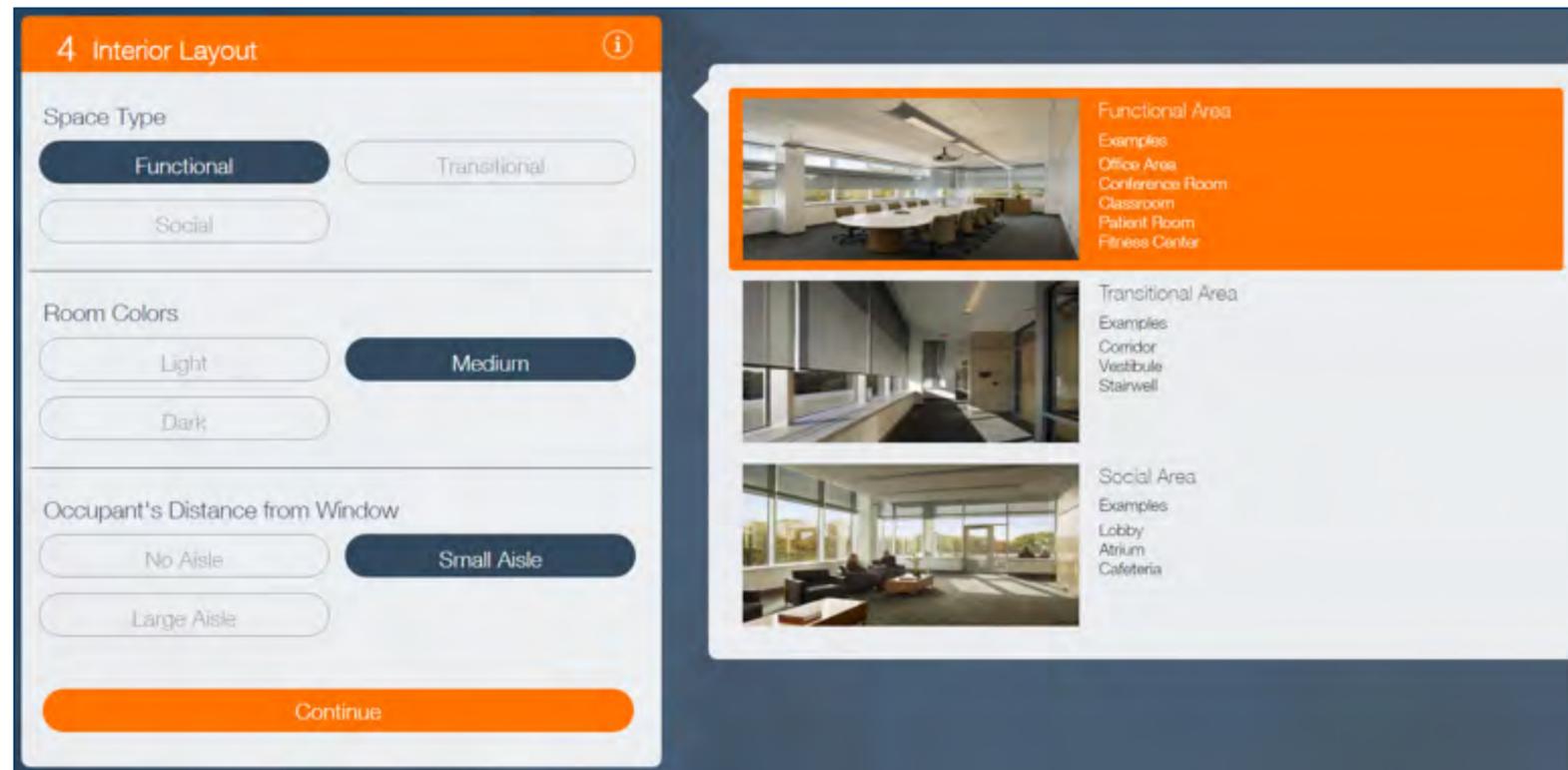
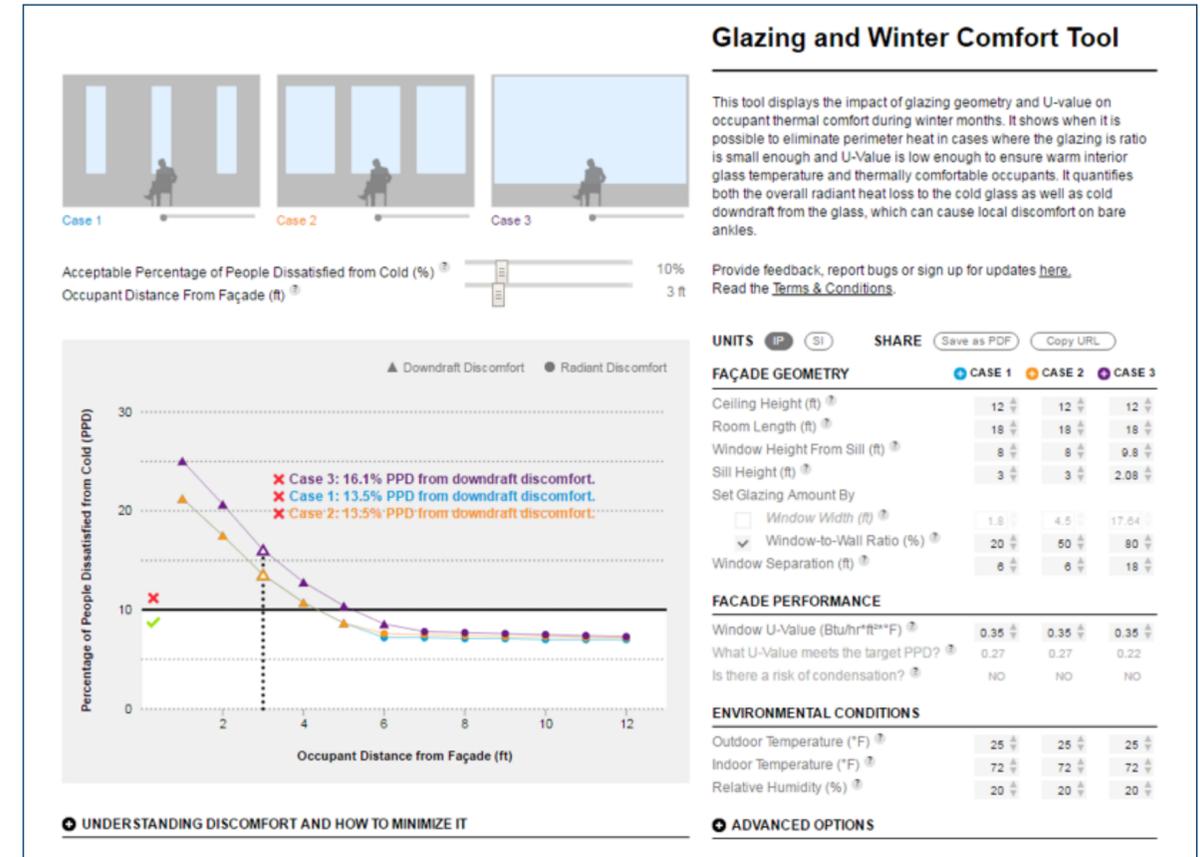
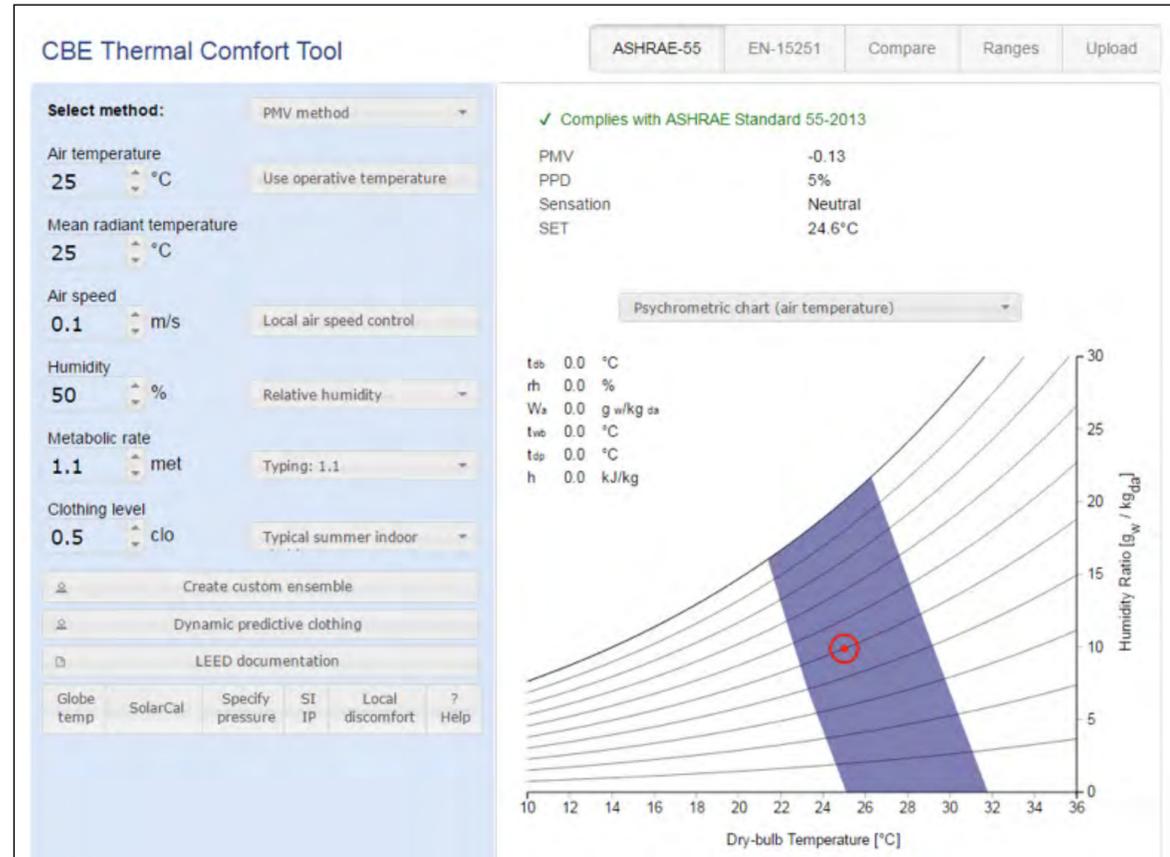
URL: <http://www.payette.com/building-science/glazing-and-winter-comfort-tool>

This tool allows users to evaluate occupant thermal comfort in the proximity of user-specifiable facades. For instance, the impact of window area and window type can be quantified.

Performance Shading Advisor

URL: <http://www.performanceshadingadvisor.com/>

This tool advises users on idea window shade fabric as a function of geographical location, façade orientation, and space uses.



RESILIENCE MEASURES

North America, along with the rest of the world, is entering an age of climate change where we are witnessing an increased frequency and severity of extreme weather events. Aging municipal and energy infrastructure has rendered many communities vulnerable to flooding and power disruptions. While these extreme events are seldom unmitigated disasters, they have the potential to disrupt our day-to-day lives, business operations, and possibly jeopardize human safety, private and public property. Fortunately, the resilience of our built environment is technically and economically feasible, but first we need to become aware of our vulnerabilities. Only then can we engage the appropriate planning strategies leading to effective resilience measures.

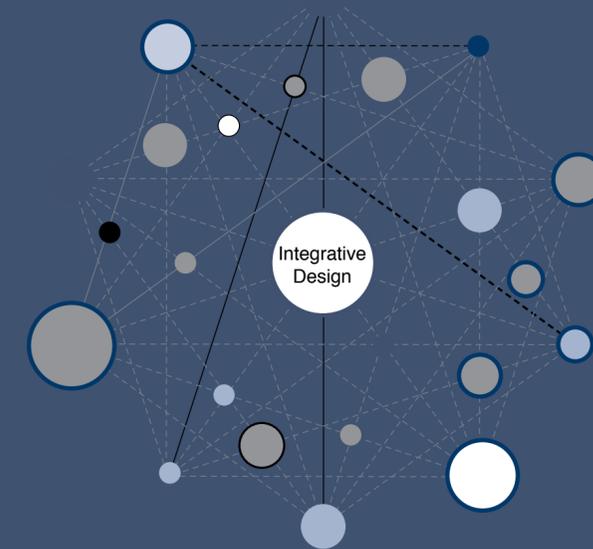
- **What Is Resilience?** – Resilience is a complex attribute that is comprised of numerous aspects - some physical, some technical and some social and cultural. We become aware of resilience when it is absent or insufficient and we are unable to persevere and overcome challenges such as extreme weather events. Resilience is the capacity to adapt to changing conditions and to maintain or regain functionality and vitality in the face of stress or disturbance. Resilience is not a new concept and in the past it formed the basis of so many of our building traditions, whether it was to ensure we survived a long, harsh winter or a dry, hot summer. Before people became dependent on the energy grid, houses were heated with wood, cooled by porches and natural ventilation, and illuminated by windows and candlelight. Before the era of agri-business and mass transportation networks, food was grown locally and preserved to last until the next growing season. Most households were self-sufficient in terms of life's necessities, but communities were also closely knit because social safety nets and vital public services such as healthcare had not yet been invented. Today, resilience is understood in terms such as emergency preparedness, climate change adaptation and support systems provided by institutions and public services. Resilience does not come about naturally, rather it is something that we have to think about and devise.
- **What Is Building Resilience?** – When disasters occur it is vital that buildings continue to provide shelter under extreme weather conditions, so that inhabitants can safely and comfortably survive until normal operating conditions are restored. It is also important that buildings can withstand exposure to extreme conditions without suffering serious and/or permanent damage.
- **What Is Resilient Building Enclosure Design?** – Buildings are durable goods and housing typically represents the average household's largest investment. Robust enclosure design ensures that buildings are durable, energy efficient, comfortable and also provide shelter under extreme conditions. A long service life should be enjoyed with only some routine maintenance being required. During extreme weather, the building enclosure should not fall apart or sustain irreversible water damage. Under both normal and extreme conditions, the building should not experience performance problems that can compromise secure shelter or devalue real estate investments. Resilient enclosure also incorporate measures for thermal autonomy and passive survivability.
- **Resilience versus Sustainability** – Resilience, like sustainability, will not go out of style. These two performance objectives are related to one another, with sustainability being a broader and longer term goal that periodically hinges on our ability to bounce back from adversity, so that the sustainability agenda is not set back and further compromised. For reasons of health and safety, resilience will one day find its way into codes and standards, but in the meantime it represents better practices that add value, safety and security.

Click on the download icon for more information about:
MURBs & Resilience



Resilience and Integrative Design

Integrative design is a process that connects peoples' needs for safety, security, health and well being while properly balancing environmental, economic, and social factors.



Integrative design connects the dots between the ecological, cultural and technological web of interrelated stakeholders, institutions and agencies. It produces appropriate housing solutions that are harmonized across all of their dimensions and contextualized within the community harnessing the resilience of all available resources, while also serving as a resource that provides safe refuge during disasters.

This process works within a web of resilience to facilitate the interests of all stakeholders. Unlike the more commonly deployed “integrated design process” for buildings, integrative design goes beyond the scope of a particular policy, legislation, development proposal or technological proposition, to consider all of the factors, all of the impacts, and then provides a means by which the stakeholders can work out solutions that work for everyone.

Integrative design is a relatively new approach to dealing with the complexities and contradictions of traditionally competing interests, such as economic growth, environmental responsibility and intergenerational equity to arrive at acceptable strategies for sustainable development.

This section on resilience is premised on principles of integrative design and while a number of aspects of resilience are examined individually, it is acknowledged they must all be effectively integrated to successfully meet the resilience challenge.

RESILIENCE MEASURES

DESIGN FOR RESILIENCE PRINCIPLES

1. **Resilience transcends scales.** Strategies to address resilience apply to different physical and time scales - from individual buildings and communities to larger regional and ecosystem scales; from the immediate to the long-term.
2. **Resilient systems provide for basic human needs.** These include potable water, sanitation, food, energy, livable conditions (temperature and humidity), lighting, safe air, occupant health, and food.
3. **Diverse and redundant systems are inherently more resilient.** More diverse communities, ecosystems, economies, and social systems are better able to respond to interruptions or change. Redundant systems for such needs as electricity, water, and transportation, improve resilience.
4. **Simple, passive, and flexible systems are more resilient.** Passive or manual-override systems are more resilient than complex solutions that can break down and require ongoing maintenance. Flexible solutions are able to adapt to changing conditions both in the short- and long-term.
5. **Durability strengthens resilience.** Strategies that increase durability enhance resilience. Durability involves not only building practices, but also building design, infrastructure, and ecosystems.
6. **Locally available, renewable, or reclaimed resources are more resilient.** Reliance on abundant local resources, such as solar energy, annually replenished groundwater, and local food provides greater resilience than dependence on nonrenewable resources or resources from far away.
7. **Resilience anticipates interruptions and a dynamic future.** Adaptation to a changing climate with higher temperatures, more intense storms, sea level rise, flooding, drought, and wildfire is a growing necessity. Non-climate-related natural disasters, such as earthquakes and solar flares, also call for resilient design. Responding to change is an opportunity for a wide range of system improvements.
8. **Find and promote resilience in nature.** Natural systems have evolved to achieve resilience; we can enhance resilience by relying on and applying lessons from nature. Strategies that protect the natural environment enhance resilience for all living systems
9. **Social equity and community contribute to resilience.** Strong, culturally diverse communities in which people know, respect, and care for each other will fare better during times of stress or disturbance. Social aspects of resilience can be as important as physical responses.
10. **Resilience is not absolute.** Recognize that incremental steps can be taken and that total resilience in the face of all situations is not possible. Implement what is feasible in the short term and work to achieve greater resilience in stages.

Excerpted from *The Resilient Design Institute*, <http://www.resilientdesign.org>

Resilience Strategies

There are many strategies available to enhance the resilience of multi-unit residential buildings. Most of them are simple and relatively inexpensive, however, some require coordination between disciplines that do not normally collaborate in an integrative manner. Resilience demands deep interdisciplinarity.

ARMOURING

This term applies generically to any form of strengthening or reinforcing of protective measures. For buildings, this can include enhancing fire or seismic safety, and designing enclosures that can resist high winds and rain penetration without damage or deterioration. Various measures for flood protection are also considered forms of armouring. In new multi-unit residential buildings, locating emergency and backup power systems well above flood water levels is a preventive form of armouring that makes the building more resilient.



Shutters represent armouring, an ancient resilience strategy that has made a recent come back due to climate change. In addition to offering protection from wind-borne projectiles that can damage windows and break glass, insulated shutters can reduce space heating and cooling energy demands and even enhance daylighting.

REDUNDANCY

This time-tested resilience strategy informs all aspects of building and site design, including essential services. Building enclosures can comprise multiple layers of defence against heat, air and moisture movement. Vital building services like sump pumps can be doubled up and supplied with backup power. Effective daylighting and natural ventilation can supplant artificial lighting and mechanical ventilation when the grid goes down. Redundancy comes at a cost but so does the failure of the only line of defence.



Using a sump pit liner that has been designed to accept two sump pumps and combining it with a battery backup power system and pump failure alarm illustrates redundancy for a vital service to keep basements dry.

DECENTRALIZATION

What happens when a centralized resource like electricity is knocked out of service? Everybody that depends upon it experiences a power outage. Decentralization involves distributing capabilities for the self-provision of services such as energy and water. It will be some time before smart energy grids power our communities. In the meantime MURBs will need to survive extended service disruptions by investing in systems and technologies that reduce dependency on centralized services. Renewable energy generation and on-site storage are a coupling of technologies to ensure energy for vital services is available, even for systems that are tied to the grid.



Integrating photovoltaic arrays with automobile parking are among the ways to double-up on land use while providing decentralized energy production.

RESILIENCE MEASURES

Click on the download icon for more information about:
Combined Heat and Power for MURBs



LOW IMPACT DEVELOPMENT

Low impact development (LID) is a stormwater management strategy that seeks to mitigate the impacts of increased runoff and stormwater pollution by managing runoff as close to its source as possible. LID comprises a set of site design strategies that minimize runoff and distributed, small scale structural practices that mimic natural or predevelopment hydrology through the processes of infiltration, evapotranspiration, harvesting, filtration and detention of stormwater.

These practices can effectively remove nutrients, pathogens and metals from runoff, and they reduce the volume and intensity of stormwater flow. Low impact development practices can significantly reduce initial and ongoing life cycle costs associated with the management of stormwater, while enhancing the environmental performance of new developments. Most importantly, low impact development measures can significantly reduce incidences of flooding.



Incorporating low impact development features into housing developments not only enhances community resilience but also provides green space amenities that help knit communities together.



Dockside Green, a complex of multi-unit residential buildings and small-scale commercial buildings in British Columbia uses rainwater retention ponds and on-site sewage treatment to manage and conserve its water needs.

Water security is often more important than energy security because we use water not just for drinking, but to wash ourselves, clothing, dishes and inside our facilities. Sanitary plumbing also requires a supply of water, and it is critical for toilets and sinks to function when people are confined to their buildings.

Rainwater harvesting is a technique for managing stormwater while capturing and storing rainwater for both potable and non-potable uses. Advances in bio-filtration technology and ultra-violet sanitization equipment make it possible to convert rainwater into potable water. Off-the-shelf technology is now available to integrate rainwater harvesting within both new and existing developments.

Hybrid approaches to rainwater harvesting involve green roofs for cleansing the rainwater before it is conveyed to a storage tank, while also providing the numerous environmental benefits of green roof technology.

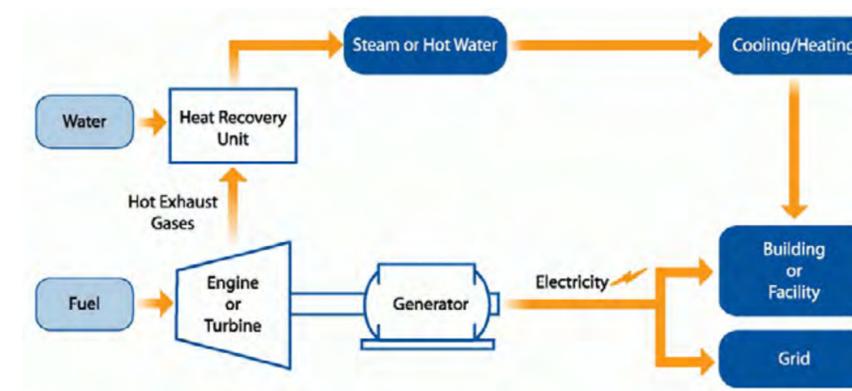
ENERGY AND WATER SECURITY

Extended disruptions of energy and water supplies can place severe stress on a community and its vulnerable citizens. People who have mobility challenges, suffer from serious illness, and/or live alone without caregivers are among the most vulnerable individuals. Low income families may not have the means to temporarily evacuate an area undergoing disaster or crisis. Some thought should be given to enhancing energy and water security so that housing developments and critical service centers are able to function until recovery is possible.

Consideration must be given to a secure supply of fuel to run CHP equipment. Natural gas distribution networks are quite robust and resilient, and alternatives include propane and fuel oil. Bio-fuels such as wood chips or pellets are increasingly deployed for co-generation.



Combined heat and power (CHP) equipment, also known as co-generation equipment, produce electricity and heat that may be harnessed to provide heating and cooling to buildings. Clean burning fossil fuels like natural gas or propane are the typical energy sources for CHP plants that also provide as back-up power.



Combined heat and power, or co-generation, technology is also ideally suited to decentralized power grids where a network of feed-in energy sources increasingly offset centralized power stations.



Biomass in the form of wood pellets or chips is a sustainable energy source for combined heat and power plants that can satisfy the backup power demands of most multi-unit residential buildings.

RESILIENCE MEASURES

Click on the download icon for more information about:
Thermal Autonomy and Passive Survivability in MURBs



Integration of Resilience Strategies

Tornadoes, hurricanes, record rainfalls, ice storms, droughts, heat and cold waves are among the extreme weather events that will challenge the resilience of building enclosures. Building enclosures comprise assemblies and components of buildings, such as the foundation walls and slabs, the above-grade walls and windows, and the roof, in order to provide a desired degree of separation between the indoor and outdoor environments. High performance enclosures can keep the heat both in and out, and this makes it possible for inhabitants to remain in their dwellings for extended periods during power outages when heating or cooling equipment is disabled. While the resilience of MURBs is largely determined by the performance of the enclosure, there are a number of measures that must be carefully integrated to achieve resilient communities in which MURBs are situated.

Determine your resilience strategies.

	Low to mid-rise walk-ups	Low-rise contemporary	Mid-rise contemporary	High-Rise contemporary	Estimated Cost	Related Strategies
Protection						
1 Wet Floodproofing	●	●	●	●	\$\$\$-\$\$\$\$	6, 8, 9, 10
2 Dry Floodproofing	●	●	●	●	\$\$\$-\$\$\$\$	3, 5, 6, 14
3 Site Perimeter Floodproofing	○	●	●	●	\$\$\$-\$\$\$\$	2, 6, 10
4 Resilient Elevators	●	○	●	●	\$\$\$-\$\$\$\$	2, 3, 6, 8, 13, 18
5 Backwater Valves	●	●	●	●	\$	2, 6, 10
6 Sump Pumps	●	●	●	●	\$	1, 2, 5, 8, 10, 13
Adaptation						
7 Envelope Efficiency	●	●	●	●	\$\$\$-\$\$\$\$	11, 12
8 Elevated Equipment	●	●	●	●	\$\$\$-\$\$\$\$	1, 7, 9, 12
9 Elevated Living Space	●	●	●	●	\$\$\$-\$\$\$\$	1, 2, 8
10 Surface Stormwater Management	●	●	●	●	\$\$\$-\$\$\$\$	2, 3, 5
11 Window Shading	●	●	●	●	\$	7
12 Distributed Heating and Cooling	●	●	●	○	\$\$	7, 8, 11
Backup						
13 Maintaining Backup Power to Critical Systems	●	●	●	●	\$\$\$-\$\$\$\$	4, 6, 8, 15, 18
14 Emergency Lighting	●	●	●	●	\$	13
15 Access to Potable Water	●	●	●	●	\$	13
Community						
16 Building Community Ties	●	●	●	●	\$	17, 18, 19
17 Creating Community Resilience Spaces	●	●	●	●	\$\$-\$\$\$	13, 15, 16, 18, 19
18 Developing an Emergency Management Manual	●	●	●	●	\$	16, 17, 19
19 Organization for Community Resilience	●	●	●	●	\$	16, 17, 18

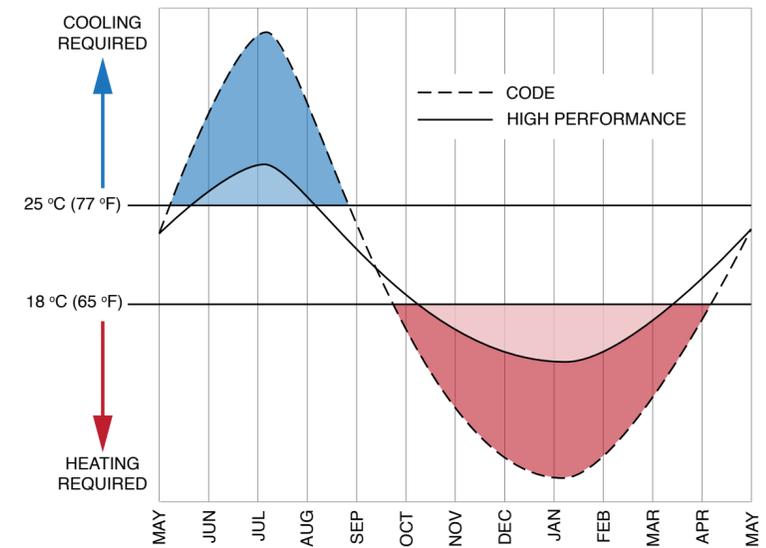
Applicability: ○ Minimally applicable, ● Priority applicable, ● Applicable

The 19 strategies to enhance resilience in existing multi-family housing developments is also applicable to the design of new multi-unit residential buildings. [Source: Ready to Respond: Strategies for Multifamily Building Resilience. Enterprise Green Communities, November 2015.]

Training and Support Networks

Social infrastructure can also be made more resilient through training and support networks. Today, special training is available to first responders and caregivers to help them become more psychologically resilient. It is well known that individuals who work in settings where they are exposed to trauma or care for those who suffer from trauma (and the families of those who suffer from the trauma), are at risk for traumatization such as secondary stress traumatic symptoms and/or disorder (vicarious traumatization or compassion fatigue), post-traumatic stress symptoms and burnout. Support networks are vital to ensure the safety and well being of vulnerable individuals, such as very old and/or ill persons who live alone, by routinely checking up with them, particularly during and after extreme weather events or disasters. Resilient people and social organizations are key to successfully engaging the resilience challenge.

In multi-unit residential buildings, facility managers should be provided with basic training in emergency measures, protocols and procedures. It is very important to provide information to inhabitants about how they can appropriately respond to various types of extreme weather events, service disruptions and disasters. Engagement among inhabitants in large housing complexes reinforces resilience.



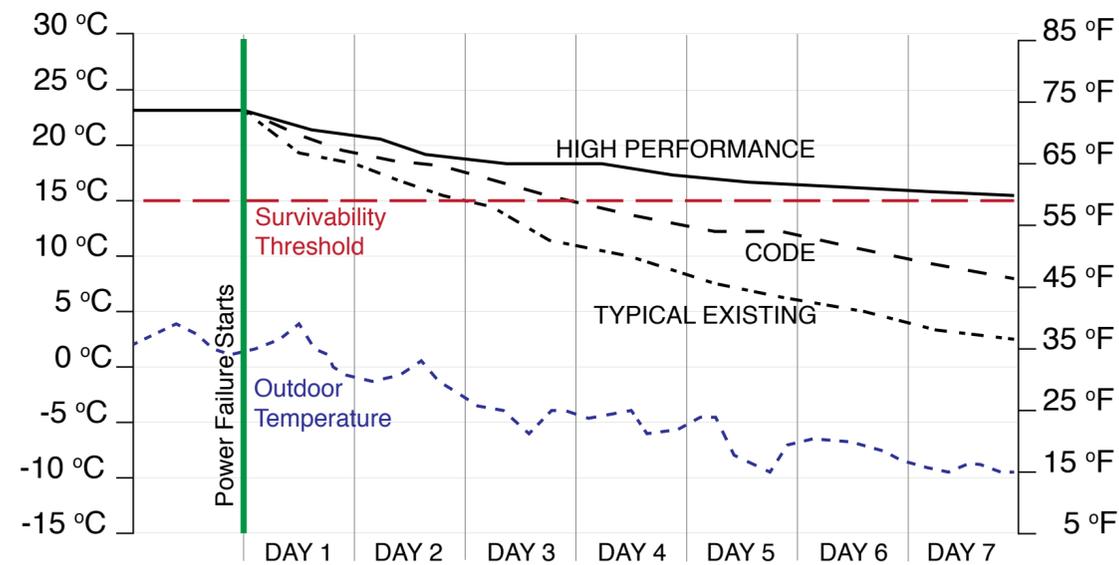
Improving the thermal efficiency of enclosures increases thermal autonomy, conserves energy and reduces the capacity of heating and cooling equipment while extending its service life. In most climate zones, it is feasible to increase thermal autonomy from about 30% for a code minimum building to well over 70% for a high performance building.

Thermal Autonomy and Passive Survivability

Housing is a very special type of building because people expect it to provide some measure of shelter against the elements. As extreme weather events increase in frequency and severity due to climate change, extended power disruptions can leave MURB inhabitants without heating and cooling. Thermally inefficient enclosures that cannot respond properly to solar gains and afford natural ventilation can quickly become too cold during extreme winter weather and too hot during summer heat waves, forcing people out of their homes. This is particularly problematic for the elderly and the ill, especially if they do not have a support network of family and friends -and the situation is further exacerbated if people are economically disadvantaged.

Two related and critical metrics for the resilience of MURBs are thermal autonomy and passive survivability. Thermal autonomy (TA) is used as a measure of the fraction of time a building can passively maintain comfort conditions without active system energy inputs. It ensures architectural parameters, such as orientation, form, fabric, glazing, shading and natural ventilation, to be intelligently arranged to improve environmental performance. Passive survivability (PS) is used as a measure of how long inhabitants may remain in their dwellings during extreme weather events that knock out their energy supply. It ensures buildings to be less susceptible to becoming uncomfortable or unliveable in the event of extended power outages during extreme weather periods. The information that follows forms part of a larger study that examined thermal autonomy and passive survivability in the context of Canada's predominant climate zones, where virtually all of Canada's new MURBs are being constructed. The specific results presented in this section of the MURB Design Guide are for the Vancouver, British Columbia, Canada climate - summary results of the larger study may be downloaded by interested readers (see download icons).

RESILIENCE MEASURES



Recent experience has shown that typical existing buildings are vacated within less than 48 hours when an extended power failure coincides with cold winter weather. Buildings constructed to code minimum requirements perform only marginally better. High performance enclosures can provide a week or more of passive survivability when disaster strikes.

Thermal autonomy and passive survivability are related to the overall effective thermal resistance of the enclosure and its airtightness. High performance enclosures confer a large number of benefits to the inhabitants ranging from comfort and economy to affordability and passive survivability. In many ways the term high performance is a misnomer simply because conventional buildings have displayed such poor performance that it appears appropriate levels of performance are all so much higher. In fact, it would be more correct to term buildings built to minimum code requirements as low performance buildings.

Energy Simulations

Energy efficiency, thermal autonomy and passive survivability were analyzed through a large number of parametric energy simulations that modelled typical multi-unit residential building suites. The predominant building type used for the construction of multi-unit residential buildings consists of a reinforced concrete frame where the shear walls are used to demise suites adjoining a double-loaded corridor or central core. The majority of suites have single aspect facades except for corner suites that have exterior walls on two sides, and are typically single storey. The provision of cantilevered balconies is optional and most of the buildings employ window-wall glazing systems with high window-to-wall ratios (>80%). At the time of these analyses, the average size of a typical condominium unit was approximately 70 m² (756 ft²) with an aspect ratio of 2:1 (width:depth). Unit heights are typically 2.5 m including thickness of a single floor slab (i.e. half thickness for ceiling and half thickness for floor attributed to internalized units). In the simulations, the actual floor area of a model unit was 63.8 m² with a gross exterior wall area is 28.25 m². Units are located on intermediate floors with no heat transfer across ceiling, floor or adjacent walls. The parameters set out in Table 1 were used in combination with a number of passive measures to assess energy efficiency, thermal autonomy and passive survivability.

Orientation	South	West	North	East
Window-to-Wall Ratio (WWR) (%)	40%		80%	
Wall U-Value (W/m ² .K)	0.278	0.210	0.180	
Glazing U-Value (W/m ² .K)	2.50	1.70	1.00	
Glazing SHGC	0.45	0.35	0.25	

Table 1. Parameters and corresponding values used to perform energy simulations using Vancouver, Canada weather data.

The window-to-wall ratios (WWR) were selected such that acceptable daylighting determined the lower limit (40%) which then ranged up to practically an all glazed facade (80%). Exterior wall U-values begin with the minimum effective thermal resistance for opaque wall assemblies prescribed by applicable codes and standards and range up to an upper value after which sharply diminishing returns in energy conservation are observed. Window U-values and solar heat gain coefficients reflect technologies that are currently available, again with the least efficient window assembly being prescribed by applicable codes and standards. (All U-values are effective accounting for thermal bridging.) To validate the correlation of the time-based metrics with annual heating and cooling loads, simple HVAC systems are modeled using ideal loads, fuel consumption is calculated from loads using seasonal efficiencies. A COP of 1.0 for the HVAC systems was used in order to estimate demands without the influence of energy conversion efficiencies. Natural ventilation and infiltration airflow rates are calculated based on opening and crack sizes (medium), buoyancy and wind pressures.

EnergyPlus software was used to perform a large number of parametric simulations through DesignBuilder interface. For each unit configuration, based on different orientations and window-to-wall ratios, three types of simulations are conducted. In the first set of runs, passive parameters are assessed through annual space heating and cooling energy use intensity (kWh/m²). Second, for thermal autonomy analysis, the systems for HVAC, lighting and equipment are turned off in the model. The number of hours above and below comfort levels of 18°C (64.4°F) and 25°C (77°F) are identified based on operative temperatures. The Thermal Autonomy metric is defined as the fraction of time over a year where a unit meets or exceeds that set of acceptability criteria through passive means only. Third, for passive survivability analysis, all active systems are shut off during a period of extreme summer or winter weather. The time between when heating is shut off and when the indoor operative temperature reaches 15°C (59°F) from an original heating setpoint of 21°C (70°F) in winter, and the time until the indoor operative temperature reaches 30°C (86°F) from an original cooling setpoint of 25°C (77°F) in summer, are defined as passive survivability metrics of multi-unit residential building units.

The passive strategies examined for each unit configuration are noted in Table 2. In addition to the base case, a total of 10 combinations of passive measures were analyzed in parametric energy simulations that considered all 4 solar orientations of a typical suite, and the 40% and 80% window-to-wall ratios.

RESILIENCE MEASURES

Click on the download icon for more information about:
Resilient Building Design



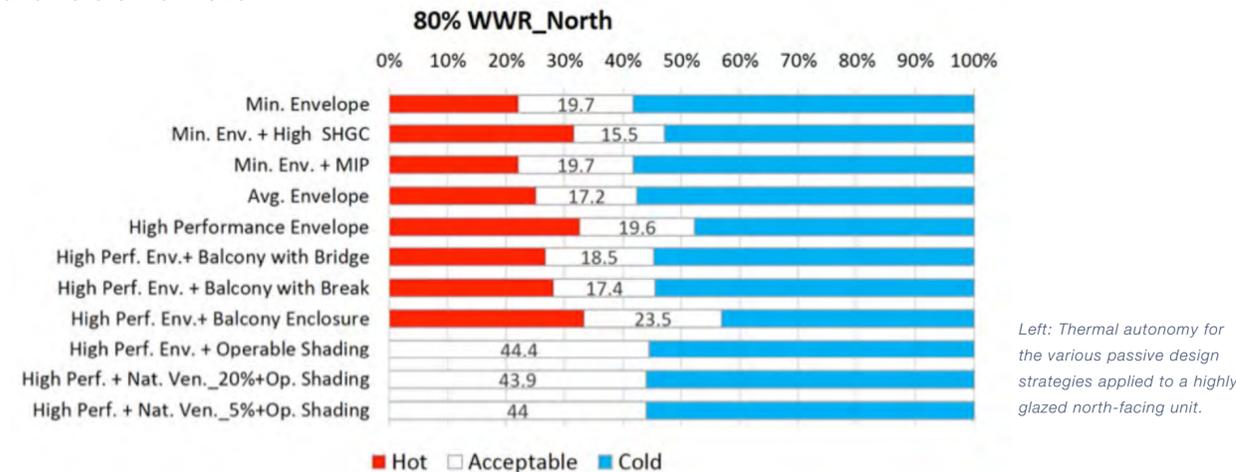
Base Case	Minimum envelope requirements (minimum U-value of wall (0.278 W/m ² .K) and glazing (2.5 W/m ² .K), and corresponding SHGC (0.45) for glazing).
Case 1	Minimum U-Value requirements of envelope, and higher SHGC of glazing. (U-value of wall 0.278 W/m ² .K, U-value of glazing 2.5 W/m ² .K and 0.60 SHGC)
Case 2	Minimum envelope requirements with movable insulation panels operated only winter nights. (Venetian blinds are used with “0” airflow permeability based on nighttime outside low air temperature.)
Case 3	Average envelope properties (average U-value of wall (0.210 W/m ² .K) and glazing (1.7 W/m ² .K), and corresponding SHGC (0.35) for glazing).
Case 4	High performance envelope properties (upper U-value of wall (0.180 W/m ² .K) and glazing (1 W/m ² .K), and corresponding SHGC (0.25) for glazing).
Case 5	High performance envelope properties and provision of 2m deep balcony overhang with bridge (balcony as a fixed shading device with thermal bridging).
Case 6	High performance envelope properties and provision of 2m deep balcony overhang with break (balcony as a fixed shading device).
Case 7	High performance envelope properties and provision of 2m deep enclosed balcony (to analyze buffer zone effect).
Case 8	High performance envelope properties and operable shading operated based on outdoor air temperature and solar on window (vertical blinds with high reflectivity slats in West, horizontal blinds in other orientations).
Case 9	High performance envelope properties, operable shading and providing natural ventilation from 20% glazing area opening.
Case 10	High performance envelope properties, operable shading and providing natural ventilation from 5% glazing area opening.

Table 2. Description of passive measures analyzed in parametric energy simulations.

Analysis of Thermal Autonomy and Passive Survivability

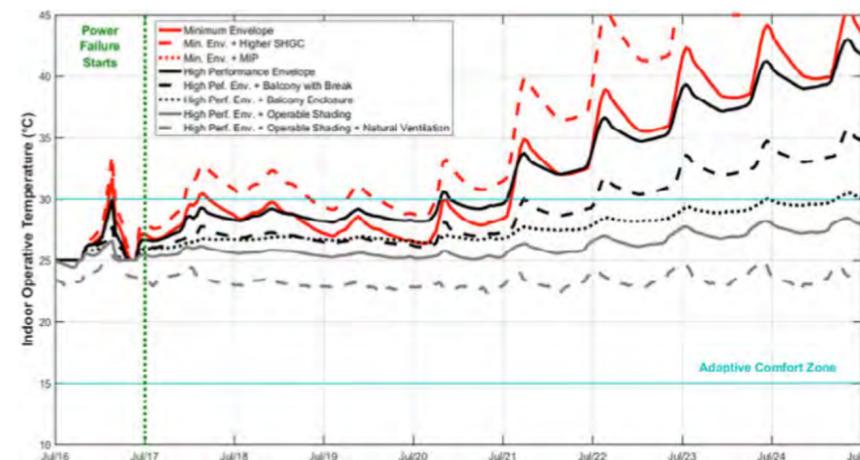
As noted previously, the parametric simulations consisted of two unit scenarios, 40% or 80% window-to-wall ratio, in four orientations. Each scenario started with minimum envelope requirements as base cases, and then 10 passive measures were applied to assess their impact on the performance of the units. Key findings related to resilience for the Vancouver climate are presented here, but more comprehensive results across climate zones may be downloaded by interested readers. The most critical cases related to resilience for the Vancouver climate are north-facing units in winter and south-facing units in summer.

Beginning with thermal autonomy for a highly glazed north-facing unit, the bar graph below indicates that space heating (indicated by Cold in blue) is required a little more than half of the year regardless of the measures. However, the need for cooling (indicated by Hot in red) can be eliminated with operable shading and natural ventilation.



Left: Thermal autonomy for the various passive design strategies applied to a highly glazed north-facing unit.

The passive survivability for the north-facing unit was found to be not as critical as the case for the south-facing unit. This may at first appear counterintuitive, but since the operative temperature range for passive survivability is between 15 oC and 30 oC, overheating in summer can occur much more rapidly than cooling in winter after the power failure starts.



Comparison of passive survivability in summer for various passive design strategies applied to a south-facing unit.

The energy modelling for passive survivability indicates that for highly glazed south-facing suites, conventional enclosures lead to overheating within the first day. A high performance enclosure extends passive survivability to a little over 4 days, whereas the high performance enclosure with operable shading devices and natural ventilation can remain comfortable almost indefinitely through hot summer weather.

It is important to note that with the high performance enclosure, the south-facing unit in winter enjoys solar gains that allow it to remain habitable for well over a week, but the north-facing unit was only able to withstand a little over 4 days before it became uninhabitable. However, reducing the WWR to 40% extended this to just over a week. Clearly, highly glazed facades should be avoided for northern exposures in multi-unit residential buildings.

Table 3 summarizes key performance metrics for the Vancouver, British Columbia climate zone. The effects of solar orientation can be seen for each of the 40% and 80% WWR cases. It is clear that the amount of glazing influences the energy demands, however, when high performance glazing (triple-glazed, argon) is substituted for conventional double-glazed windows, the absolute difference between the 40% and 80% window-to-wall ratios is very small. Looking at thermal autonomy, on average the 40% WWR unit has about 75% TA while the 80% WWR has about 70% TA.

Important considerations related to energy efficiency and resilience that emerge from the analyses are:

- There are no active measures that can impact energy demand, thermal comfort, thermal autonomy and passive survivability to anywhere near the same degree as passive measures related to the thermal efficiency of the enclosure.
- High performance enclosures, and in particular high performance glazing, provide architects with ample design freedom in terms of window apertures without appreciably compromising performance.
- Additional measures such as balcony enclosures, daylighting, shading devices and natural ventilation can be intelligently deployed to mitigate adverse phenomena related to solar orientations.

Based on present-day knowledge and available technology, multi-unit residential buildings can fulfill the promise of robust, resilient shelter that exerts a sustainable ecological and carbon footprint.

RESILIENCE MEASURES

Comparison of Solar Orientation and WWR Effects - Vancouver BC

Unit Floor Area 63.8 m²
 2X1 unit exterior façade gross area = 28.25 m²
 40% WWR = 11.3 m² glazing
 80% WWR = 22.6 m² glazing.
 Legend: WWR% U-value Window-SHGC U-value Wall-Additional Passive Measures

2X1 Aspect Ratio 63.8 m² Floor Area
40% WWR - Windows U-1.0 W/m2.K, SHGC 0.40 - Opaque Walls U-0.18 W/m2.K

	South	West	North	East
EUI (ekWh/m ² .vr)	1.0	4.9	7.6	5.3
TEDI (ekWh/m ² .vr)	1.0	4.9	7.6	5.3
Annual Heating (kWh)	63.5	314.1	485.2	341.1
Annual Cooling (kWh)	0.0	0.0	0.0	0.0
Peak Heating (W)	494.0	625.8	721.1	631.0
Peak Cooling (W)	3.1	0.0	0.0	0.0
% TA-Acceptable	96.7	75.8	57.4	72.4
% Active Heating	1.8	24.1	42.6	27.3
% Active Cooling	1.4	0.0	0.0	0.3

2X1 Aspect Ratio 63.8 m² Floor Area
80% WWR - Windows U-1.0 W/m2.K, SHGC 0.40 - Opaque Walls U-0.18 W/m2.K

	South	West	North	East
EUI (ekWh/m ² .vr)	2.1	7.6	12.3	8.2
TEDI (ekWh/m ² .vr)	2.1	7.6	12.3	8.2
Annual Heating (kWh)	133.4	484.0	786.2	522.0
Annual Cooling (kWh)	0.1	0.0	0.0	0.0
Peak Heating (W)	924.2	1002.8	1153.5	1037.3
Peak Cooling (W)	26.3	11.0	0.0	10.8
% TA-Acceptable	91.0	72.1	54.1	70.3
% Active Heating	4.8	27.1	45.9	28.4
% Active Cooling	4.2	0.8	0.0	1.3

- Discussion**
1. High performance enclosure confines difference in annual space heating energy demand to a narrow range across all four solar orientations and well below passive house and ZEN targets.
 2. Acceptable energy performance is achieved over a wide range of window-to-wall ratios (40% minimum for adequate daylighting to 80% practically fully glazed).
 3. South-facing units with 40% WWR are almost entirely passive with marginal heating and cooling inputs required.
 4. South-facing units with 80% WWR demand about twice the space heating and cooling energy, but are still largely passive.

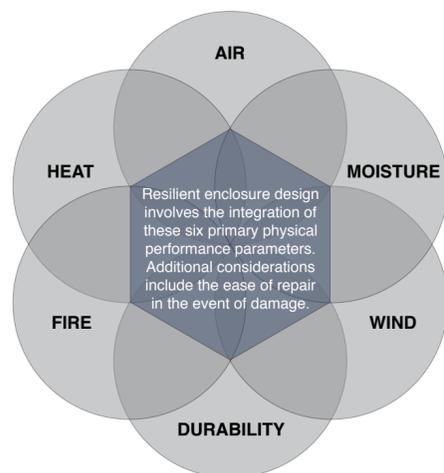


Table 3 (Above). The results in the above table indicate that high performance enclosures can substantially reduce annual and peak energy demands while providing a high degree of thermal autonomy. Robust passive systems are key to resilience. (Note: EUI and TEDI are identical since only space heating and cooling loads are considered.)

Left: The design of robust enclosures remains the key to the resilience of not just multi-unit residential buildings, but all buildings. Passive systems that do not rely on external sources of energy, or have moving parts that become deteriorated or defective, should be privileged in MURB design.

Dr. Ted's MURB Resilience Recipe

Building codes and standards represent the minimum requirements for health and safety in buildings - they do not address resilience. The table below lists the minimum requirements for resilient MURBs in the context of a Canadian climate and the need for climate change adaptation.

Minimum Requirements for Resilient MURBs ASHRAE Climate Zones 4, 5, 6, & 7	
High Performance Enclosure	<ul style="list-style-type: none"> • minimum overall effective thermal resistance of RSI 1.76 (R-7.5) • maximum 80% WWR south-facing suites • maximum 60% WWR east/west/north-facing suites • balcony thermal break • airtightness
Daylighting, Natural Ventilation, Shading Devices	<ul style="list-style-type: none"> • maximum depth of 5 m (16 feet) for principal rooms (kitchen, dining, living, bedrooms) • minimum window ventilation opening area of 5% of room floor area (10% in windows if insect screens are fitted) • external shutters and/or internal blinds, shades
Combined Heat and Power (CHP) for Emergency and Backup Power	<ul style="list-style-type: none"> • space heating • hot water boilers and pumps • domestic water booster pumps • sump pumps • elevators • intercom/security
Flooding and Sewer Backup Protection	<ul style="list-style-type: none"> • elevated equipment • wet/dry floodproofing • backwater valves • sump pumps • stormwater management
Operations and Maintenance	<ul style="list-style-type: none"> • operations and training manuals • qualified facilities management personnel • protocols and procedures manual • inhabitant education resources
Community Resilience	<ul style="list-style-type: none"> • community resilience organization • community resilience spaces (meeting, refuge, first aid) • emergency manual (plans, protocols and procedures) • inhabitant engagement and outreach

Resilience, carbon footprint and energy efficiency are interrelated, particularly within the context of multi-unit residential building design. The energy performance of multi-unit residential buildings is largely determined by the thermal effectiveness of the building enclosure but the effectiveness and efficiency of ventilation systems must also be addressed in design. Energy or heat recovery from exhaust air and the delivery of outside air to each suite on a demand controlled basis are critical to conserving energy while providing acceptable indoor air quality. Efficient lighting and appliances also play a role in MURB energy efficiency, but are far less critical because they do not impact comfort or resilience, and they can be easily and inexpensively retrofit, unlike building enclosures and ventilation systems. Water conservation also plays an important role in resilient building design because using less water helps extend the capacity of municipal water supply and sewage treatment systems. The notion that resilience is only relevant to extreme weather events, crises and disasters fails to recognize that resilient design makes a wiser use of precious resources and avoids the need to expand infrastructure to accommodate wasteful inefficiencies.

COMMISSIONING

There is often a considerable difference between the construed and the constructed in contemporary buildings. Regardless of the quality of architectural design and engineering that is manifest in the drawings and specifications, the building will only perform as well as it has been constructed and subsequently operated, and may not reflect how well it has been designed. The term used to describe what is often the unacceptable difference between what was intended or expected, and what is actually delivered, is the performance gap.

Modern buildings are made up from a wide range of materials, assemblies, components and equipment, held together and connected by countless fasteners, adhesives, membranes, sealants, piping and wires. If all of these elements are not properly integrated by the constructor then serious performance problems can result. One of the most effective means to ensure that the building is constructed and operated as designed and specified is to

The benefits of building commissioning are manifold and include:

- Assurance that design intent has been achieved;
- Delivery of a durable and resilient building asset;
- Congruence with societal sustainability objectives;
- Provisions of properly performing and functional building systems;
- Realization of energy and water efficiency targets;
- Balance between passive and active systems;
- Excellence across building performance rating systems;
- Properly trained and qualified building operators;
- Comprehensive and cost-effective operations and maintenance protocols; and
- Code compliance (many of today's buildings are not fully compliant). invoke occupancy. Whole building commissioning involves both the active and passive systems constituting a building. The latest addition to the whole building commissioning process is termed building enclosure commissioning (BECx).

Standards and Protocols

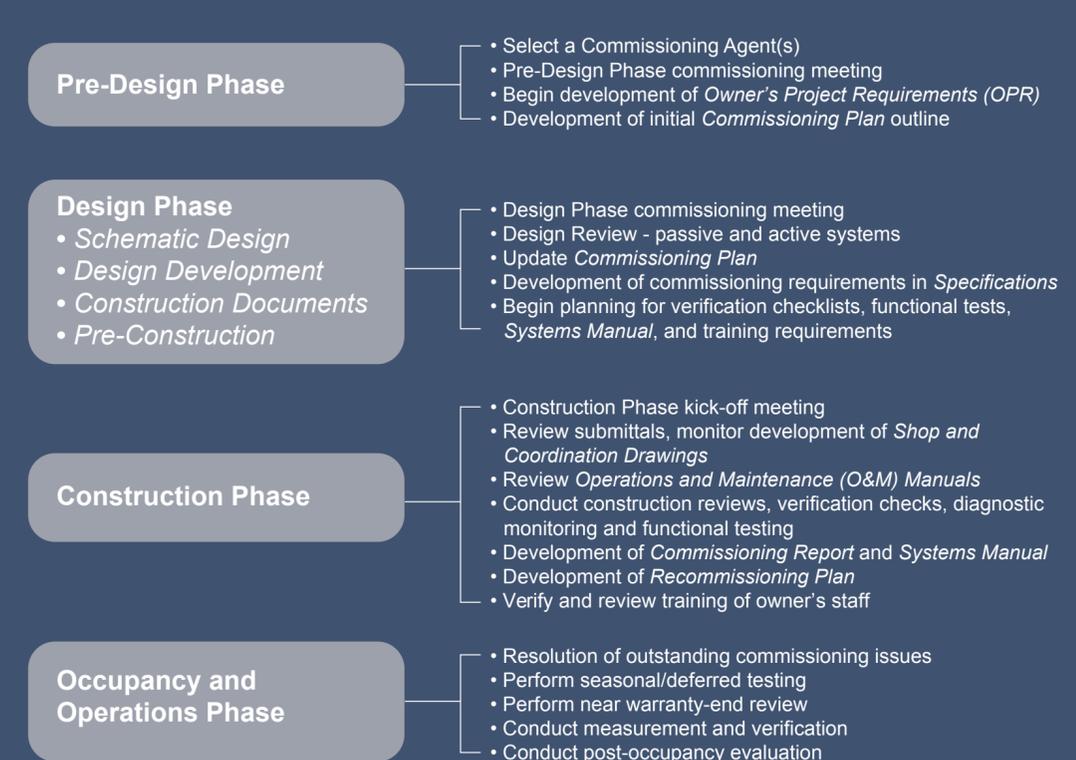
Building commissioning involves a number of standards and protocols that are typically referenced within specifications forming part of the contract documents for a building project. Currently in North America, the most commonly referenced standards and guidelines for commissioning are:

- ASHRAE Guideline 0-2013 The Commissioning Process;
- ASHRAE Standard 202-2013 The Commissioning Process for Buildings and Systems;
- ASTM E2813-2012, Standard Practice for Building Enclosure Commissioning;
- ASHRAE E2947-16a Standard Guide for Building Enclosure Commissioning; and
- CSA Z320-11 (R2016) Building Commissioning.

Within these standards and guidelines are found specific references to other testing and quality assurance standards, guidelines and protocols, for example, airtightness testing. The basic framework for commissioning standards and guidelines considers these following key aspects:

- Owner's Project Requirements;
- Basis of Design;
- Commissioning Plan;
- Pre-functional Checks of Facility Systems;
- Functional Tests;
- Systems Manual;
- Training Documents; and
- Final Commissioning Report.

The commissioning of buildings attempts to reflect the same quality assurance, product documentation, operations and maintenance instructions associated with other manufactured goods such as aircraft or automotive vehicles.



This chart provides a helpful overview of a typical whole building commissioning process. Standards and protocols continue to evolve as commissioning is more widely implemented by building owners and developers that seek to avoid the performance gap in their projects. A proper commissioning plan guides this entire process.

COMMISSIONING

Click on the download icon for more information about:
[Enclosure Field Testing](#)



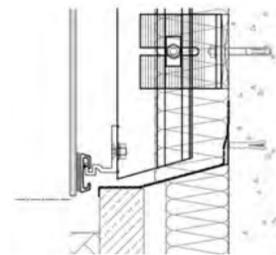
Operationally, a Commissioning Plan accomplishes the following:

- Assigns team members and responsibilities;
- Establishes objectives and criteria for quality, efficiency, and functionality;
- Sets out a commissioning scope;
- Develops commissioning budgets;
- Establishes commissioning sub-plans (passive versus active systems);
- Delineates commissioning schedules;
- Identifies testing and inspection protocols and procedures;
- Develops commissioning specifications;
- Determines special testing needs (measurement and verification);
- Defines operational staff training needs;
- Conducts post-occupancy evaluations; and
- Conveys the facility and supporting documentation to the owner, and facilities management personnel and operations staff.

With respect to resilience measures, it is especially critical to identify all related protocols and procedures along with associated emergency responses based on the nature of the emergency situation. In some cases, practice drills should be incorporated into the routine operations schedule.

Review, Inspection, Testing

The vast majority of resources in building commissioning are devoted to building enclosure commissioning since other more traditional forms of quality assurance and warranties are usually associated with HVAC, electrical and plumbing equipment. Building enclosures are typically assembled in the field and hence require extensive review, inspection and testing.



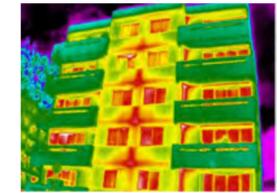
Peer review of critical details at the design stage addresses heat, air and moisture management issues.



Airtightness testing during and following construction ensures a continuous air barrier system.



Field testing of windows and wall interfaces for moisture penetration avoids water damage and mold.

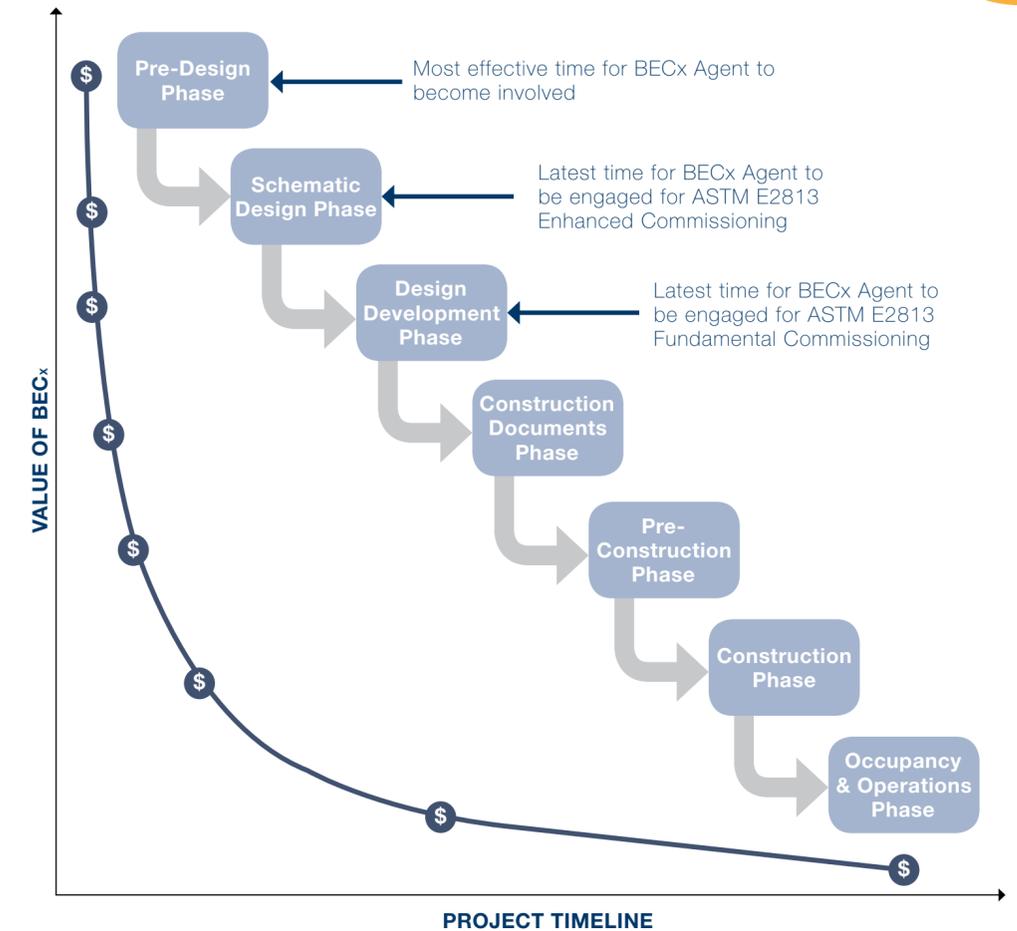


Thermographs of the completed enclosure identify hidden flaws, defects and discontinuities.

Building enclosure commissioning is a prudent and proactive means of providing quality assurance to building projects. Peer review, field testing, measurement and verification are critical to establishing the actual quality and performance of the constructed building. Airtightness testing and thermography are essential methods for detecting deficiencies and ensuring they are properly remediated.

Building enclosure commissioning focuses on the materials, components, systems, and assemblies intended to provide shelter and environmental separation between interior and exterior, or between two or more environmentally distinct interior spaces in a building or structure. It is gaining in importance because the vast majority of performance problems, claims and litigation involve the enclosure.

From a lifecycle performance perspective, building enclosure commissioning is a high yield investment that ensure values for money and buildings that perform as expected. It forms a critical part of the integrative design process and plays a role from the earliest beginnings of a building project until it is handed over after being fully occupied.



The value that building enclosure commissioning (BECx) brings to any building decreases the longer implementation of this comprehensive quality assurance process is delayed. By establishing the owner's project requirements prior to the commencement of design, architectural and engineering resources can be more efficiently and effectively focused on well defined targets. Since the building enclosure drives so much of the HVAC system design, it is far more critical to fully engage building enclosure commissioning than traditional commissioning of active systems. It does not make sense to devote resources to commissioning HVAC systems that are entirely inappropriate and mismatched for a building.

COMMISSIONING

Click on the download icon for more information about:
Whole-Building and Building Enclosure Commissioning



RX FOR SUCCESSFUL BECx

The following steps are key ingredients for a successful building enclosure commissioning recipe.

1. Make building enclosure commissioning a process.
2. Retain an independent third party as BECx authority.
3. Define the owner's project requirements (OPR).
4. Align the building envelope commissioning scope with the OPR and the project's complexity.
5. Produce a written BECx plan.
6. Plan design reviews for maximum impact.
7. Establish enclosure system performance metrics during the design phase.
8. Monitor construction early and often.
9. Confirm performance after commissioning and occupancy – address defects as per provisions in the contract documents.
10. Document all modified and rejected details and specs then update / purge your knowledge base accordingly.

*Adapted from 8 Strategies for Successful Building Enclosure Commissioning,
Emily Hopps and Peter Babaian, Simpson Gumpertz and Heger. Building Design &
Construction, November 17, 2014.*

Operations and Maintenance

Buildings must be properly operated and maintained to achieve their performance objectives and realize their intended service lives. Commissioning enables proper operations and maintenance by ensuring the building is not defective and constructed in compliance with its design intent. Defective or deficient building equipment, components and assemblies will fail and require repair and replacement rather than routine maintenance. There is a significant difference in cost and disruption between maintenance and repair and/or replacement.

In multi-unit residential buildings, the operation and maintenance of common elements is the primary focus of the commissioning exercise, but attention must also be paid to routine maintenance of equipment and services in each suite. Inhabitant education and engagement is essential to maintaining the quality and condition of MURBs.

A proper and effective commissioning process makes the following contributions to operations and maintenance over the lifecycle of a multi-unit residential building:

- **Complete Documentation** – warranties, manuals, protocols and procedures for operation and maintenance of the building, including services and site infrastructure;
- **Professional Facilities Management** – personnel who have the education and demonstrated experience in managing MURBs;
- **Properly Trained and Qualified Building Operators** – staff who can operate and maintain the entire facility, including day-to-day operations (snow removal, recycling, garbage, landscaping, etc.);
- **Monitoring** – Measurement and verification of performance (energy, water, indoor air quality, etc.) and the adjustment of settings and schedules to maintain peak performance;
- **Comprehensive Maintenance, Repair, Replacement** – Evidence-based reserve fund studies that account for proper maintenance, prompt repair and proactive replacement;
- **Inhabitant Education and Engagement** – Working with the inhabitants and/or condominium owners so that they observe better housekeeping practices; and
- **Feedback and Continual Improvement** – Implement feedback mechanisms to inform designers, constructors, manufacturers, staff, management and inhabitants on how to improve the quality and performance of the MURB and buildings in general.

The next section of the MURB Design Guide examines the role of post-occupancy evaluations in closing the knowledge management loop supporting the sustainability, resilience, comfort and liveability of multi-unit residential buildings

BUILDING PERFORMANCE EVALUATION

Click on the download icon for more information about:
Measurement and Verification of Building Performance



Historically, buildings were the result of a trial and error process of evolution that produced typologies such as offices, schools, hospitals and housing whose performance was accepted without much attention paid to improvement. As long as multi-unit residential buildings were affordable and durable, and accommodated the needs of their users, issues like thermal comfort and indoor air quality were off the societal radar, with possible exception to the wealthiest classes of apartment dwellers in large urban centres. Innovation in methods and materials of construction swept in with the Industrial Revolution and became widespread in the second half of the 20th century. More recent demands for sustainable architecture, net zero energy and carbon neutral green buildings continue to drive innovation, but this wholesale departure from vernacular architecture over a century ago was not accompanied by objective means to assess the quality and performance of buildings. The absence of a feedback loop connecting everyone from designers through to occupants has often had dire consequences for housing quality.

“Unfortunately, the majority of people who design, pay for, and formally judge the quality of architecture are not the ones who have to occupy those buildings. The result is a legacy of many unsuitable and unsustainable buildings.”¹

There is significant evidence to suggest that many buildings do not perform nearly as well when they are completed as was anticipated when they were being designed. The difference between predicted and actual performance is known as the performance gap.

There is often a considerable difference between the construed and the constructed in contemporary buildings. Regardless of the quality of architectural design and engineering that is manifest in the drawings and specifications, the building will only perform as well as it has been constructed, commissioned and subsequently operated and maintained. In view of a persistent performance gap in multi-unit residential buildings, as well as many other common building typologies, the scientific evaluation of building performance is seen as a means of gaining information needed to improve all aspects of the design, construction, commissioning, operations and maintenance of buildings.

¹ Mallory-Hill, S., Preiser, W., & Watson, C. (2012). Introduction to building performance evaluation: Milestones in evolution. In *Enhancing building performance* (pp. 3-18). UK: John Wiley & Sons.

Building performance evaluation (BPE) is a comprehensive and holistic process can be used at any point in a building's lifecycle to assess various aspects of performance and to make comparisons with design targets. Post-occupancy evaluation (POE) falls under building performance evaluation and focuses on that part of a building's lifecycle that begins after it is fully occupied and operational. For both BPE and POE, the critical questions for multi-unit residential buildings remain the same:

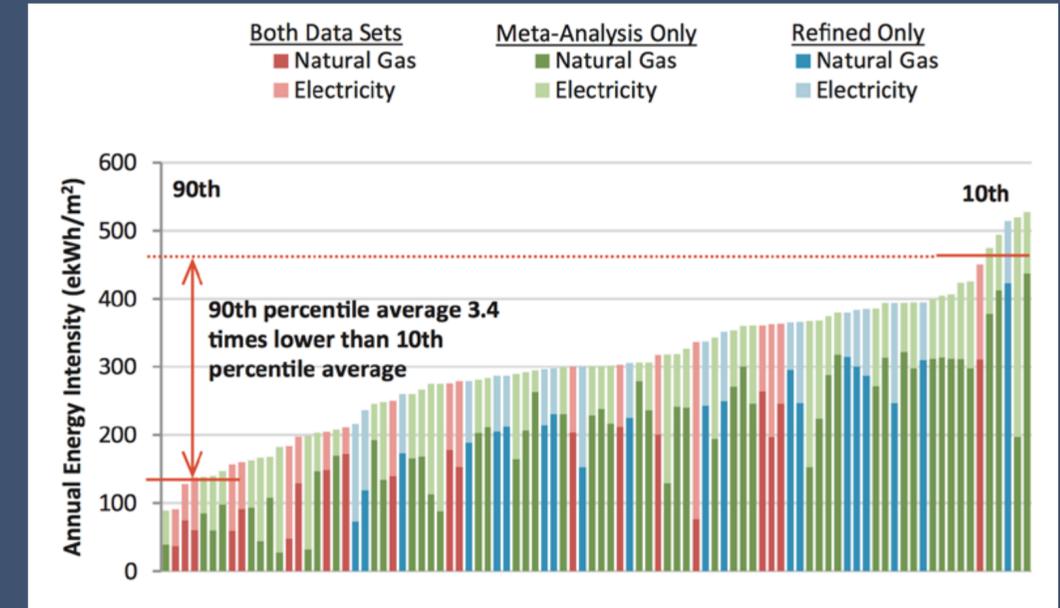
- How successful is the delivery (design, procurement, commissioning) of a building?
- How well does the completed development fit into the community and contribute to the surrounding urban fabric?
- Does the building achieve its social, environmental and economic targets?
- Where is there potential for further improvement, and what should be avoided?
- What lessons can be learned for future projects?

In reality, there are no absolute standards for building performance. Every aspect of performance is based on a comparison between what is achievable and what is actually achieved.

Benchmarking

Practically speaking, all building performance evaluation is comparative and employs a technique termed as benchmarking. Benchmarking is the process of tracking and recording data associated with various performance metrics, such as energy and water use, and comparing it with that of other buildings similar in size, function and vintage. Benchmarking enables comparative measure of a particular building's performance against that of other buildings to determine if it is atypical. It also allows for longitudinal comparison against itself to see if performance is persistent, improving or declining. This is particularly important for assessing the impact of retrofit measures or changes in building operations.

Benchmarking also identifies opportunities that can be seized to improve a building's energy performance. By comparing the energy efficiency of a particular building to that of other facilities, benchmarking helps prioritize capital upgrades and uncover ways to achieve operational savings. Benchmarking can also identify the need for re-commissioning buildings that need a major tune-up.



Data from a survey of annual energy use intensities for multi-unit residential buildings are useful in comparing the performance of a particular building to its cohort of similar buildings. [Source: M. Touchie, C. Binkley, and K. Pressnail. *Correlating Energy Consumption with Multi-Unit Residential Building Characteristics in the City of Toronto. Energy and Buildings* 66 (2013) 648-656.]

Benchmarking is entirely dependent on accurate and objective protocols and procedures for the measurement of building performance. It assumes that building performance data are widely reported, accurate and complete. This is presently not the case across Canada and most of North America. Much of the potential for improving the condition and performance of multi-unit residential buildings is being thwarted by government failure to formally rate housing quality and mandate energy, water and waste use. It appears that the means for measurement and verification are more sophisticated than our social policies.

“You cannot manage what you do not measure.”

Jack Welch, Former CEO of General Electric

BUILDING PERFORMANCE EVALUATION

Click on the download icon for more information about:
Post-Occupancy Evaluations of MURBs



Measurement and Verification

Assuming there is a political will to measure and verify building performance, particularly that of multi-unit residential housing, there exist all manner of protocols and procedures to accommodate this interest.

The benefits of measurement and verification include:

- Better performing buildings;
- Assurance of return on investments in performance enhancements;
- Encouragement of better engineering and commissioning;
- Accurate record of emission reductions and resource conservation; and
- Advancement of measurement and verification as a public policy tool.

The importance of metering and sub-metering in order to isolate energy and water consumption based on their end uses cannot be over emphasized. Disentangling electricity use data from a single utility bill for an entire multi-unit residential building, for example, is an impossible exercise and there is no way of identifying the cause of abnormal energy draws in the building.



Digital submetering of electricity delivered to each suite in a MURB is now conventional technology. Advances in microprocessors and sensors have extended submetering to the flow of gases and fluids such that the use of centralized resources, such as domestic hot water or chilled water, can be accounted for at the individual suite level.

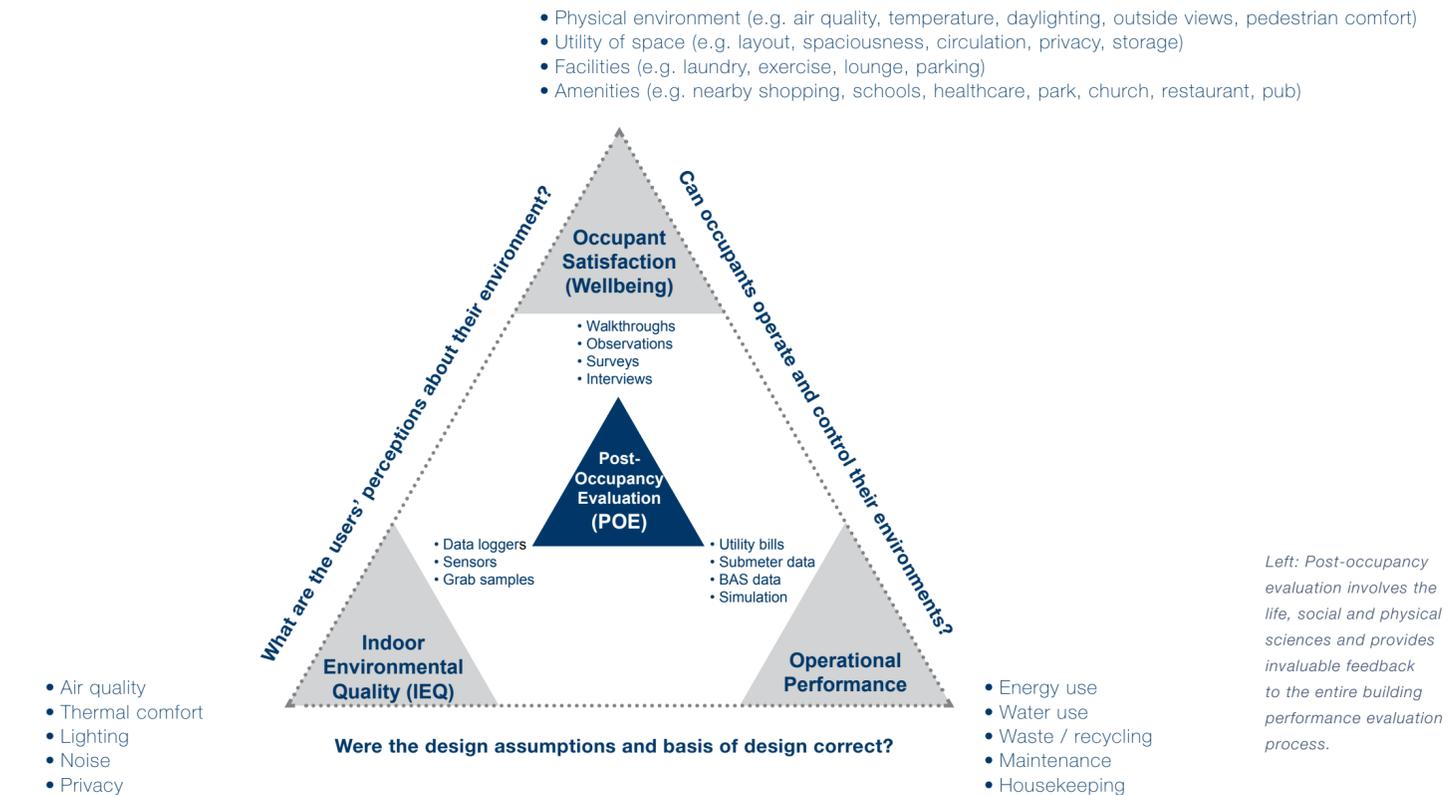
Properly planned and implemented building automation system (BAS) technology can continuously monitor performance and serve as a means of perpetual measurement and verification. It requires an investment in sensors and meters coordinated with wiring and piping layouts to provide disaggregated measurements of electricity, natural gas, hot water, chilled water and potable water to distinguish between suites versus common areas, and among end uses in the building. These are critical measures to inform better facilities management practices.

Post-Occupancy Surveys

As cities grow and become more intensified through higher concentrations of multi-unit residential buildings, the quality of life afforded by this housing type will affect a growing proportion of our urban citizens.

*"I asked a well-known social scientist what tools he thought most important when researching occupant satisfaction in buildings. Instrumentation? Physical measurements? Occupant surveys? "A functioning set of eyeballs," he said. He had a point. Buildings aren't nearly as mysterious as some people like to make out. Most problems are right in front of you, if you bother to look properly. The big question is whether what you've found actually matters. And that, as is often the case, is a matter of judgement."*¹

Anyone looking at what apartment dwellers leave out on their balconies can easily judge the lack of convenient storage (and free space) in most multi-unit residential buildings. But the trend in post-occupancy evaluations is toward occupant satisfaction and wellbeing.



Post-occupancy evaluations are the only means of discovering underlying causes to issues that are negatively impacting quality of life and compromising the condition of a multi-unit residential building.

¹ *What Do We Know About Wellbeing?* November 2016. Roderic Bunn, Building Performance Analyst, Building Performance Analyst, Building
<https://www.bsria.co.uk/article/what-do-we-know-about-wellbeing/>

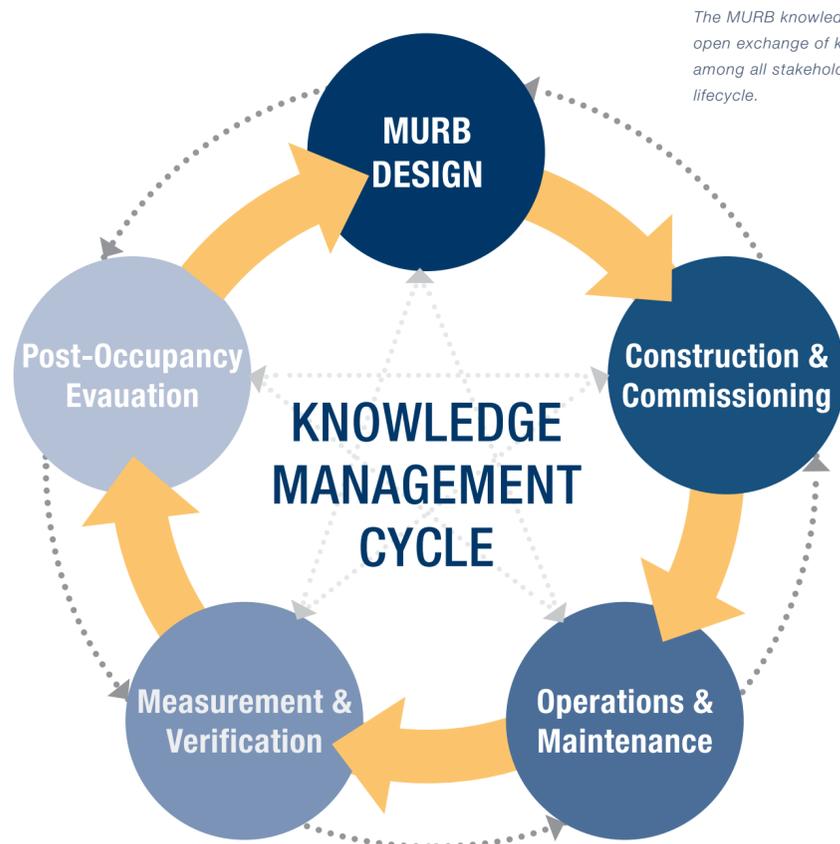
BUILDING PERFORMANCE EVALUATION

Occupant Education and Engagement

It has been estimated that up to one-third of the energy use in a building can be attributed to occupant behaviour. This suggests that how multi-unit residential buildings are occupied and operated by the individual households will have enormous impacts on energy and water use, and the diversion of waste towards recycling and composting. Even phenomena like the generation of offensive odours and the proliferation of bed bug epidemics stem from occupant behaviour.

One means of constructively addressing this reality is through occupant education and engagement. Much of the public health and services aspects of education and engagement normally fall under the auspices of municipal governments and agencies however, facilities management and operations staff can work with inhabitants to promote positive behaviour and etiquette.

In an era of climate change and increasingly frequent and severe extreme weather events, it is also important to discuss resiliency strategies and inform inhabitants about emergency measures for their building and surrounding community.



Click on the download icon for more information about:
Occupant Education & Engagement

EPILOGUE

This guide has been fashioned as a loose-fitting armature to house contemporary knowledge and information about the design of multi-unit residential buildings across all aspects of their lifecycle. It does not presume to be definitive or comprehensive. Over time it is anticipated the framework will be expanded and filled in with more and better information including precedents of successful housing projects that embody sustainable and resilient building systems promoting a high quality of life, architecture and city building. The idea is to always keep it as a guide and resource to inform the work of policy makers, planners, developers, designers and constructors - not a rigid recipe that excludes precious ingredients such as creativity and delight that are so obviously absent from today's ubiquitous and uniform condominium towers.

The rationale behind the MURB Design Guide was to reveal the relatively poor and unacceptable performance of Canadian MURBs and to provide access to resources that would enable designers to combine building science and evidence-based approaches to develop durable, healthy, comfortable and resilient housing that is both affordable and sustainable. As it turns out, the knowledge base supporting this ambition is practically complete and quite sophisticated. The only barriers are voluntary ignorance, greed and a lack of political will to promote high quality housing. One additional step taken by the team behind this publication was to provide a companion buyer's guide to better inform the housing consumer about the consequences of their choices, so that in the absence of design professionals, developers and governments doing the "right thing" consumers would be armed with information needed to make prudent choices and protect their housing investments.

The Royal Architectural Institute of Canada (RAIC) was founded in 1907. It acts as the voice for architecture and its practice in Canada and provides the national framework for the development and recognition of architectural excellence. On January 1, 1946, the Central Mortgage and Housing Corporation was created (changed to "Canada" Mortgage and Housing Corporation in 1979) to house returning war veterans and to lead the nation's housing programs. Neither of these two organizations has succeeded in advancing best practice guidelines for the design of multi-unit residential buildings, a housing typology that has been gaining in prominence across Canada's urban regions. This is not a criticism, rather an acknowledgement of how excellence in the design of multi-unit residential buildings remains a formidable challenge resisting advancement by the architecture profession and Canada's national housing agency.

It is also important to note that the design of multi-unit residential buildings is not part of the core curriculum of any of Canada's accredited architecture schools. Unfortunately, there is no centre of excellence in housing design at any school in Canada where research and practice are merged to spur innovation. This may be surprising to many readers, but the more necessary and commonplace the building type, the greater the odds of it being excluded from professional design education and research in Canadian architecture programs, housing being the most conspicuous by its absence.

In view of this unfortunate situation where the design of housing has not benefitted from continuous interdisciplinary research among the life, social and building sciences, it would be presumptuous for any guide to attempt to compensate for over a century of benign neglect toward professional education and best design practices. However, some modest first steps are now warranted and readers are encouraged to provide feedback and identify helpful resources, as this guide is intended to remain a living digital publication that will be updated and refreshed to reflect emerging best practices and insights. It is the beginning of a long overdue process of identifying the key pieces in the performative building design puzzle and adding them to the mix of creative design ideas that will help enhance the liveability and resilience of multi-unit residential buildings.

[Ted Kesik](#) and [Liam O'Brien](#)
January 2017