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Efficient HVAC System Operations for Multi-unit Residential Buildings

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Agenda

1. Introduction to Save on Energy
2. Review common HVAC systems found in Multi-unit Residential Buildings (MURBs)
3. Overview of heat pump technology
4. Understand sources of energy savings opportunities in MURBs
5. Discuss implications of oversized systems
6. Present case studies

Retrofit Program 2023 updates

Visit the Resources and Support page for Application Checklists, Tips and Best Practices

- **Custom track** introduced in May 2023.
- Updated incentive structure.
  - New and increased incentives
  - $1 million incentive cap for Retrofit projects has been removed
  - Incentives continue to be capped at 50% of project costs
- Changes to **networked lighting** control incentives.
  - Incentives now calculated on **$/kWh** (moving away from $/sq. ft.)
  - An incentive offering for networked lighting controls — from $0.15/sq. ft. to **$0.35/kWh**

Retrofit Program fall 2023 changes

- Prescriptive incentives for most **non-lighting** measures have increased as of October 30, 2023.
- Most non-lighting incentives have **doubled,** and some have increased three- or fourfold, including air source heat pumps.
- The **Instant Discounts Program** for lighting launched **December 18, 2023.**
- In this program, incentives will be paid directly to distributors, enabling them to offer instant point-of-sale discounts on energy-efficiency lighting to customers.
- Visit the Retrofit program website for the updated measures and incentives.

New Measure Incentives Rates

Measure	New Incentive
Unitary Air Source Heat Pump 20.0 to <63.3 Tons	$18,000/unit
Refrigeration Compressors High Efficiency Scroll Compressors	$240/HP
Circulator Pumps with ECMs >=750<1490 W (>=1<2HP)	$2,200/unit
Compressed Air VD Variable Displacement Compressor >= 20 HP	$3,120/unit
Demand Control Ventilation – Enclosed Parking Garage >50 to <= 75 HP	$29,850/unit
Unitary Air Conditioning Unit 20 to < 63 tons	$4,880/unit
Variable Frequency Drive 5 HP	$1,050/unit
Variable Frequency Drive 150HP	$29,400/unit

The complete list of incentives can be found on the Retrofit program webpage.

Retrofit regional adders

In certain areas of Ontario where electricity constraints exist, Save on Energy introduced Retrofit regional adders that **double the incentive for non-lighting prescriptive measures** to further encourage uptake in the Retrofit program. The target areas are:

- Niagara region
- Kingston area
- Southern Huron Perth
- Pembroke area
- Kenora
- Waubaushene
- Barrie/Muskoka
- Elmira
- Peterborough/Belleville

Postal codes for each eligible target area are available on the Save on Energy website

Energy Affordability Program

Social Housing providers and their residents may be eligible for Save on Energy's Energy Affordability Program, which offers no-cost Energy Saving Kits and Comprehensive Support. This offering can result in improved comfort, resiliency and reduced electricity costs.

Energy Saving Kits	Comprehensive Support
LED light bulbs and night lights	Energy Saving Kit items
Low-Flow water fixtures*	ENERGY STAR appliance upgrades
Weatherstripping for doors and windows	Basement or attic insulation**
Retractable clothesline	Smart thermostats**
Block heat timers	Cold climate air source heat pumps**

To learn more about eligibility, visit the Save on Energy website or contact an authorized vendor.

* For residences with electric water heating

** For residences with electric space heating

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Training Courses

Save on Energy offers incentives of up to 50% for ~20 training courses, plus certification exam fees, including:

- Achieving Net-Zero Buildings
- Energy Management and the ISO 50001 Standard
- HVAC Optimization for High Performance Sustainable Buildings
- Certified Energy Manager (CEM)
- Certified Measurement & Verification Professional® (CMVP)

To register, visit: https://saveonenergy.ca/Training-and-Support/Training-Courses

Training Courses for Enbridge Customers

Enbridge customers are eligible for incentives of up to 75% for three courses:

- Dollars to $ense Workshops - up to $500 a day
- Certified Sustainable Building Operator® (CSBO) - up to $2,250 of course fees
- Certified Energy Manager® (CEM) - up to $2,500 of course fees

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Save on Energy's Capability Building Program

- Save on Energy's Capability Building program is designed to increase awareness of energy-efficiency opportunities, and to enhance knowledge and develop skills in organizations and communities across Ontario so they can undertake energy-efficiency actions and participate in Save on Energy programs.
- The Capability Building program includes tools such as workshops, webinars, training courses, coaching, peer learning and information resources including guides and videos.

HVAC Systems in Multi-unit Residential Buildings (MURBs)

Decentralized system characteristics

- One or more individual HVAC units, each with an integral refrigeration cycle, heating source, and direct or indirect outdoor air ventilation.
- Components are factory designed and assembled into a package that includes fans, filters, heating source, cooling coil, refrigerant compressor(s), controls, and condenser.
- Equipment is manufactured in various configurations to meet a wide range of applications.

Examples of decentralized HVAC equipment

- Window air conditioners
- Through-the-wall room HVAC units
- Air-cooled heat pump systems
- Water-cooled heat pump systems
- Residential and light commercial split systems
- Self-contained (floor-by-floor) systems
- Outdoor package systems
- Single-zone variable-air-volume systems
- Variable-refrigerant-flow systems

Centralized system characteristics

- Large chilling and heating equipment.
- Configuration and ancillary equipment vary, depending on the facility's use.
- Can be located as part of the facility, or in remote standalone plants.
- Different combinations of centralized and decentralized systems can be used.

Examples of centralized HVAC equipment

- Central refrigeration equipment/systems with chilled-water distribution
  - Water-chilling equipment, cooling towers, pumps, and water system specialty items
- Central boiler equipment/system with hot-water distribution
- Low-, medium-, and high-pressure steam plants
- Cogeneration central equipment/systems
- Condenser water systems used with water-source heat pumps

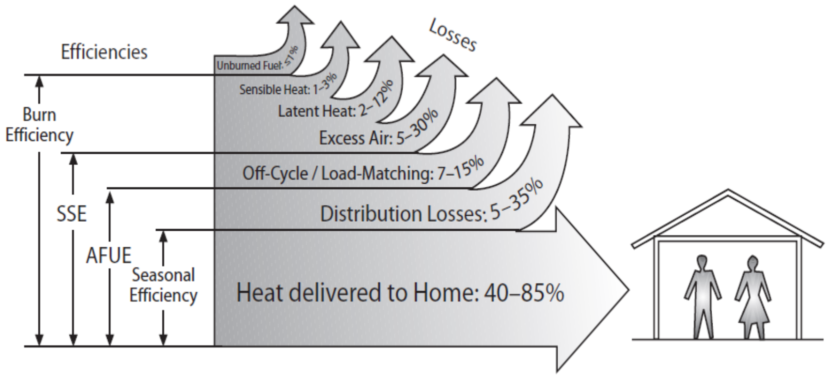
Direct and indirect heating

- Direct heating is when the heating source is in direct contact with the building air.
  - Better heat transfer = better efficiency BUT combustion products are being inhaled.
- The boiler heating surface is that portion of the surface of the heat transfer apparatus in contact with the fluid being heated on one side and the gas or refractory being cooled on the other side.
- The surface that comes in contact with the hot gases is called the indirect surface.

Heating efficiency; energy losses in heating

1. Fuel burning efficiency.
2. Steady-state efficiency (also called combustion efficiency).
3. Annual fuel utilization efficiency (AFUE).
4. Delivered heating efficiency (also called **seasonal efficiency**).
5. Heating seasonal performance factor (HSPF): rating for heat pumps describing how many BTUs they provide per watt-hour of electricity consumed.

Losses from Combustion Heating Systems and Resulting Efficiencies



Much of the heat contained in the fuel never reaches the living space as useful heat. Fuel-burning efficiency counts losses from incomplete combustion. Steady-state efficiency (SSE) counts chimney losses. Annual fuel utilization efficiency (AFUE) counts cycling and jacket losses. Seasonal efficiency counts distribution losses in addition to the others and would be the lowest efficiency (40% to 85%).

Measuring efficiency in HVAC systems

- **Seasonal Energy Efficiency Ratio (SEER)**
  - Measurement of the cooling efficiency of an air conditioning system, typically central systems, over an entire cooling season.

$$SEER = \frac{output\ cooling\ energy\ over\ a\ season\ in\ BTU}{input\ electrical\ energy\ over\ the\ same\ season\ in\ Wh}$$

- **Energy Efficiency Ratio (EER)**
  - Measurement of the cooling efficiency of an air conditioning system, typically room AC units, at a specific temperature and humidity level.

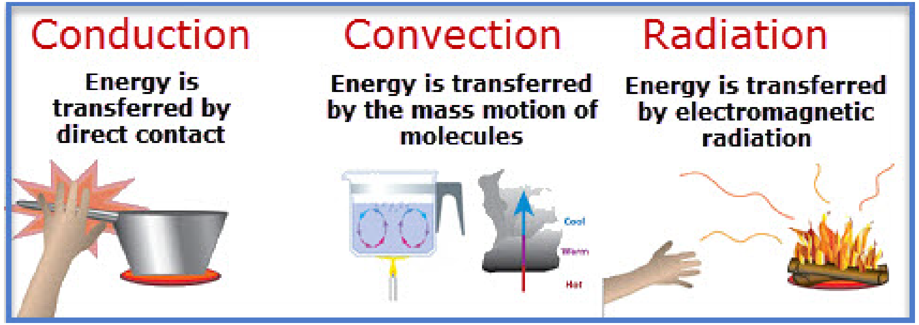
$$EER = \frac{output\ cooling\ energy\ in\ BTU}{input\ electrical\ energy\ in\ Wh}$$

- **Coefficient of performance (COP)**
  - A heat pump or air conditioner's output of heat moved divided by electrical input. It is unitless.

$$COP = \frac{output\ power}{input\ power}$$

Types of heat flow

- Energy is neither created nor destroyed, it merely flows from place to place and changes form.
  - More common to say that energy is used or consumed.
- Heat travels from areas of high temperature to areas of lower temperature in three ways:



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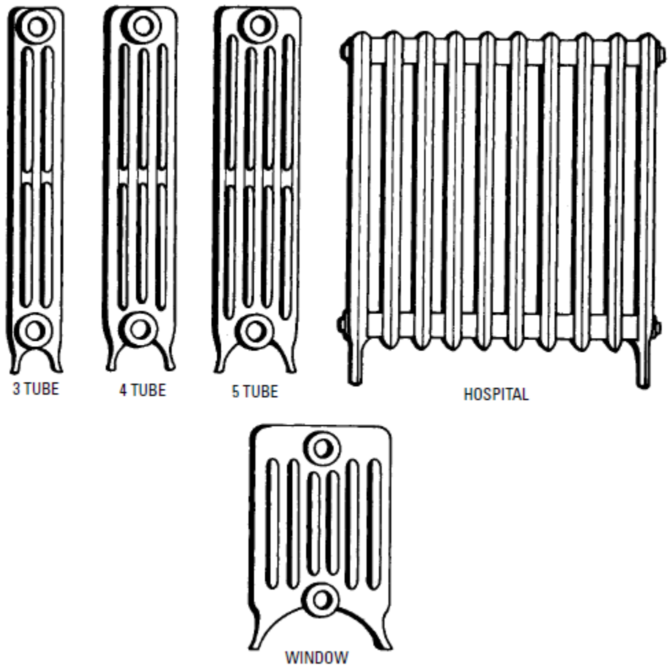
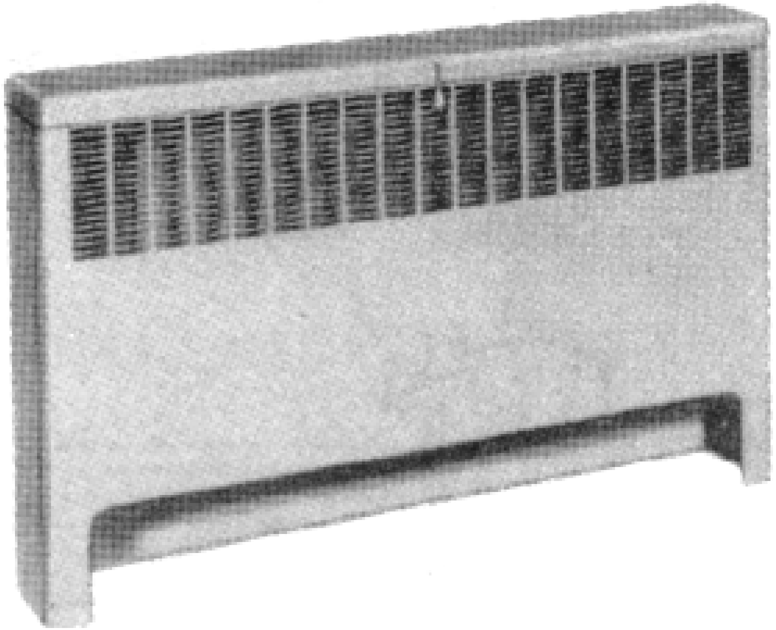
Heat-emitting units

The principal types of heat-emitting units used in heating systems are:

1. Radiators
2. Convectors
3. Baseboard heaters
4. Kickspace heaters
5. Floor and window recessed heaters
6. Unit heaters

Examples of heat-emitting units





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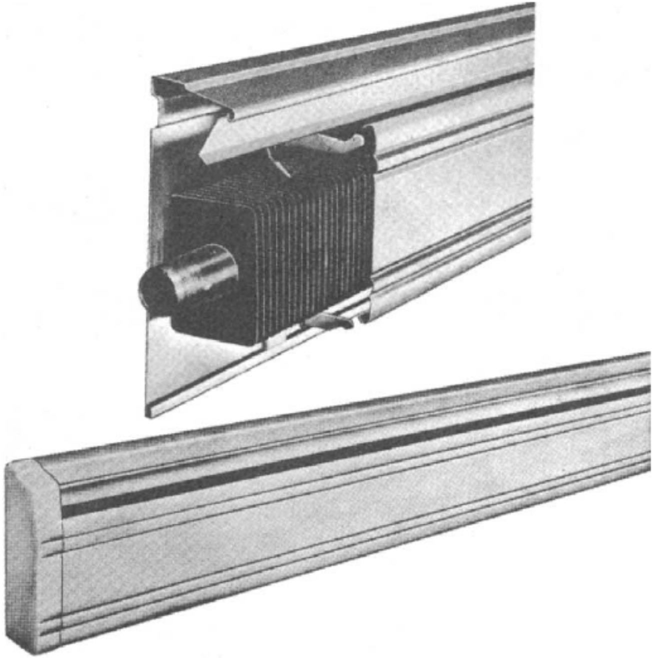
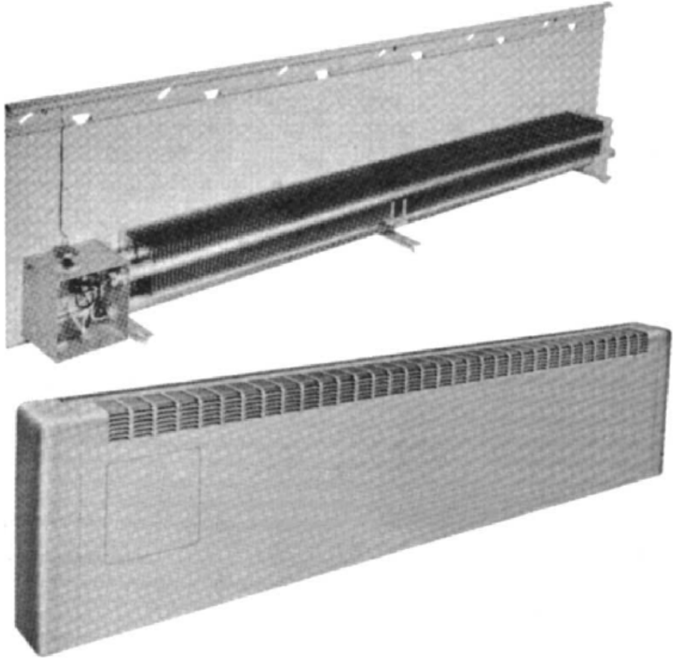
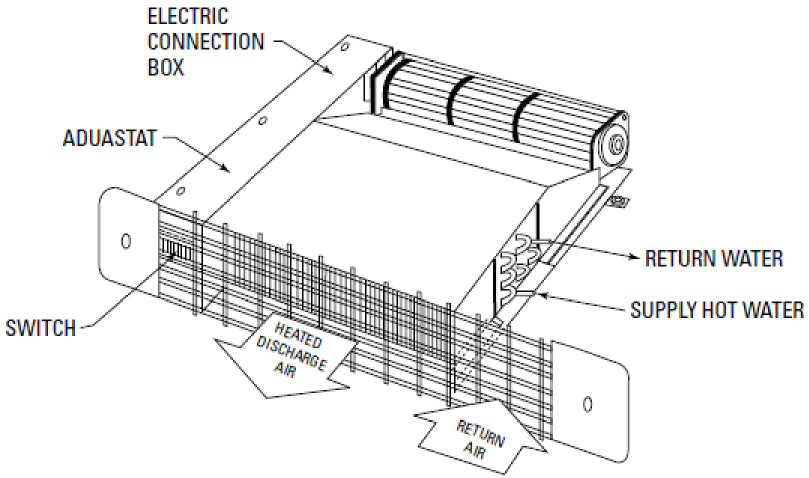
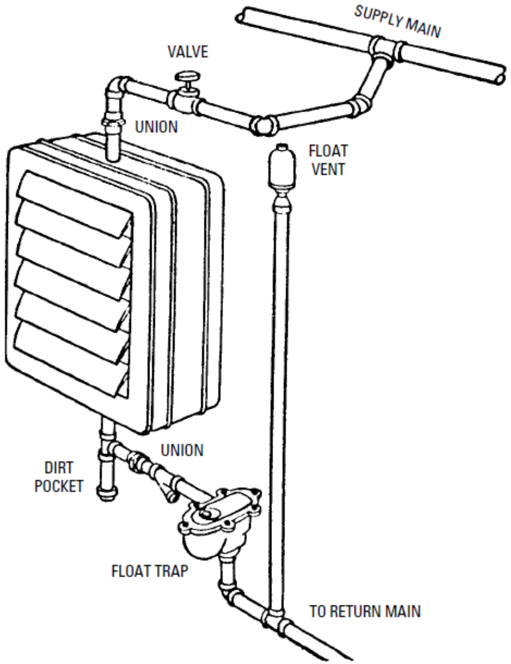
Examples of heat-emitting units continued





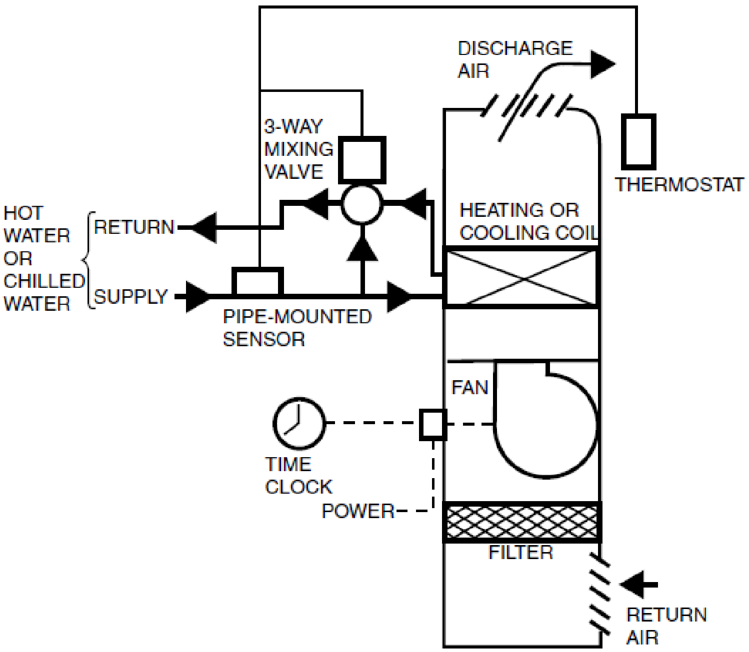
Examples of heat-emitting units continued





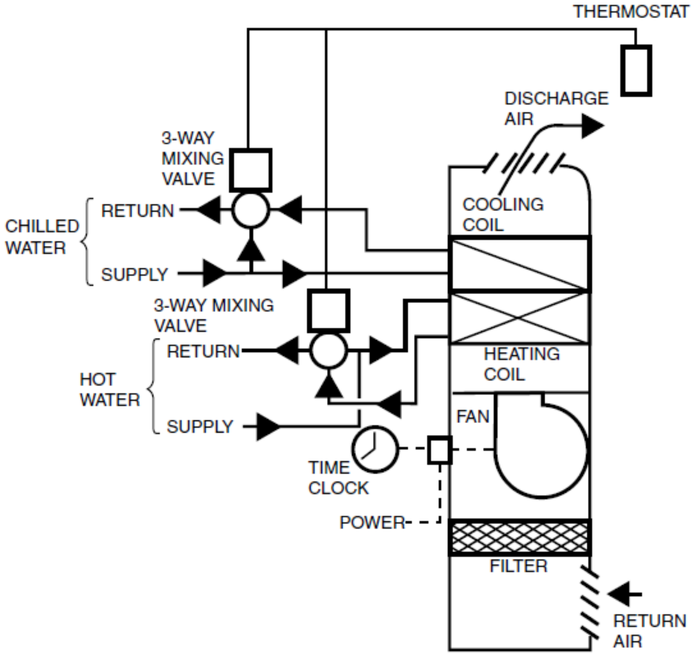
Two-pipe systems with central ventilation

- Two-pipe systems, one supply and one return pipe.
- Each unit is conditioned by primary air from a central apparatus.
- The system design and control must be such that all rooms can be satisfied during both heating and cooling seasons.

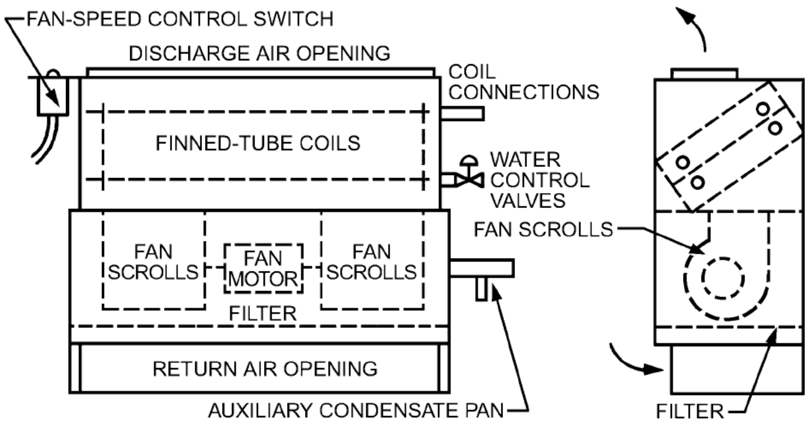


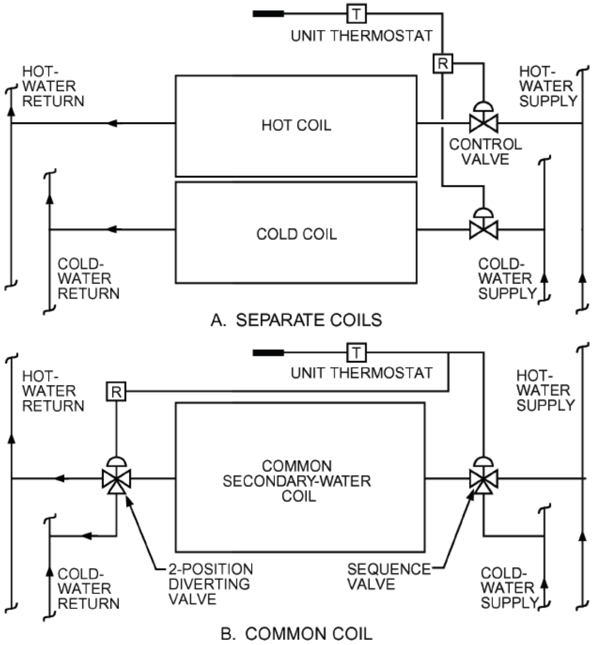
Four-pipe systems

- Four-pipe systems have a chilled-water supply, chilled-water return, hot-water supply, and hot-water return.
- Between seasons, any unit can be operated at any level from maximum cooling to maximum heating, if both cold and warm water are being circulated, or between these extremes without regard to other units’ operation.



Fan-coil unit





Heat pumps

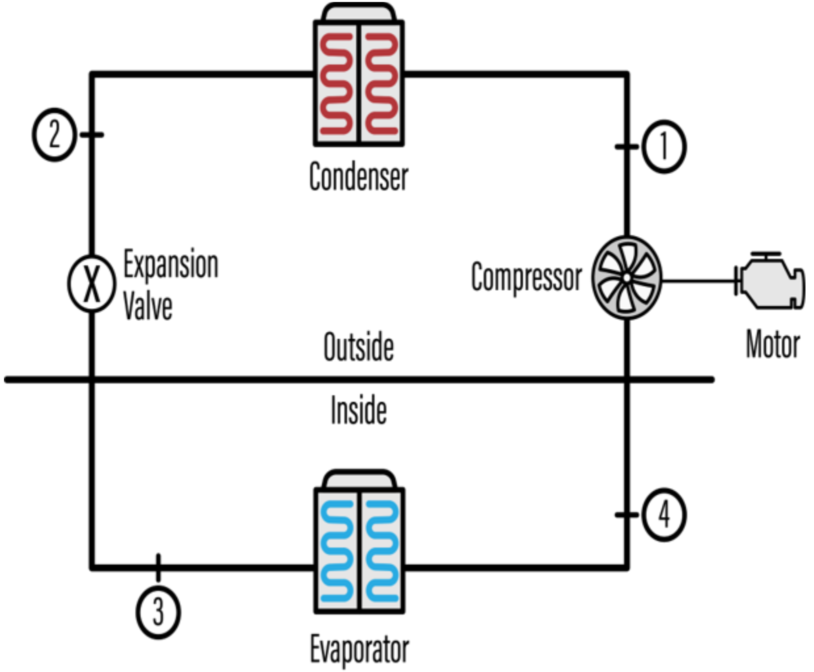
- A heat pump is a vapour compression cycle device used to transfer heat from the source to the sink.
  - Cooling mode:

    Source – Indoor conditioned space

    Sink – Outdoor
  - Heating mode:

    Source – Outdoor

    Sink – Indoor conditioned space
- Heat pumps do not generate heat, they **move** it.



Heat pumps

- The two principal modes of heat pump operation are heating and cooling. A third mode, the defrost cycle, is used to protect the coils from excessive frost buildup.
- The two common types found in Canada are:

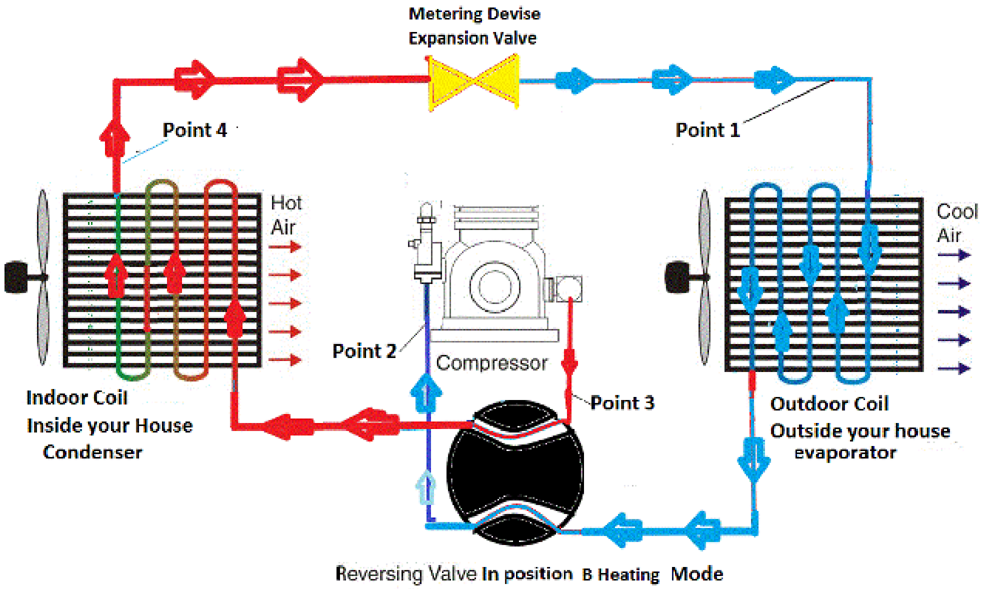
Air-Source:

- The heat pump draws heat from the outside air during the heating season and rejects heat outside during the summer cooling season.

Ground-Source:

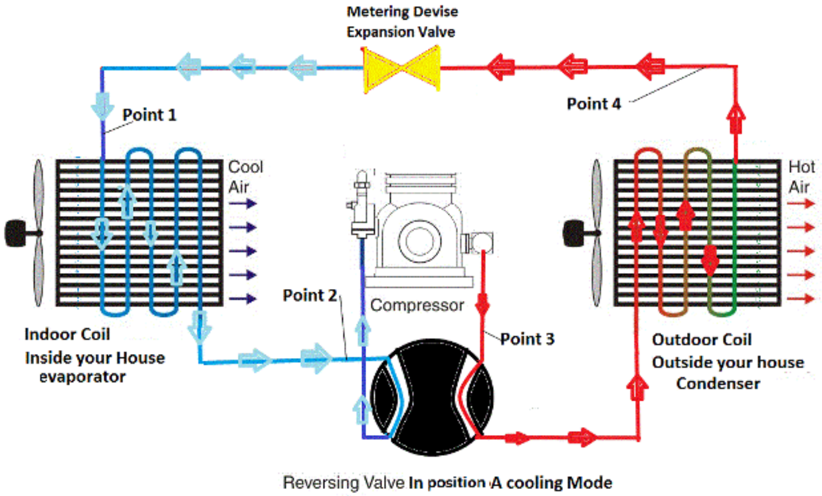
- A ground-source heat pump uses the earth, ground water, or both as the source of heat in the winter, and as a reservoir to reject heat removed from the home in the summer.

Heat pump modes



Heating Mode

Cooling Mode



ASHP example performance curves

- ASHP Ductless Mini-Split
- Mitsubishi PUZ-HA36NHA
- Indoor Unit: PKA-A36KA
- HSPF 9.3
- SEER 14.0
- Heating Capacity: 12,000 – 38,000 Btu/h
- Cooling Capacity: 12,000 – 34,200 Btu/h
- Compressor: Variable Speed
- Refrigerant: R-410a

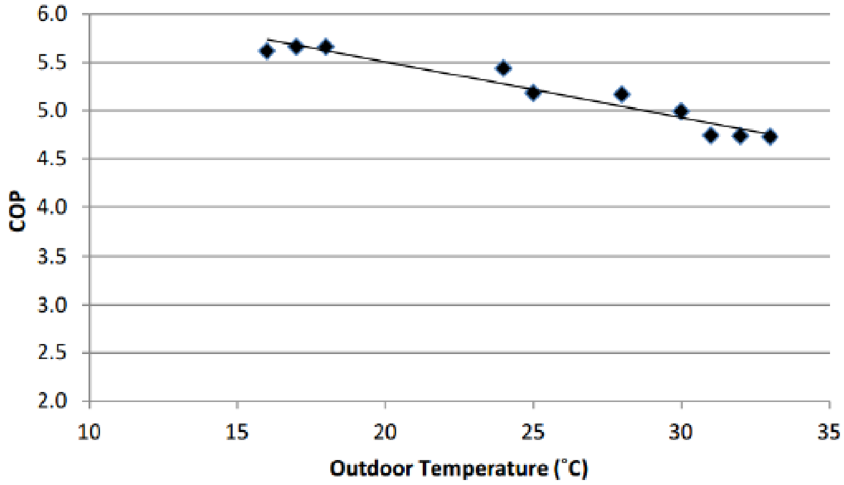


Figure 30: ASHP Cooling COP

Example of an air source heat pump (ASHP)

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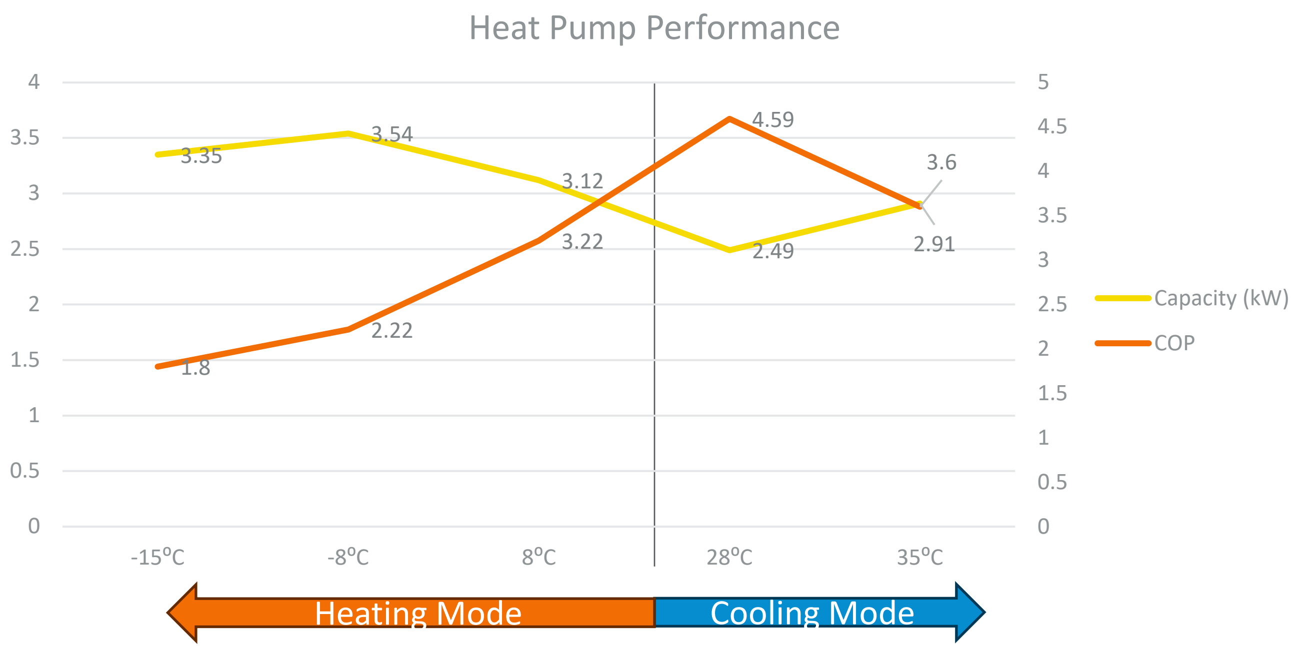
ASHP example performance curves



For specific equipment refer to third-party data sources, for example: https://ashp.neep.org/#!/

Typical efficiencies in HVAC systems

Heating system type	Typical annual heating system seasonal efficiency
Standard boiler/furnace (with pilot light)	55 to 65%
Mid efficiency boiler/furnace (spark ignition)	65 to 75%
High efficiency or condensing boiler/furnace	75 to 85%
Electric resistance	100%
Heat pump - air-source	130 to 200%
Heat pump - ground source	250 to 350%

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Cooling system type	Typical annual cooling system seasonal COP
Compressor - centrifugal	5 to 6.7
Compressor - reciprocating	3.8 to 4.6
Compressor - screw	4.1 to 5.6
Compressor - scroll	4.6 to 7
Heat pump - gas	1.1
Heat pump - air-source	1.3 to 2
Heat pump - ground-source	3 to 3.5
Absorption - single stage	0.5
Absorption - two stage	0.7
Steam jet refrigeration	0.2 to 0.3

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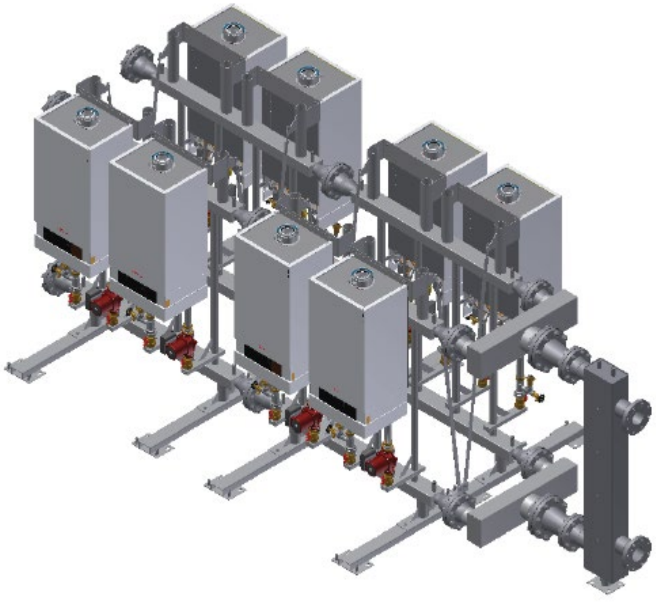
Cascade control systems

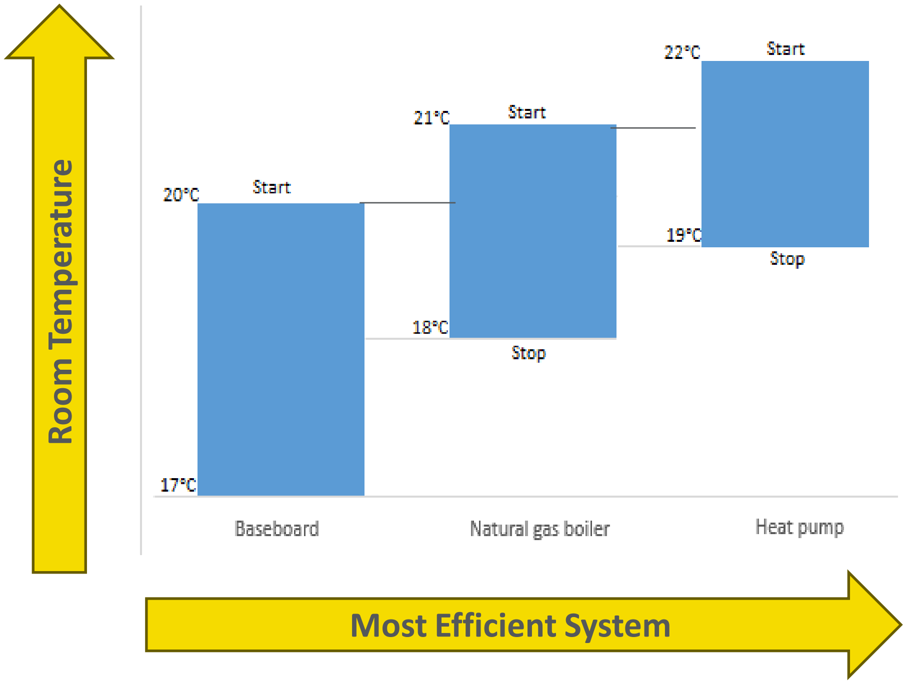
- A cascade system uses multiple units (for ex. boilers, modular chillers) as required to meet fluctuating heating/cooling demands.
- It maintains maximum efficiency at all times by precisely matching the load and, if applicable, using most efficient equipment first.
- Controller will modulate, stage and rotate equipment, regulate equipment water and common supply temperature.



8-boiler cascade system in back-to-back configuration

Advantages of cascaded systems

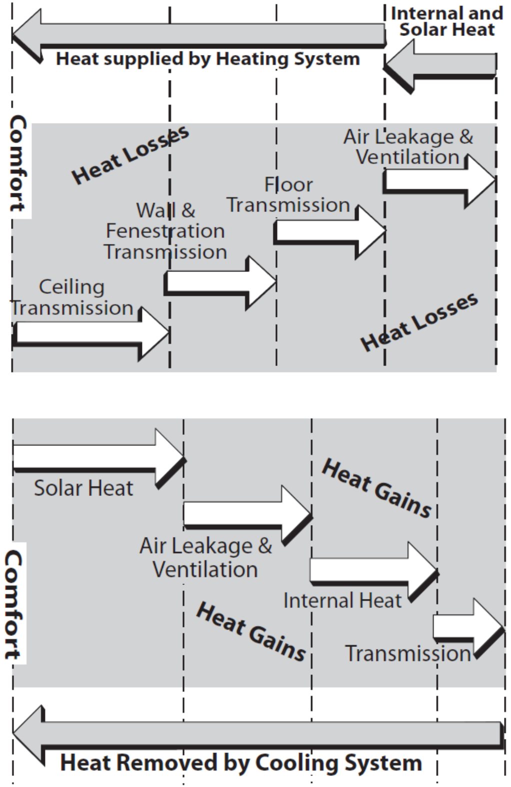
- Greater energy efficiency
- Greater life expectancy of equipment
  - Increased modulation ratios
- Beneficial redundancy
  - Multiple units available as back up
- Flexible installation
- Appropriate approach for efficient operation of hybrid heat pump systems



Inefficiencies and Opportunities for Improvement

Building envelope

- Heat loss and gain through the building envelope are the largest energy demands on residential buildings.
- To maintain comfort, heating and cooling systems supply or remove heat at a rate roughly equaling the heat's flow rate through the building envelope.



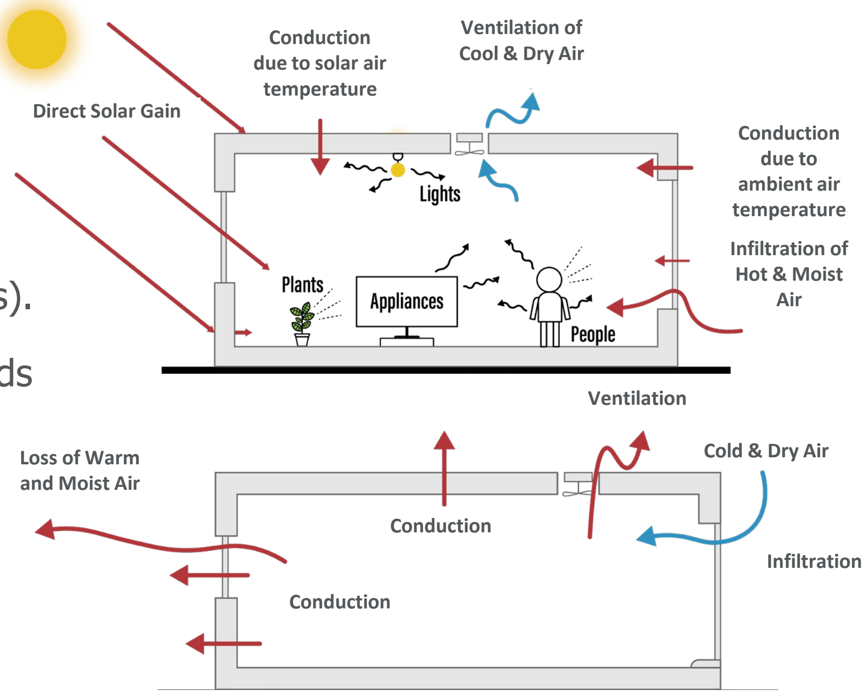
Building envelope heat flow

Heat flows through the building envelope by two mechanisms: transmission and air leakage.

Transmission and air leakage occur through four independent pathways: floors and foundations; walls; roofs and ceilings; and fenestration (windows and doors).

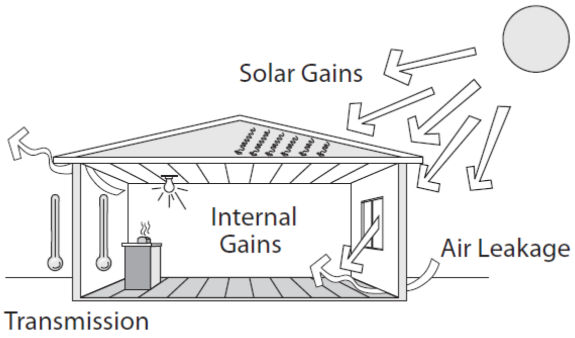
Heat transmission through the building envelope depends on two factors: thermal resistance and surface area.

Air leakage depends on the surface area of the envelope's holes and the pressure differences between indoors and outdoors.



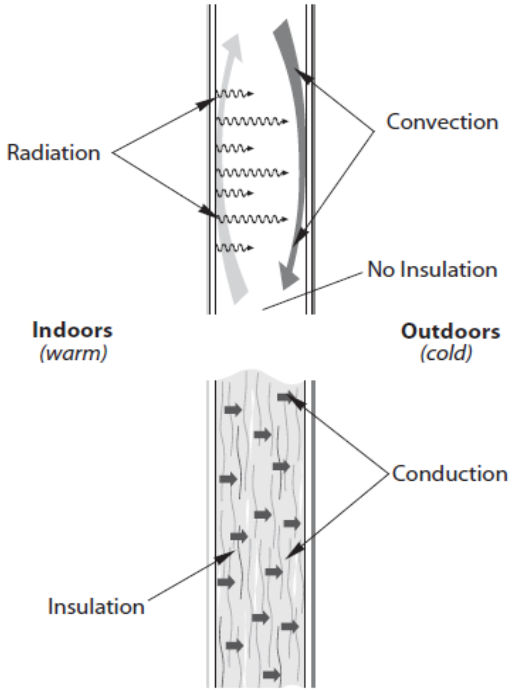
Heat gains and insulation effects

Four Types of Heat Gains



When heat accumulates in a home, the home can become uncomfortably hot. Heat accumulates inside in four ways: solar gains, internal gains, air leakage from outdoors, and the transmission heat gain due to temperature difference.

Effect of Insulation



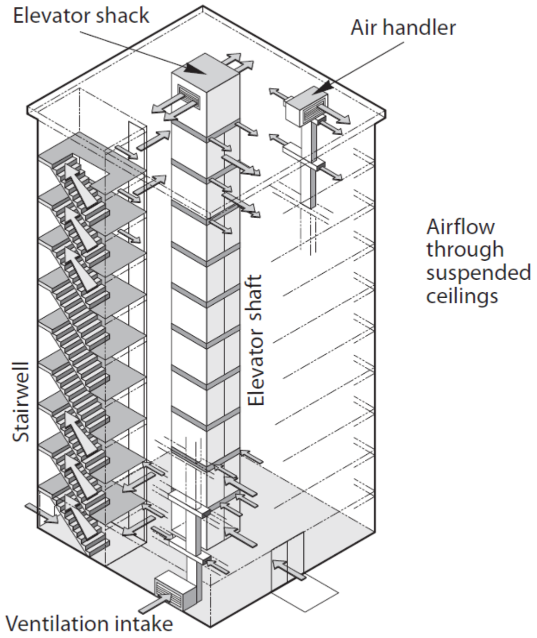
The uninsulated wall transmits heat through its air space by convection and radiation. In the insulated wall, heat must conduct through the tiny air pockets trapped by the insulation — a slower process.

Points of weakness in MURB building envelope

- Thermal bridging from steel and aluminum components.
- Protruding or recessed balconies, eaves, windows, and canopies.
- Roof protrusions and penetrations, such as rooftop elevator shacks and air handlers.
- Air intake and exhaust vents for heating, cooling, and ventilation systems.

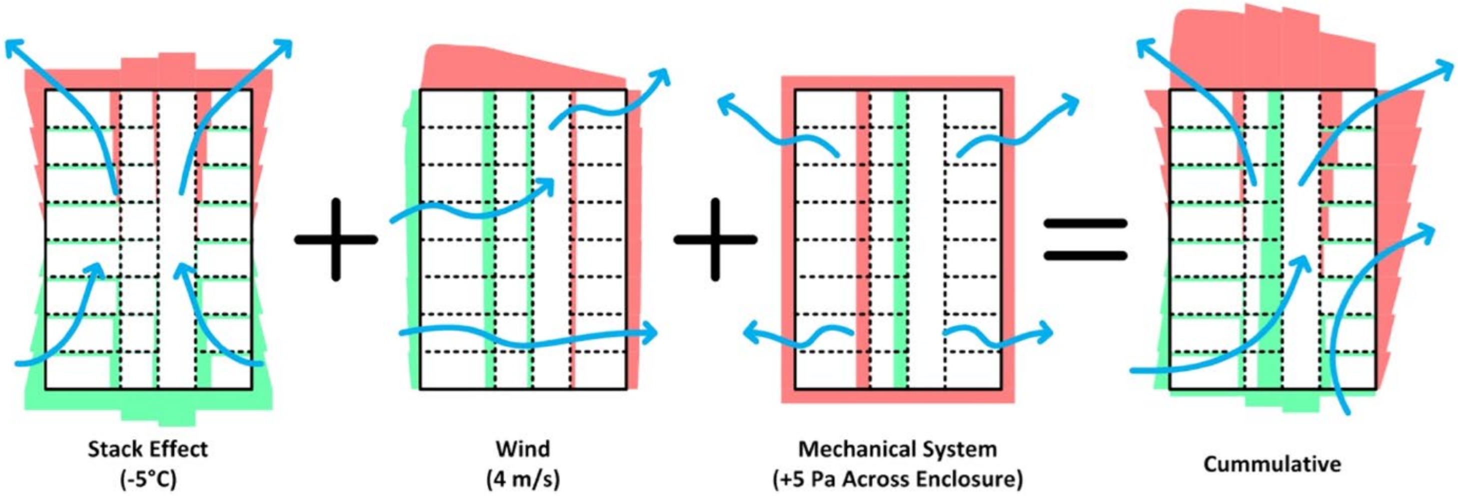
Points of weakness in MURB building envelope

A high-rise building's vertical shafts act as chimneys, drawing air into lower openings and exhausting conditioned air through openings near the top of the building.



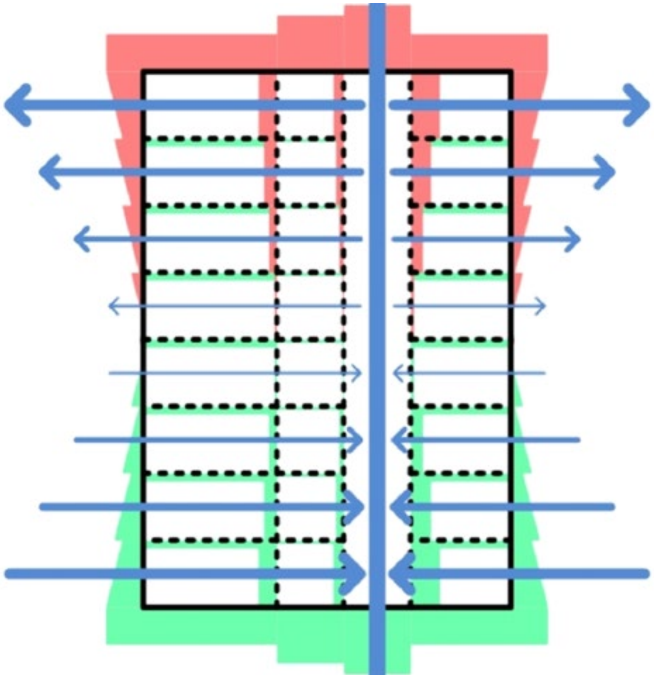
Pressures driving air leakage

Pressure difference is created by three forces that drive airflow:



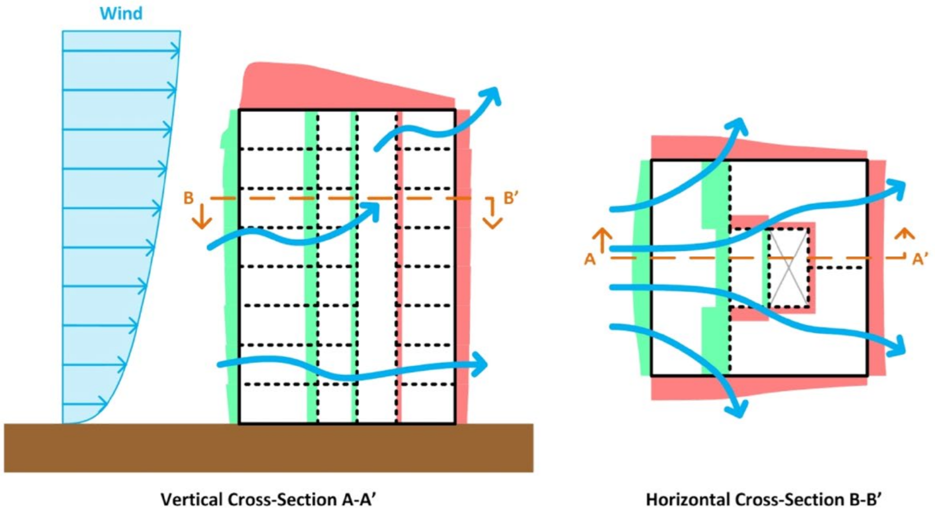
Stack effect

- Caused by the relative buoyancy of warmer air.
- Warmer air’s upward force exerts an outward pressure.
- Airflow, through holes in the building’s top, creates suction at lower levels, pulling air in.



Wind

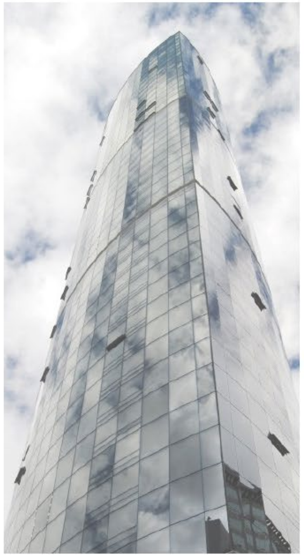
Wind creates pressures on the surface of a building and tends to drive airflow from windward to leeward.



Source: Ricketts, L. (2015). Ventilation in Multi-Family Buildings (PowerPoint). 19th Annual Westford Symposium on Building Science. RDH Building Engineering Ltd.

Airtightness

Resistance to airflow is provided by airtightness of building elements such as walls, windows, doors etc.

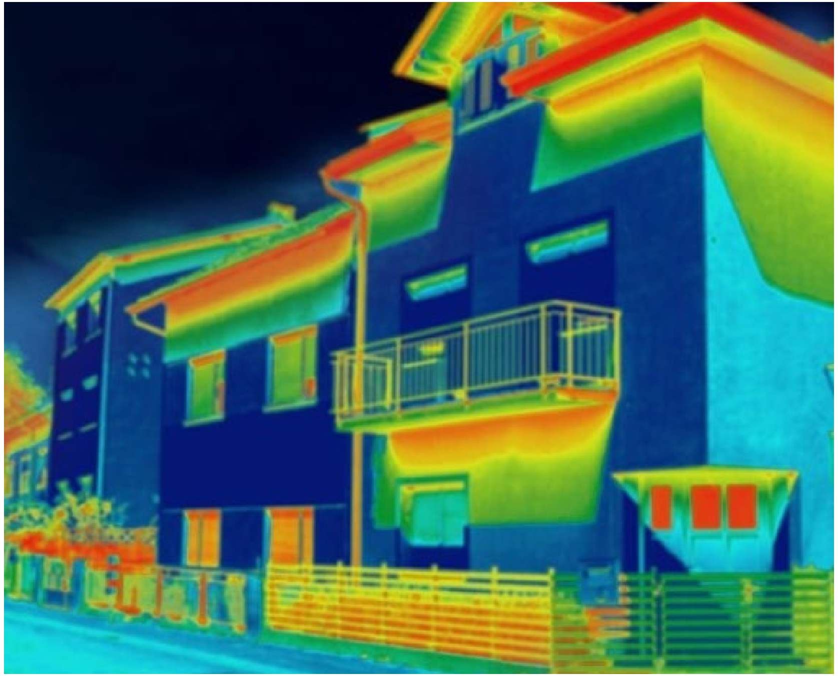


Blower-door testing and thermography

Blower doors depressurize the home/building area to amplify air leakage so leakage can be measured, and air leaks can be located.

The blower door measures how much airflow is necessary to maintain a particular pressure difference between indoors and outdoors — usually 50 pascals.

Blower-Door Testing and Thermography



- Thermography measures surface temperatures by using infrared video and still cameras.
- These tools see light that is in the heat spectrum.
- Images on the video or film record the temperature variations of the building’s envelope.

How to Improve Airtightness

Thermal insulation upgrades such as overcladding

Energy efficient windows: double or triple pane, low-e, argon filled

Air sealing: caulking, weatherstripping, pressurized sealant applications

Airtight component layers should be permanently and airtightly joined

Thermal bridge free design for new builds or extensive renovations

Poll

Why is ventilation important in multi-family housing?

- Attendants to give custom answers…
- Answer: on following slides, see Exhaust and Supply Ventilation slides

Oversized equipment leads to losses

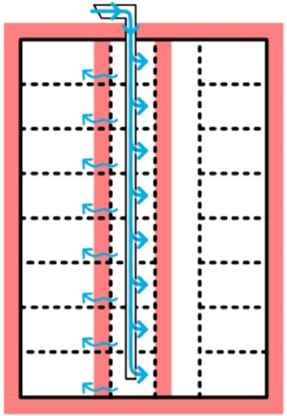
- Oversized heating and/or cooling equipment has more capacity than required to meet the building's loads.
  - Results in inefficiencies due to cycling which may lead to equipment failures.
  - May result in higher than normal humidity levels due to short-cycling. This can create moisture issues that impact health and safety
- Consider assessing the size of central heating/cooling systems if building upgrades were implemented over the years, especially when replacing HVAC equipment as part of capital repair plans.

Exhaust ventilation in MURBs

- MURBs in Canada typically contain:
  - Bathroom exhaust fans
  - Kitchen exhaust fans
  - Clothes dryers
- These create a slight vacuum indoors because they exhaust air out of the building.
- They also move the neutral pressure plane up because more of the building's interior space is under negative pressure.

Supply ventilation in MURBs

- Most apartments/condos are commonly ventilated using pressurized corridor systems.
  - Air supplied to corridors directly via a vertical shaft which pressurizes the corridor.
  - Corridor pressurization forces air into suites via intentional gaps under the entrance doors.
  - Control flow of air contaminates between zones.
- Newer, more airtight buildings have less tolerance for poorly performing ventilation systems.
  - Less infiltration and exfiltration to supplement ventilation.

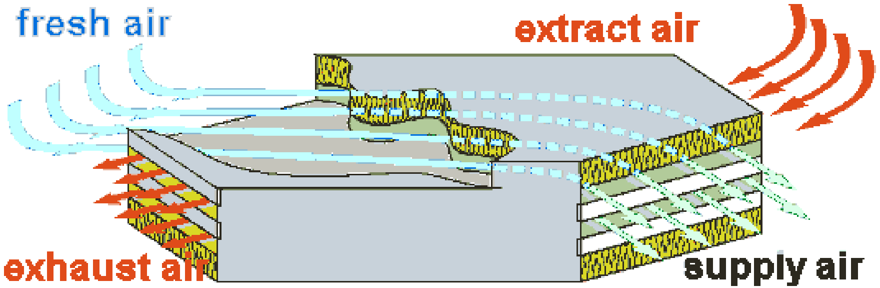


Dedicated outdoor air system (DOAS)

- Decouples air-conditioning of the outdoor air from conditioning of the internal loads.
- The DOAS introduces 100% outdoor air, it may heat, cool, humidify or dehumidify it, and filters it, then supplies this treated air to each of its assigned spaces.
- DOAS can accommodate an exhaust or relief airflow for heat recovery between the outdoor and exhaust or relief airflows.
- A second, more conventional system is intended to control space temperature.

Efficient ventilation with heat recovery

- Recovers the heat from the exhaust air and using a heat exchanger, transfers it back into the supply air without mixing the air flows.
- Modern ventilation technology allows a heat-recovery rate of between 75% and 95%.
  - Counterflow heat exchangers and energy-efficient fans



Easy upgrades in MURBs

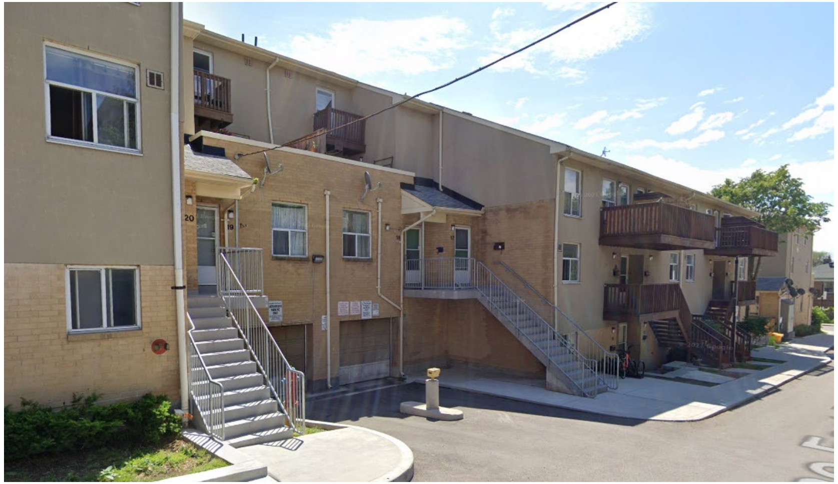
- Easy-to-install devices that can improve comfort and lead to savings should be made:
  - Timers for kitchen and bathroom ventilation
  - Smart thermostats that reduce setpoints during unoccupied hours
  - Lighting retrofits to LED
  - Installing efficient appliances
  - Cleaning filters and coils to reduce wear in equipment, reduce power consumption and improve heat distribution.

Efficient Operations Strategies

- Design is very important
- Cascaded system control
- Commissioning and re-commissioning periodically
  - Oversized equipment leads to losses
- Maximizing airtightness
- Blower-door testing & Thermography
- Heat recovery ventilation

ASHP case study in a MURB

- Location: 66 Walpole Ave, Toronto
- **Building type:** Townhouse complex (1987), owned by Toronto Community Housing Corporation
- **Old system:** Electric baseboard radiators, electric hot water tank, 7.6 LPF toilets
- **New system:** LG multi-split cold climate air source heat pumps, Rheem Air Source domestic hot water heat pumps, and low-flow toilet retrofit.



ASHP case study in a MURB

What was done

- Installed LG cold climate-ASHP multi-split units in each suite, with one indoor head in the main living space, and an additional indoor head per bedroom.
- Piloted Rheem air source DHW heat pumps in five units.
- Upgraded all toilets from a standard toilet to a three LPF low-flow toilet.

Key takeaways

- Heat pumps **improve resident comfort**, especially in the summer months.
- Air source DHW heat pumps can **reduce DHW energy consumption**; however, the opportunity to use this technology in a retrofit can be limited by the conditions and design of the existing space.
- Low-flow toilet upgrades significantly **reduce water consumption**.

ASHP case study in a MURB findings

- CC-ASHPs improve thermal comfort, but sizing can be challenging.
- **29%** reduction in heating energy with introduction of CC-ASHP.
- **56%** reduction in domestic hot water heating energy.
- **33%** reduction in water consumption with low-flow toilets.

ASHP case study in a MURB findings

- Oversizing was necessary due to the ASHPs carrying the full heating load in the winter without relying on back-up heating.
  - The outdoor unit needed enough capacity to match the combined output of all indoor heat.
  - Oversizing results in shorter run cycles in the shoulder seasons.
- DHW ASHPs draws heat from the surrounding air, so there needs to be room for ample air flow.
  - Added benefit in the summer as it adds further cooling to the suite but is a detriment during the heating season.
  - The system also needs access to a drain.

ASHP case study in a MURB challenges and solutions

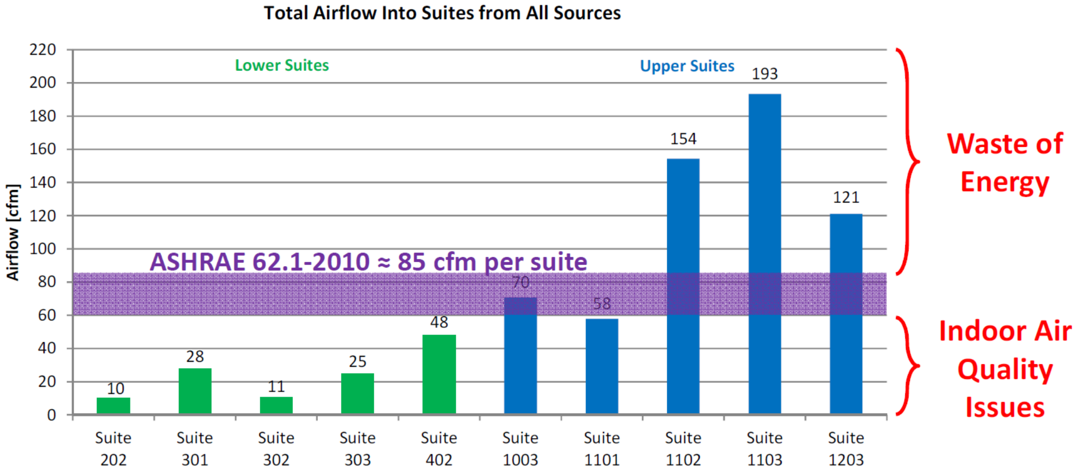
- At the time of installation (2019), most of the heat pump products on the market involved indoor heads with a larger capacity than the project needed.
- Due to this, cycling is occurring more frequently than expected, reducing performance.
- There are currently far more options available on the market for smaller units.
- With the thermostats available for this product at the time, it was possible to set an upper and lower temperature limit.
- However, the control logic available only allows for one upper and lower setpoint for all modes, rather than individual setpoints for each mode (particularly heating and cooling).
- This results in the need to set a rather large temperature band and reduces potential energy savings.
- There are now more thermostat options available on the market with customized temperature limits.

Ventilation case study in a MURB

- 13-storey MURB in Vancouver, Canada, with 37 residential suites
- Constructed in 1986
- Building envelope retrofit completed in 2012
  - Windows (R5), air sealing, insulation increase to exterior walls (R4 to R16)
- Below-grade parking garage located under the building
- Ventilated using a pressurized corridor ventilation system by a single make-up air unit (MUA)

Ventilation MURB case study findings

- Order of magnitude variation in the ventilation rates
- Significantly higher rates for upper suites than lower suites
- Most suites under-ventilated or over-ventilated



Ventilation MURB case study findings

- The ventilation driving forces are not the only problems – the pathways are as well.
- A lot of the ventilation air does not make it to the corridors because of leakage to elevator shafts, stairwells, and other places (floors above and below, electrical closets, garbage chute).
- 40% of intake flow reaches the corridor directly and 20% of that makes it to the suite door hence 40%*20%= **8%** of intended ventilation only
- The lower floors have more indoor air quality problems than the upper floors.
  - The levels of carbon dioxide were higher.
  - There was more infiltration from the garage at the bottom of the building.
- Stack effect and wind pressures are often similar or greater than mechanically induced pressures.
  - Ventilation system cannot practically overwhelm nature.

Ventilation MURB case study findings

- Ventilation air should be directly supplied to suites to limit the potential of loss along the flow path and of the system being overwhelmed by stack effect and wind.
  - Heat recovery ventilators (HRVs) installed in each suite.
- Central ventilation, i.e., the MUA size should be reduced to only ventilate the corridors.
- Suites and vertical shafts should be compartmentalized (airtight) to limit the impact of wind and stack effect on ventilation.
  - Air sealing between suites reduces internal transfer of contaminates and energy.
- Air sealing between parking garage and the interior.
  - Reduces infiltration of harmful contaminates.

Tower Renewal case study in a MURB

- Project: Ken Soble Tower
- Location: 500 MacNab Street North, Hamilton, Ontario
- Owner: CityHousing Hamilton (CHH)
- Building type: 18-storey concrete slab high-rise
- Size: 7,525 square metres (81,000 square feet)
- Units: 146 units of affordable housing
- Tenants: low-income seniors
- Cost to build: $34 million
- Rents: averaging 50% below market rates

Tower Renewal case study building features

- The retrofit adopted a “building envelope first” approach which focuses on high levels of insulation and air tightness, as well as reducing thermal bridging of assemblies and components.
- non-combustible R38-effective over-cladding using a mineral wool EIFS rain screen
- triple-glazed Canadian fibreglass windows (0.65 W/m2K U-Value)
- airtight construction, measuring 0.235 ACH at 50Pa
- internal shading and ceiling fans
- ASHP centralized heating and cooling
- high-efficiency energy recovery ventilators
- drain water heat recovery

Tower Renewal case study findings

- Compared to the original building, the retrofitted tower's Passive House design strives to:
  - Cut thermal energy demand intensity by **89%**
  - Reduce greenhouse gas emissions by **88%**
  - Heat or cool each unit with the equivalent energy to three 100-W light bulbs

Tower Renewal case study findings

Metric	Before Retrofit	After Retrofit
Annual heating energy demand per square meter (aka TEDI Thermal Energy Demand Intensity)	250 kWh	22.3 kWh
Annual cooling energy demand per square meter	No cooling present	1.9 kWh
Annual primary energy demand per square meter	650 kWh	145 kWh
Air tightness	5.41 ACH @ 50Pa	0.235 ACH @ 50Pa

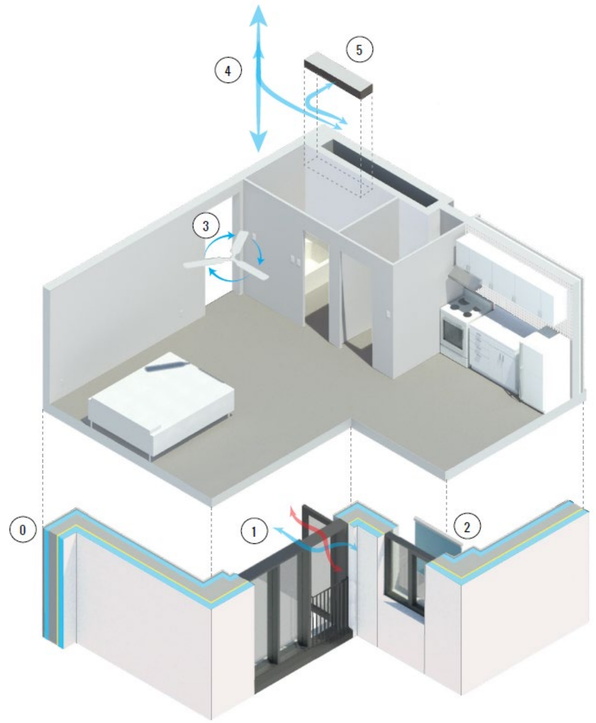
Tower Renewal case study passive and active systems

DYNAMIC THERMAL COMFORT THROUGH COOLING

0 1 2 3 4 5

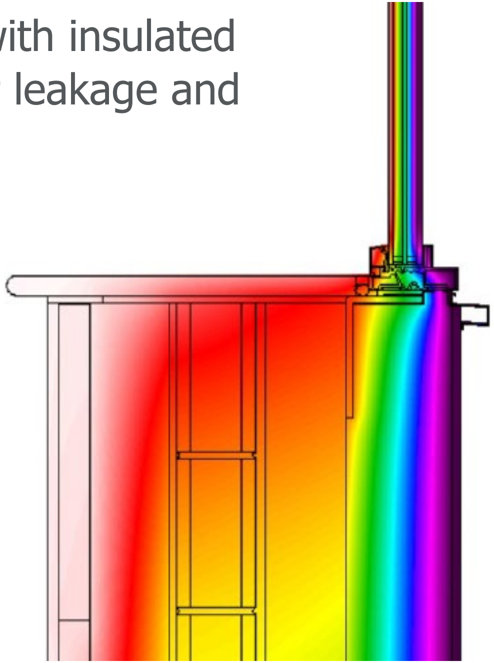
Passive → *Active*

0. R38 Effective Envelope
1. Glazing with a low Solar Heat Gain Coefficient
2. Low emissivity interior shades
3. Ceiling fans to circulate air within units
4. Lightly tempered air delivered through a centralized ventilation system
5. Decentralized cooling ‘boost’ through a Variable Air Volume Unit activated by in-suite controls



Tower Renewal case study passive and active systems

New triple-glazed windows with insulated frames reduces heat loss, air leakage and thermal bridging.



Tower Renewal case study lessons learned

- Integrated design process meant more work upfront, but the result was both a less costly and better quality retrofit.
- Localized investigations and demolition 'mock-ups' could have helped to uncover concealed conditions prior to beginning construction.
  - Remedial measures for elements such as discontinuous partition walls between suites, hidden black mould, and deteriorated heated air distribution systems.
- Preserving and renewing an existing building also meant significant savings in time, cost and carbon compared to decommissioning the existing building and then building new.
- Rather than digging foundations or building walls, investments could be made in features like better insulation and mechanical systems.

Q&A Period

Ask questions via the chat or raise your hand please!

Thank You

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