

HEATING & COOLING  
**ENVELOPE MECHANICAL SYSTEMS**  
 PLUMBING CONVECTION RADIATION  
**STRUCTURE CONDUCTION**  
 ELECTRICAL  
 THERMAL BOUNDARY AIR BARRIER  
**LIGHTING VENTILATION AIR LEAKAGE**  
 AIR FLOW HEAT FLOW CAPILLARITY MOISTURE  
**WIND MOISTURE FLOW DIFFUSION CONTROL**  
 STACK EFFECT **BULK MOISTURE**

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## BUILDINGS ARE COMPLEX SYSTEMS

A small commercial building could be viewed as a type of organism. It consists of multiple isolated systems, each of which play a role in its overall health. These systems must operate in tandem, responding to and communicating with one another in order for a building to perform as designed. When improving building performance it is important to understand how each of these systems are linked within a complex system so an integrated, whole-building design approach can be developed.

### What does a building need?

Understanding the building as a complex system means appreciating how the various components interact together and affect overall performance, durability, safety, health and comfort. The building system has multiple critical elements:

- **Structure:** the bones of the building creating stability and space for occupants.
- **Envelope:** the skin of the building resisting the elements, managing heat gain and loss and retaining conditioned air.
- **Plumbing:** water supply and waste removal.
- **Electrical:** energy delivery and nervous system.
- **Moisture control:** managing moisture in the systems themselves and for the occupants.
- **Heating and cooling systems:** temperature management.
- **Ventilation:** providing air, moving air and exhausting it.

Each of these building elements impacts the other and collectively serve to create a stable condition for occupancy and operations.

### Understand how air, heat and moisture move in a building

Creating a high performing, comfortable building requires strategic control of air, heat and moisture flow. Before trying to manipulate these elements, it is important to first understand how they behave. As a general rule, each will always use the path of least resistance in an effort to create equilibrium. For example, in metal framed buildings, highly conductive metal studs will act as the path of least resistance for heat to transfer across the building envelope to the cooler interior. Similarly, in a building that is negatively pressurized, outside air will infiltrate using the path of least resistance, gaps and cracks in the air barrier such as wall penetrations and junctures, in an effort to create equal pressure.

## AIR FLOW



Air flows from regions of high pressure to regions of low pressure through large or small physical pathways (holes, cracks, etc.). Depending on how a building is pressurized with reference to the outside, air can leak into a building (infiltration) or out of a building (exfiltration).

**Wind** - Prevailing winds will cause positive pressure on the building's windward side (infiltration), and negative pressure on the leeward side (exfiltration).

**Stack Effect** - Warm air is naturally buoyant. As it rises to the top of a building and escapes through cracks in the envelope, cool air will enter through a lower opening to replace the air lost. This creates high pressure at the top of the building and low pressure at the bottom. The greater the thermal difference and the height of the building, the stronger the air flow will be.

**Mechanical Systems** - Mechanical fans in a building can create significant pressure differences, which drive air exchanges. When a building is put under negative pressure it will attempt to regain neutral pressure by pulling air in through the path of least resistance.

## EFFECTS OF NEGATIVE PRESSURE



The cumulative effect of wind, stack effect and mechanical fans can induce severe negative pressure within a building. In such scenarios, the building will pull air from any source available where air is flowing with least resistance. This air could be drawn from attics, crawl spaces, mechanical rooms, garages and other undesirable locations. If combustion equipment is located within the building envelope, negative pressure can cause back drafting on the normally vented flue pipe. This can cause harmful combustion gases to enter living spaces and pose a health threat to occupants.

To control air quality, it is best to provide intentional sources of makeup air through proper ventilation. For more information, refer to the *Ventilation fact sheet*.

## HEAT FLOW



The second law of thermodynamics indicates that heat always flows from hot to cold areas. Therefore, heat transfer in a building is driven by the temperature gradient between indoors and outdoors and even temperature gradients within buildings (e.g. hot and cold floors). Heat transfer occurs in three ways:

**Conduction** - heat flow through a solid material. When two conductive materials are in contact, thermal bridging occurs. Insulation works by creating millions of tiny trapped air pockets that slow the transfer of heat.

**Convection** - heat transferred by the movement of a fluid (liquid or air). This most commonly occurs as air leakage into and out of a building. The primary function of an air barrier is to slow air leakage and thus reduce convective heat loss or gain.

**Radiation** - heat transfer from a hot surface to a cold surface with nothing solid or opaque interfering. When radiant energy from the sun hits a window, some of the energy is absorbed or reflected, but most of it is transmitted through the glass and to the interior. Low emitting surfaces on windows or radiant barriers slow radiant heat transfer.

## MOISTURE FLOW



Moisture transfer occurs from wet areas to dry areas as either a liquid or vapor in these ways:

**Air Leakage** - moisture laden air flowing through gaps or cracks in the air barrier.

**Bulk** - liquid water (rain, drainage, plumbing leaks).

**Capillarity** - wicking through porous materials (concrete, fiberglass and cellulose insulation, wood).

**Diffusion** - water moves at the molecular level through porous materials (shower steam diffusing through a wall).

## STRUCTURE

Building structure components do more than just support walls and roofs, the materials comprising structural aspects can aid or mitigate the transfer of unwanted heat and fluids between the outside environment and our inside space. For example, metal studs as wall supports will transfer more heat into or out of the building than comparable wooden studs.

## BUILDING ENVELOPE



The envelope forms the boundary separating conditioned space from unconditioned space and is comprised of roofs, walls, floor, doors and windows. Together these elements act as system resisting the flow of air, heat and moisture. An ideal building envelope maximizes heat retention during the winter and minimizes heat gain during the summer, and is often referred to as the thermal envelope.<sup>1</sup> The thermal envelope is comprised of two critical parts:

- » Air barrier (pressure boundary)
- » Thermal boundary (insulation)

It is critical for these two parts to be physically touching and continuous around the entirety of a building's conditioned space. Special attention should be paid to critical junctures that are the most likely location for gaps and breaks between the air barrier and the insulation. For more information, visit the *Building Envelope fact sheet*.

## PLUMBING



The plumbing fixtures within our building convey access to hot and cold water where needed (kitchens, bathrooms, etc.). Having this access allows occupants comfort, sanitation and the ability to effortlessly complete their work. By optimizing the plumbing, fixtures and water systems within your building, you will both increase occupant comfort and productivity and reduce excessive consumption of this resource, consequently reducing the amount you pay each month in water bills.

Point-of-use electric water heaters are becoming common place in small commercial buildings. These small units effectively supply hot water where needed throughout your building without having to rely upon a central heating system. By having the source of hot water located near the point-of-use, users spend less time waiting for hot water, are more comfortable and waste less by not having to run cold water for long periods of time. By optimizing this

system, you can save on operation costs given that running a large central system costs substantially more to maintain. Additionally, implementing such water heating alternatives will have an impact upon the design and operation of your HVAC systems. By heating the water electrically, your building avoids the complication of designing specified combustion appliance zones and the pollutants they introduce into your space (carbon monoxide, etc.)

## LIGHTING



Many building occupants have learned the hard way that light bulbs emit heat. Our lighting systems generate and release heat energy into our building spaces.

Upgrading to the most recent lighting technologies results in less direct electricity consumption by the users, but by using more efficient light fixtures and advanced control systems, your building as a whole will see an increase in the efficiency of HVAC systems. By using lights that emit less heat, and by having them on less and not always at full light output, less heat will accumulate in your building space. This effectively reduces the load that space-conditioning equipment must cool during the summer months. For more information, refer to the *Lighting & Lighting Controls fact sheet*.

## HEATING, VENTILATION AND AIR CONDITIONING (HVAC)



The purpose of heating cooling and ventilation is to supply or remove heat from a building while providing fresh outside air to living spaces. The efficiency of the HVAC system is dependent on the amount of tightness of the pressure boundary and the heat resistance of the thermal boundary.

## INTERACTING SYSTEMS



How might your building's thermal envelope and HVAC systems interact? Many buildings have HVAC equipment located in attics that are not thermally sealed within the building envelope. In this situation, the efficiency of the air handling equipment will decrease as the machines work harder to heat or cool air appropriately for the conditioned space. A common solution to this scenario is to seal the building roof's lining and encapsulate the HVAC equipment within the thermal envelope, effectively improving occupant comfort and decreasing operation expenses.

The integrity of the building's thermal envelope depends upon the consistency of both an air barrier and thermal boundary. What effect on the building as a whole does this type of sealing have? Gaps in the air barrier significantly undermine the effectiveness of even the best installed insulation, therefore it is essential to tightly seal your building. With a tightly sealed building, contaminants within the interior environment can accumulate; thus it is essential to provide adequate make up air, which is outside air brought in to dilute and refresh the breathing air inside the building. With extra air being brought in from the outside, additional steps may need to be taken to maintain a healthy, comfortable and productive interior space. The air may need filtration or treatment for humidity to maintain air quality standards.

This is an example of how systems interact and when planning to upgrade one system, a person must consider the impact upon the building as a whole. All these things are manageable and it is essential to plan accordingly when improving upon the performance of your building.

## REFERENCES AND RESOURCES:

1. Krigger, J. et al. Residential Energy. Saturn Resource Mgmt. Inc. (2009)