2.0 Introduction to House-as-a-System

by HPSC Admin

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2.0 Introduction to House-as-a-System

Learning Objectives of this Section

- Define the concept of house-as-a-system, explain why it is relevant to retrofit contractors, and identify the contractor's role in it
- Define the components included in house-as-a-system (occupants, environment, mechanical systems, building envelope) and describe how they impact, or are impacted by, the flow of heat, air, and moisture

2.1 House-as-a-System Defined

What is it?

House-as-a-system (HAAS) is a building science concept that defines the house as a system of interacting, interrelated or interdependent components. These components can be organized into four inter-dependent categories: building envelope mechanical systems, occupants, and environment (see Figure 1). The HAAS approach to home energy retrofits considers the intended or unintended consequences that changing one component can have on other components, in terms of energy performance, air tightness, moisture levels, air quality, occupant comfort, health and safety, and home durability.

Why does it matter to retrofit contractors?

As explained above, the HAAS approach is essential to the health and comfort of the occupants, and the durability of the home – factors that can make or break customer satisfaction and even be the difference between a safe home and a dangerous one. Beyond the benefits to the home itself, the HAAS approach can also help maximize cost savings for the homeowner while reducing the carbon footprint of the home.

Since most home retrofit work will involve interaction with other building components, sometimes in ways that are not immediately obvious, it is important for contractors to understand how their work affects, and is affected by, other components of the home's system.

Common consequences of failing to retrofit with a HAAS approach include:

- Systems and products not performing to their anticipated efficiency standard or longevity
- Uncomfortable homes that are drafty, overheated, insufficiently heated, or humid
- Compromised occupant health and safety issues from exposure to radon, mould, poor indoor air quality or combustion spillage, or moisture
- Home durability and aesthetics issues from moisture, condensation or humidity
- High energy bills

This introductory course on HAAS helps contractors identify some of the many pitfalls of retrofits, find solutions to common home issues, and learn how to avoid causing issues themselves during their own work.

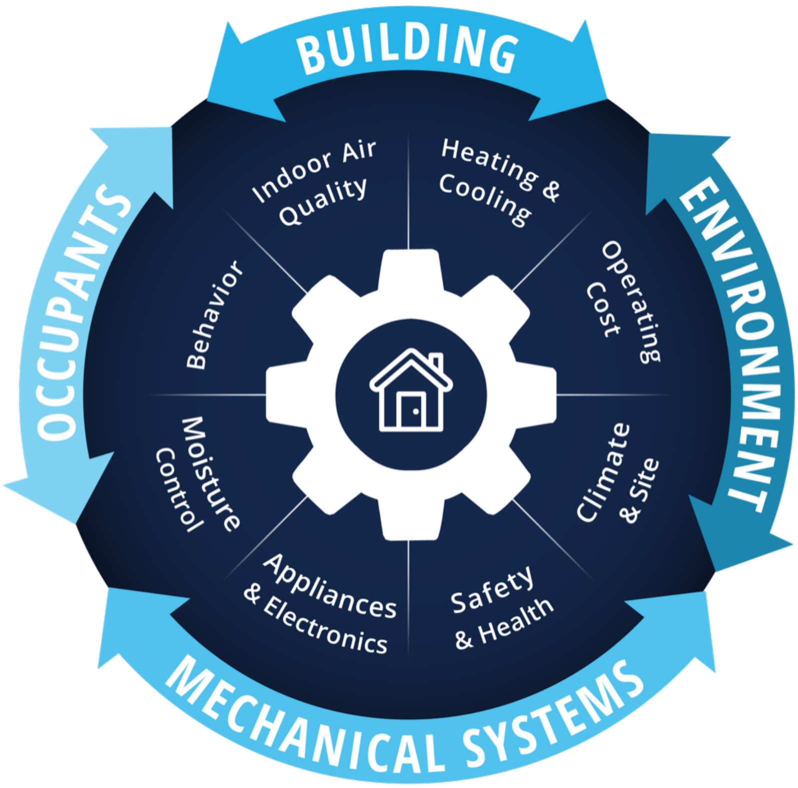

Figure 1 Components of a House

The Role of the Contractor

The role of the contractor in the HAAS approach is to

- Understand that there are various interacting and interrelated components to the houses' systems,
- Consider the impacts/consequences on the home's system when completing a single retrofit,
- Make an informed recommendation to the homeowner to complete multiple retrofits, as suitable, to fix existing issues or avoid potential unintended consequences from new retrofits, and
- Refer to additional contractors, as needed, to address pre-existing home issues or proactively take steps to avoid unintended consequences.

Two true-story examples are provided on the following pages to help imagine what this looks like in the real world.

Example 1

An HVAC contractor was speaking to a new customer about their home concerns and asked why they are interested in a new heating and air conditioning system. The customer explained that the bedrooms and basement are always too cold in the winter but that the living room gets too hot in the summer, and that their energy bills were high. They assumed this meant that their existing furnace and air conditioner were not working properly.

The contractor inspected the furnace and air conditioning system and confirmed that indeed, the units were older models which were inefficient and aging. The contractor also completed a quick assessment of the home and identified multiple other energy efficiency issues with the home that would impact homeowner comfort and energy bills: the home appeared to have a lot of air leakage, was under insulated in the attic, and had large single pane windows that were exposed to the sun for many hours of the day.

The contractor explained his assessment to the customer:

> "A new, more efficient, heating and cooling system will definitely help your comfort and energy bill issues but will likely not adequately solve all of the problems. I have a few options I can recommend for you. The issues you've been experiencing are also affected by the overall low efficiency of your home and all heating and cooling systems work better in homes that are more efficient. I want to make sure that you get the greatest possible benefits from your new system."

The contractor explained that there could be several options for assessing the home's energy retrofit needs:

- The contractor could complete a heat load calculation and size the heating system based on the existing heating needs of the home.
- The contractor could complete a heat load calculation and size the heating system based on retrofits that the homeowner plans to complete either retrofits before the heating system installation or before the next heating season started.
- The homeowner could hire an Energy Advisor to complete an EnerGuide Home Energy

Evaluation to confirm the contractor's observations about the efficiency of the home and recommend a detailed and prioritized list of retrofits specific to the home. The contractor could then return to complete work based on the findings of the evaluation.

The contractor walked the homeowner through their options and the benefits and risks of each:

Option A: If the homeowner wanted to forgo the additional retrofits or leave them for some time in the future, the contractor could proceed with sizing and installing a heating and cooling system for the current state of the home.

- Benefits:
  - The homeowner would save money upfront by not also tackling the insulation, windows, and air sealing retrofits.
  - The homeowner could still be able to access limited-time rebates for their heating and cooling system (depending on the type of system installed).
- Risks:
  - Due to the remaining energy efficiency issues with the home (e.g., air leakage or inadequate insulation), the homeowner might not experience the hoped-for energy savings and/or continue to experience the original discomfort issues.
  - A new cooling system would likely work more efficiently to keep them cool in the summer, but it would be masking the other major causes of overheating: the under-insulated attic and high solar gain from the large windows and sun exposure. This will affect energy savings and cause more wear and tear on the cooling system.
  - The HVAC contractor would be sizing the heating system for the current home (to ensure that it would sufficiently heat the home in the next winter). If the homeowners were to retrofit the insulation, windows, and air sealing in the future, the heating system may become oversized. Although variable speed heating systems are less prone to oversizing, the problems with oversized heating systems can include short cycling (turning off and on frequently), issues with occupant comfort, and possibly increased energy bills.
  - The homeowner may miss out on limited-time rebates for insulation and window upgrades.

Option B: If the homeowner wanted to complete additional retrofits prior to the heating and cooling system retrofit to address the root causes of their comfort issues, the contractor would either: proceed with sizing, commissioning, and balancing the systems to the anticipated heating and cooling load of the home after the anticipated retrofits; or schedule a follow-up assessment once the homeowner has completed the additional retrofits. The latter is recommended out of caution for changing timelines or product selection.

- Benefits:
  - The heating and cooling systems would be properly sized to the lower heating and cooling loads (which may result in lower upfront cost).
  - The homeowner can expect to experience lower energy bills and greatly increased comfort.
  - The homeowner could access limited-time rebates for their heating system, insulation, windows, and cooling system (depending on the type of products installed)
- Risk: The homeowners would be incurring additional upfront costs by completing multiple retrofits.

In this example, the contractor approached the job with a HAAS perspective and was able to adequately inform the homeowners about the benefits and risks of the various retrofit options. The contractor knew that the home would benefit from a new heating and cooling system and, importantly, also recognized that just replacing those systems was not going to fully address their customer's issues with comfort and expensive energy bills. They also helped the homeowner understand the risks and benefits to their home's durability. The contractor took a customer-first approach to maximize the homeowner's level of satisfaction and reduce the risk of a call-back for troubleshooting.

This was also an opportunity for the contractor to make referrals to other contractors (i.e., Energy Advisors, and insulation and window contractors), a benefit that is explained later in the course.

Example 2

A window contractor received a call from their customer a few months after project completion to complain that there is now excessive condensation on the inside of their windows when it is cold outside. The customer explained that this problem did not occur before the new windows were installed. The contractor, having since learned about the HAAS approach, understood that condensation is likely an unintended consequence of completing one retrofit (i.e., new energy efficient windows) without addressing others (e.g., ventilation, homeowner behaviour, etc.). The contractor explained the following to the homeowner:

- The windows installed were high performance double pane, low-energy, argon-filled windows. These windows provide warmer interior glass surfaces that are much less likely to have excessive condensation. The professional installation of the windows also created a more airtight and comfortable home.
- When warm, moist air encounters cooler surfaces, the excess moisture in the air condenses (i.e., turns into liquid water). That is because the cooled air next to the cool surface cannot hold as much moisture as the warmer surrounding air. When there is a lot of moisture in the air in a home, it may create condensation on the windows.

The contractor then explained how everyday activities in a home can also contribute excess indoor moisture in the home and provided examples. They explained how, similar to the importance of proper programming of their thermostat to manage temperature levels, proper operation of other home systems can help manage moisture levels. In this case, the contractor was able to determine that the homeowner's kitchen and bathroom ventilation fans were old, loud, and not working effectively and as a result, the occupants had recently stopped regularly using them during cooking or after bathing. The occupants had also started drying laundry indoors during winter months. Before the new window installation, the home was less airtight allowing the excess moisture in the home created by the occupant activities to leak out around the old windows along with the heated air. After the window installation the occupants had changed their behaviours and had started creating more moisture in the home by not using their ventilation systems and drying laundry indoors.

With this information the contractor recommended:

- That the homeowner contacts an HVAC contractor to either install high efficiency, quiet, and effective bathroom and kitchen ventilation systems with a humidistat and/or to consider a balanced heat recovery ventilation system
- That when the occupants hang laundry inside, to do so in the bathroom with the new high efficiency bathroom fan left operating continuously while it dries or adding a dehumidifier to the room where they hang laundry.

In this example, the contractor identified an unintended consequence of their single retrofit and educated the homeowner on a solution by applying a HAAS perspective. This shows how a retrofit to one component of the house's system (e.g., building envelope: new windows and air sealing) can result in an issue that is actually caused by different components (e.g., mechanical systems: inefficient ventilation; occupants: behaviour). This was also an opportunity for the contractor to make referrals to another contractor (i.e., HVAC, ventilation), a benefit that is explained later in the course.

2.2 Building Science Basics and Components of the House System

To understand how the house operates as a system and how to make appropriate recommendations to your customers, it is useful for contractors to understand the building science of how heat, air, and moisture flow in a home, as well as how they interact with the envelope. The HPSC has also developed sector-specific training which complements these building science principles and explores them further for specific trades. For more in-depth information, you can also visit the resources section of this course.

Building Science Basics

In the following section, italicized text denotes content from borrowed with permission from Natural Resources Canada (Keeping The Heat In - Section 2: How your house works" Natural Resources Canada, [2021]. Reproduced with the permission of the Department of Natural Resources, 2021).

Heat Flow

Heat flow between the interior and exterior of a home affects the comfort and safety of occupants. Most people are comfortable and safe in a home when the temperature range is between 18°C (65°F) to 24°C (75°F) in winter and 20°C (68°F) to 27°C (80°F) in summer.

Heat will move wherever there is a difference in temperature. Many people believe that because hot air rises, most heat loss will be through the ceiling. This is not necessarily so. Heat moves in any direction - up, down or sideways - as long as it is moving from a warm spot to a colder one. In a home, the most common ways for heat to flow in or out is through direct contact or air movement between the outside of the home and inside (e.g., uninsulated wall space)[1]*.*

Air Flow

Air flow between the interior and exterior of a home affects the comfort, safety, and health of occupants.

Under winter conditions, inside air is forced out through the [upper portions of the] *building envelope, carrying heat and moisture, while incoming replacement air brings drafts and dry winter air* [from the lower portions of the home]. *For air to move from one side of the building envelope to the other, there must be holes in the envelope and a difference in air pressure between the inside and outside. The difference in air pressure can result from any combination of wind, a temperature difference creating a stack effect in the home, exhaust of combustion appliances, or exhaust fans*[2]*.*

Moisture flow

Moisture flow between the interior and exterior of a home affects the comfort, safety, and health of occupants. It can also affect the durability of the home's structure. Health Canada recommends that homes' relative humidity be kept between 30 and 55%[3] for occupants' health and comfort.

Water, in all of its states, is the major cause of damage to a building and affects its durability. Moisture can cause concrete to crumble, wood to rot and paint to peel; it can also damage plaster, ruin carpets and encourage mould growth. Moisture can appear as a solid (ice), a liquid or a gas (water vapour). It can originate from the outside of a building as surface runoff, ground water, ice, snow, rain or fog. It can also originate from the inside as water vapour produced by the occupants and their activities like washing, cleaning and cooking, and direct sources like houseplants, aquariums and humidifiers. Moisture can also come from plumbing leaks, open sumps, and damp or leaky foundations [as well as cooking, aquariums, plants, pets, bathing, and human activities such as breathing and sweating]*. Water vapour becomes a problem when it condenses into liquid water. Condensation on windows is a typical example. When air contacts a cold window, the air loses heat. The air can then no longer hold all the water vapour and some condenses out onto the surface of the window. If the window is extremely cold, the condensation may appear as frost. Condensation is more likely to occur in humid areas such as the kitchen, bathroom, and some basements and crawl spaces or in areas where window coverings* [e.g., blinds, curtains, shutters] *are used that insulate and decrease the temperature of the surface of the glazing*[4].

Heat, air, and moisture flow can affect or be affected by one another and all three affect, and are affected by, the different components of a house's system.

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[1] "Keeping The Heat In - Section 2: How your house works" Natural Resources Canada, [2021]. Reproduced with the permission of the Department of Natural Resources, 2021. URL: https://www.nrcan.gc.ca/energy-efficiency/homes/make-your-home-more-energy-efficient/keeping-the-heat/section-2-how-your-house-works/15630

[2] "Moisture Problems" Natural Resources Canada, [2007]. URL: 2PP_eng.qxd (publications.gc.ca)

[3] "Keeping The Heat In - Section 2: How your house works" Natural Resources Canada, [2021]. Reproduced with the permission of the Department of Natural Resources, 2021. URL: https://www.nrcan.gc.ca/energy-efficiency/homes/make-your-home-more-energy-efficient/keeping-the-heat/section-2-how-your-house-works/15630

[4] "Keeping The Heat In - Section 2: How your house works" Natural Resources Canada, [2021]. Reproduced with the permission of the Department of Natural Resources, 2021. URL: https://www.nrcan.gc.ca/energy-efficiency/homes/make-your-home-more-energy-efficient/keeping-the-heat/section-2-how-your-house-works/15630

Components of the House System

The four main components of a house's system are shown in Figure 2 and elaborated on in the following pages.

1. Building Envelope

2. Mechanical Systems
3. Occupants
4. Environment

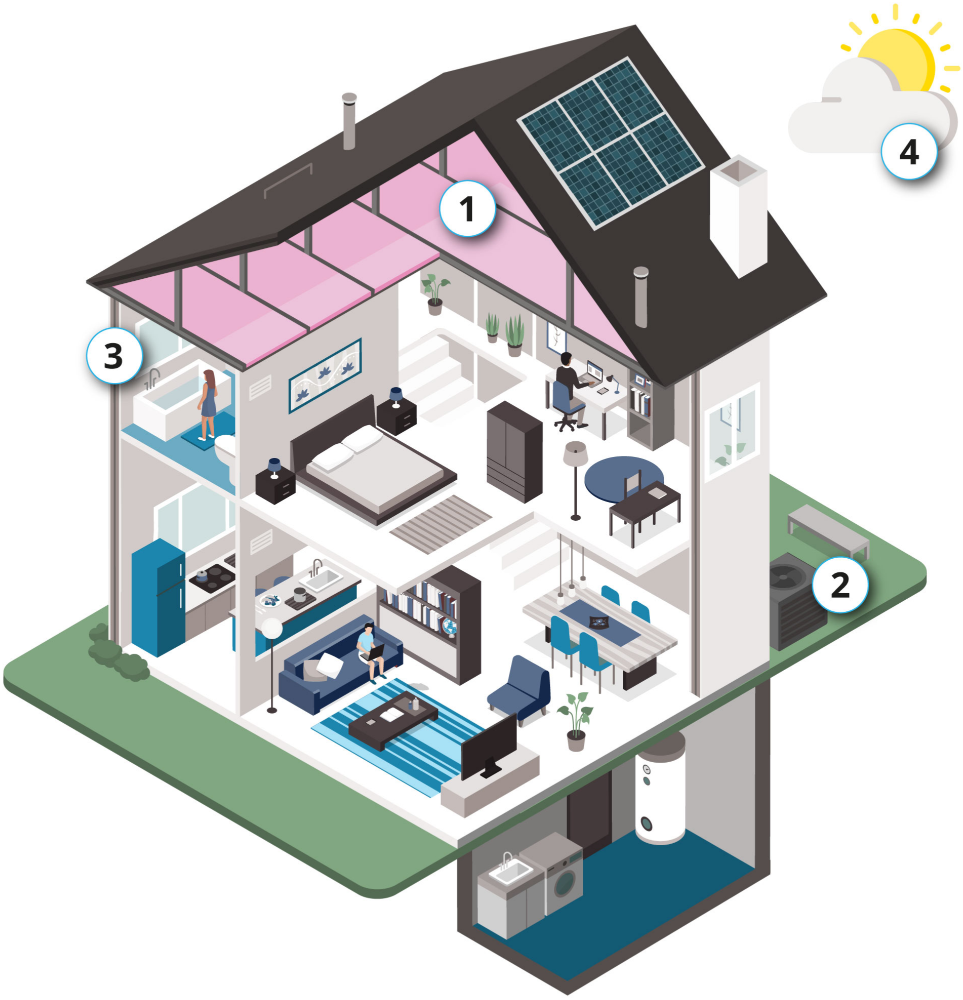

Figure 2 Components of a House

#1 Building Envelope

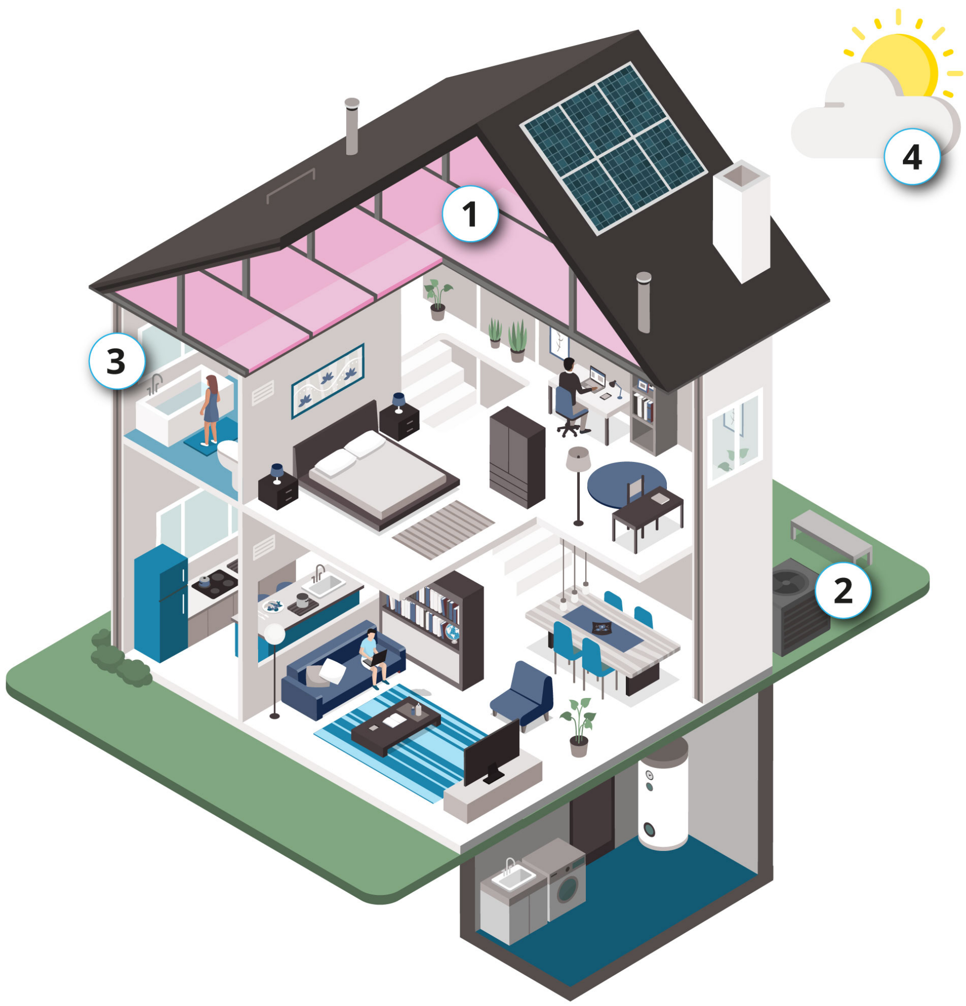

Figure 2 Components of a House

BUILDING ENVELOPE[3]

The building envelope is the shell of the house, the physical barrier that separates the indoor heated and cooled area (conditioned space) from the outdoor elements. The building envelope aids in the maintenance of the indoor environment by controlling the flow of heat, air and moisture between the inside and the outdoors. The building envelope includes the:

- Exterior walls and their components (i.e., air barrier, vapour barrier, water resistance barrier, insulation, framing, siding, etc.)
- Foundation (i.e., basement or crawl space walls and floor)
- Roof (i.e. flashing, rain gutters, venting, solid decking, shingles or other roofing material, etc.)
- Windows, doors, skylights

The more energy efficient and airtight the building envelope is the less energy is needed to replace heat loss in the winter and reduce overheating in the summer.

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[3]"Keeping The Heat In - Section 2: How your house works" Natural Resources Canada, [2021]. URL: https://www.nrcan.gc.ca/energy-efficiency/homes/make-your-home-more-energy-efficient/keeping-the-heat/section-2-how-your-house-works/15630

#2 Mechanical Systems

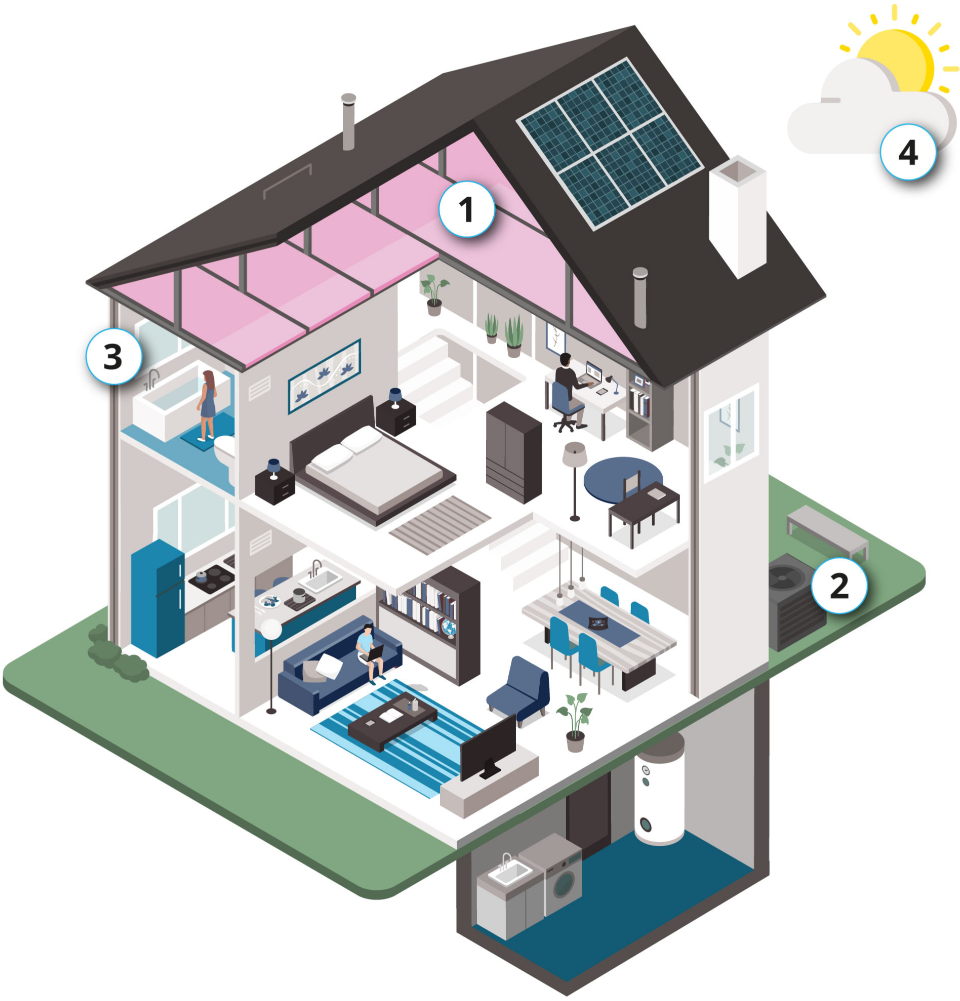

Figure 2 Components of a House

MECHANICAL SYSTEMS

Mechanical systems in a home include:

- Space heating systems (e.g., heat pumps, furnaces, boilers, etc.)
- Space cooling systems (e.g., heat pumps, air conditioner)
- Ventilation systems (e.g., kitchen and bathroom fans, make-up fans and supply fans, range hoods, heat recovery ventilators)
- Plumbing systems (e.g., hot water heating systems)

The HAAS approach promotes proper sizing of the heating, cooling, and ventilation systems that are appropriate for the level of airtightness, size, efficiency, and environment of the home. Heating and cooling systems that are appropriately sized, installed, commissioned, balanced, controlled, and maintained' contribute to reliable home comfort and affordable energy bills. Ventilation systems that are correctly sized and installed help improve air circulation, maintain appropriate humidity levels, remove indoor pollutants, and increase the comfort, health, safety, and energy-efficiency of a home.

The efficiency of the building envelope and mechanical systems are closely linked and their relationships plays a large role in determining the overall efficiency of the home. The higher the efficiency of the building envelope, the less energy is needed to be consumed by mechanical equipment to heat or cool the home. Paying particular attention to these two HAAS components will result in energy savings, improved occupant comfort, and home durability.

#3 Occupants

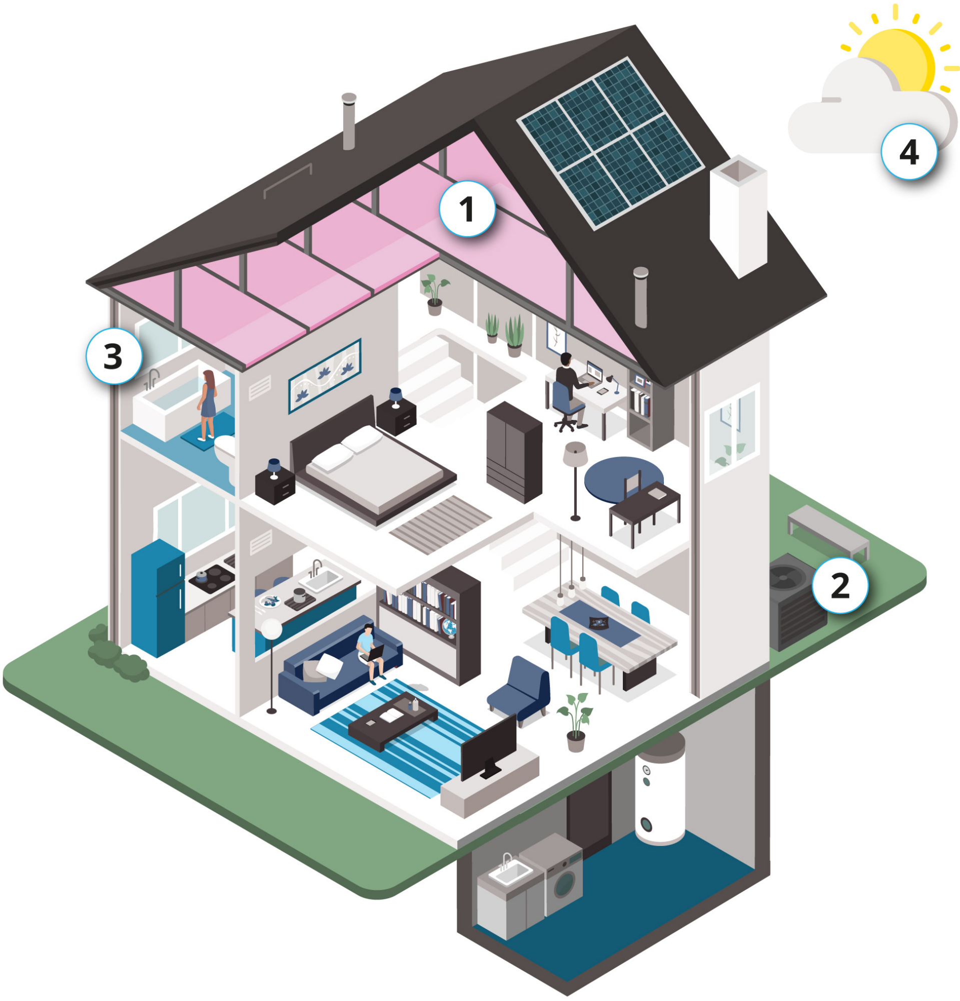

Figure 2 Components of a House

OCCUPANTS

Occupant comfort is one of the most common reasons why clients seek the business of retrofit contactors. Ironically, many occupants may not realize that they themselves are a part of the home's system, and that their actions impact the efficiency of the home and their overall comfort. This is due not only to their physical presence in the home, but also because of the effects of their activities and behaviours. Examples include:

- Activities like washing, bathing, cooking and cleaning introduce moisture into the home
- Items such as houseplants, aquariums, and humidifiers also introduce moisture into the home
- Using, or not using, exhaust fans or opening and closing windows, affects the moisture levels and, therefore, efficiency of the home
- Programing and scheduling maintenance of heating or cooling systems affect their performance

It is important then to understand how your customers' activities factor into the house system as they can affect, and be affected, by other components. Explaining HAAS to your customer and interviewing them on their activities and behaviours can assist you in factoring this component into your recommendations. This also highlights the important role contractors have in educating their customers to understand how to use their products and services, and how to avoid unintended consequences from occupant activity. The previously provided example of homeowners drying laundry indoors and not using their ventilation systems is an example of occupant behaviour that impacts the home.

#4 Environment

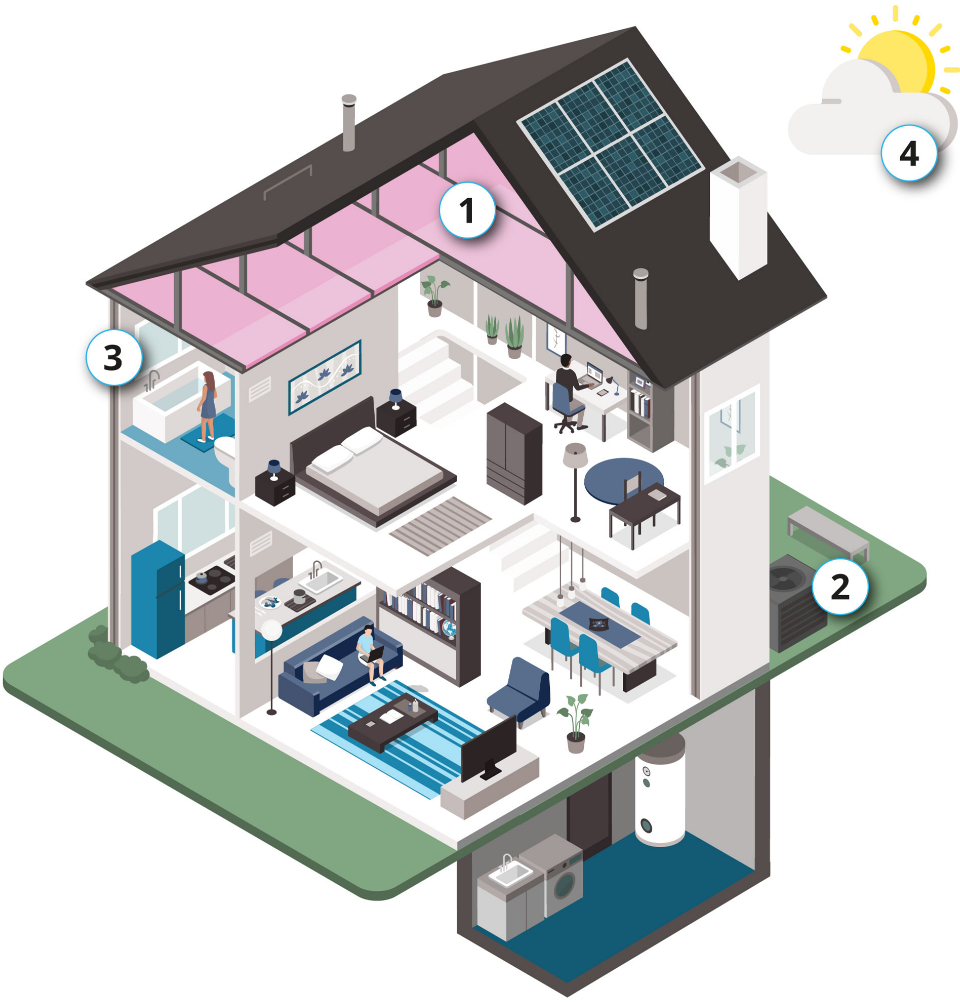

Figure 2 Components of a House

Environment

The environment is another important component of HAAS, especially in B.C., where different climates, micro-climates, and topographies make it impossible to suggest a one size fits all approach. The environment and location of a home can impact the efficiency and durability of the home and the comfort and safety of the occupants. Environmental factors to consider include:

Local Climate

The local climate will determine a home's heating and cooling requirements and potentially the home's susceptibility to overheating or not being able maintain comfortable temperatures in the winter. Heating degree days (HDD) are a measure of heating demand based on the difference between the average daily outdoor temperature and 18°C. Cumulative totals for the month or heating season are used to estimate heating needs. Although it is important to have right-sized and efficient heating systems in all locations of the province, in locations with a higher number of HDD, retrofitting the building envelope (insulation, windows, and air sealing) and having a right-sized and efficient heating system is even more important to minimize the operation costs and keep occupants comfortable

Figure 3 shows the different heating degree days, meaning which areas of the province experience colder temperatures and will therefore require more protection from the cold through more efficient new construction or retrofits that increase the energy efficiency of the home. Each zone represents an area that experiences a similar range of HDD. For example, a home in zone 7A (e.g., in Dawson Creek) may require twice as much energy to heat than one in zone 5 (e.g., in Kamloops)[4].

The local climate also determines the likelihood of high winds and extreme temperatures, trends in humidity levels, and the different forms, frequency, and amounts of precipitation.

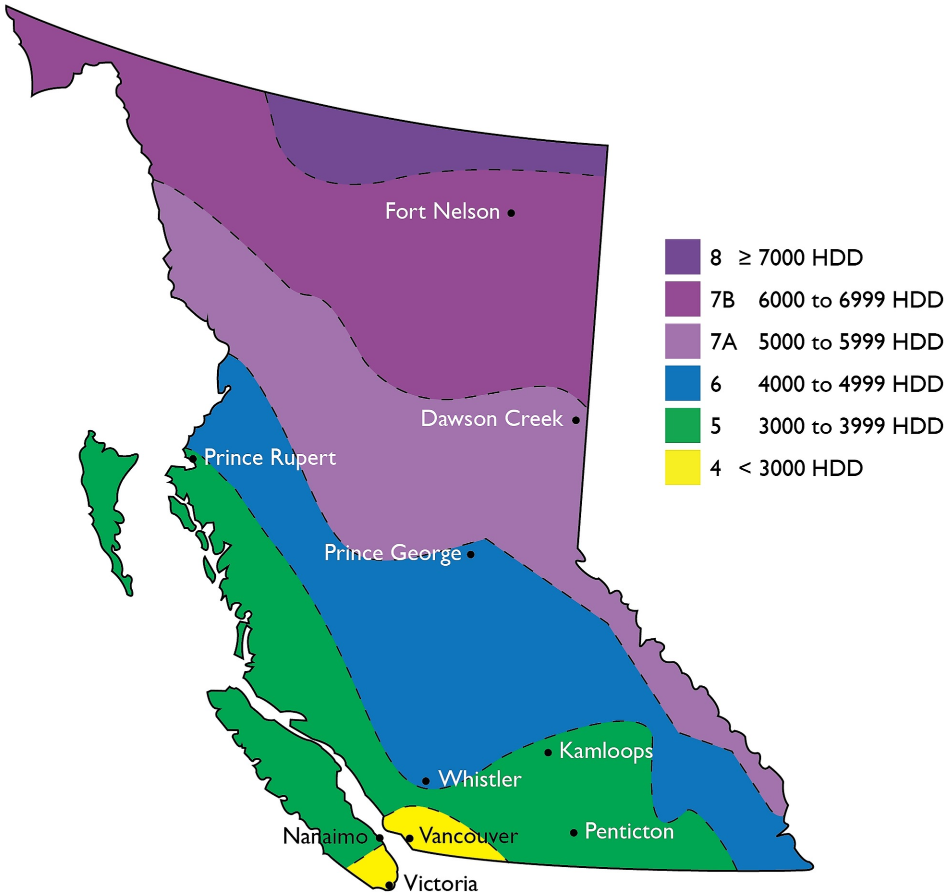

Figure 3 Heating Degree Days (HDD) in BC[5]

While it may seem obvious that varying climates will impact homes differently, it is also true that two homes in the same climate and city can experience diverse heating and cooling needs. The next two factors explain why.

The home's orientation to the sun

This affects the home's heating load. More exposure to sun, for example unshaded homes and homes with large and/or lots of windows (especially south- and west-facing), can decrease heating loads and increase occupant comfort in the winter but can also increase cooling loads and decrease occupant comfort in the summer. Conversely, less exposure to sun, for example shaded homes and/or homes with smaller and/or less windows (especially south- and west-facing), can increase heating loads and decrease homeowner comfort in the winter but can also decrease cooling loads and increase occupant comfort in the summer. Keep in mind that changes to the environment around the home can sometimes influence this. For example, without modifying a house - planting a tree can increase shade or removing trees can increase sun exposure.

The home's exposure to other environmental factors

This can affect various aspects of the home's performance. Examples include the home's exposure to:

- wind - is the home protected from strong winds by trees or other shelters?
- water and moisture - does the property experience flooding or is it open to wind-driven rain?
- local air quality - is the home located in an area of vehicle exhaust, allergens, wood smoke or other pollutants?

Climate change

The changing climate in BC affects the need for homes to be future-proofed, meaning they can meet the needs of homeowners both now and in the future when regional patterns of weather are anticipated to change. For example:

- Rising temperatures between spring and fall will increase the risk of homes overheating. Home energy retrofits can prevent overheating.
- Increases in extreme weather events may lead to higher numbers of power outages. Higher home efficiency can allow homeowners to maintain comfortable indoor temperatures for longer during power outages.
- Increased frequency and intensity of heavy-rain events will result in homeowners needing to weatherproof their homes, which is complementary to other energy retrofits.
- Continued, and possibly increasing, instances of forest fires will mean ongoing issues with poor air quality. This highlights the increased importance of controlling air flow in and out of a home through air sealing and ventilation, providing opportunities to manage or filter harmful particulates.

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[4]" What is my Climate Zone" CleanBC Better Homes [2019]. URL: https://betterhomesbc.ca/faqs/what-is-my-climate-zone/

[5] "Heating Degree Days in BC" RDH Building Science. URL: https://www.rdh.com/Shared with permission.