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An Overview of Internal Cooling Load Components and Dynamics in HAP

HAP

HOURLY ANALYSIS PROGRAM

This article will discuss and illustrate fundamental concepts of how internal loads, such as lighting, miscellaneous electric equipment and people sensible loads, are accounted for in HAP. The scope here will be limited to the discussion of internal sensible loads-only, since latent loads are really a separate topic altogether. We will discuss the current HAP, v5.11, as well as provide an overview of the way the upcoming HAP v6.0 program will model internal loads using the Heat Balance Method, *which will be discussed in more detail in a future* EXchange *article.*

To simplify the discussion, we will omit the discussion of conduction through the building elements (walls, fenestration, floors & roofs), as well as solar heat gains entering the space through windows, and instead focus only on the internal load effects. Those other factors will be covered in detail in a full Heat Balance Method *discussion to be published in a future* EXchange *article.*

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Internal heat sources emit heat into the space by ***radiation*** and ***convection***. The most important concept to understand, with regards to internal load heat gains, is that all loads are both ***instantaneous*** and ***dynamic***; that is the convective component of the heat gain from an internal load source, such as a lighting fixture, is immediately released into the space while the radiative component of the heat from the light is also emitted and stored in the thermal mass of the space then released over time (see Figure 3, page 3).

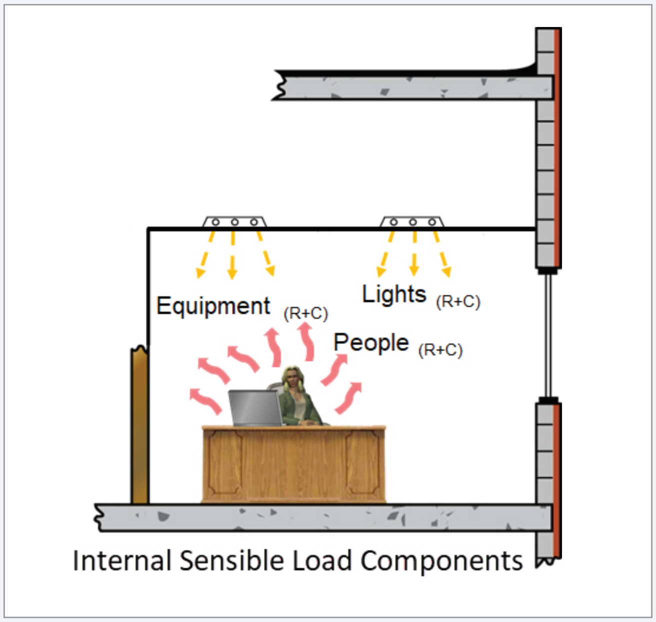

Figure 1. Internal Sensible Cooling Load Components (Radiative + Conductive)

Typical internal sensible cooling load components are shown in Figure 1 above (lights + people + electric equipment). So, while the convective portion of the heat gain becomes an instantaneous space cooling load, the radiative component of the heat gain is comprised of infrared radiation, which contacts the walls, floor, ceiling and furnishings (furniture) and is temporarily stored in the mass of the space. This stored heat is then released over time, much like a capacitor stores and releases energy over time.

Therefore, from a load calculation perspective, for example, say a space has 1.0 kW of lighting power present, when the space sensible cooling load is calculated, a portion of this energy is immediately released into the space as a convective load, while the remaining radiant energy is stored in the thermal mass of the space and released over-time. So, this means the normal conversion (1.0 kW = 3,412 BTU) sensible heat gain does not apply for loads with radiant components. The amount of radiative/convective split of heat gain from a lighting fixture depends on the type of fixture (recessed, free-hanging or vented), the type of light bulb, whether or not there is a ceiling space (plenum) above the space and if the plenum is used for an open return air chase or is the return air ducted?

Electric equipment (plug loads) and people internal heat gains also have both a convective and a radiant component, since they are warmer than the surrounding air, walls, floor, ceiling and furnishings.

HAP v5.11

HAP 5.11 utilizes the ASHRAE *Transfer Function Method* (TFM), which is a simplified version of the *Heat Balance Method.* In the TFM calculations there is no differentiation between light bulb types. In the next section we discuss how HAP v6.0 models lighting using the *Heat Balance Method,* which is slightly more complex than in HAP 5.11. Each of the three internal load types is discussed separately below.

Lights: There are three different lighting fixture types modeled in HAP v5.11. The type of lighting fixture used influences the relative sizes of the convective and radiative components and the way in which radiative heat gains are distributed in the space, which are illustrated in Figure 2 (on page 3).

A ***recessed, unvented*** fixture radiates energy only to the walls and floor in a space. A ***recessed, vented fixture*** has return air flowing through the fixture into the ceiling plenum return, therefore has higher rates of convective heat transfer to the ceiling plenum space than an unvented fixture. Further, a ***free-hanging*** fixture is completely exposed to room air and radiates heat to all room surfaces including the ceiling. If task lighting is used, the fixture is assumed to be the same as a free-hanging fixture. There is a single radiant heat model in HAP v5.11 for all light bulb types (incandescent, fluorescent & LED). In comparison, HAP v6.0 models specific light bulb types, which is discussed in more detail later.

As mentioned previously, the radiant component of the lighting fixture output is stored in the thermal mass of

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the building, to be released later over time by convection, while the convective component of the lighting heat becomes an instantaneous space cooling load. This is illustrated in Figure 3.

Figure 3 illustrates sample load profiles (blue, red and black plots) for each of the three lighting fixture types for a scenario in which a 5,000 BTU/h lighting heat gain (not load) occurs for a duration of nine hours starting at 0700 and continuing through 1600 hrs. The actual cooling loads are smaller than the heat gains while the lights are on. This is because a large portion of the heat gain is thermal radiation. This radiant heat is absorbed by the mass of the floor, walls and furnishings in the room, stored in the mass and then released by convection to the room air where it then becomes a cooling load. This process causes a delay between the time a heat gain occurs and the time its full effects as a cooling load appear.In general, the amount of delay depends on the nature of the heat gain and the building construction. For example, heavier construction absorbs and holds heat longer than light construction.

Of all three fixture types, the recessed, unvented fixture (blue rectangle plot) exhibits the lowest amount of direct heat gain to the space. During the first hour, 0700, of the 5,000 BTU/h heat gain approximately 3,300 BTU/h becomes an instantaneous space load by convection, while the remaining 1,700 BTU/h is either convected into the ceiling space above or into the room directly. The remaining load is radiant energy, which is stored in the room mass and is released over time. Also, note that cooling loads continue

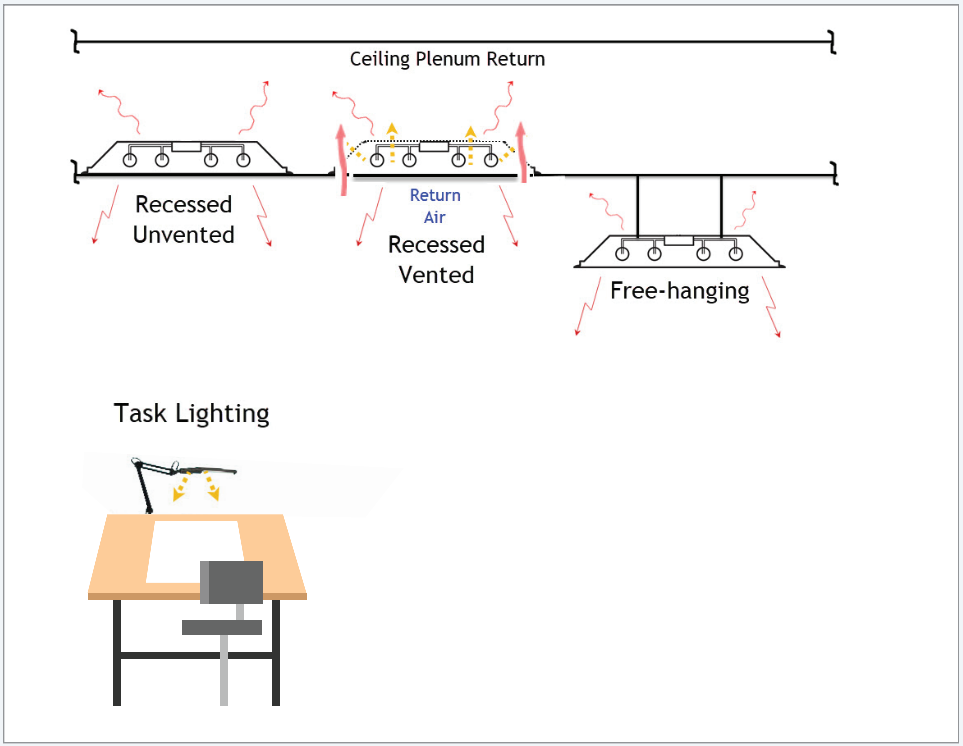

Figure 2. Lighting Fixture Types Modeled in HAP v5.11

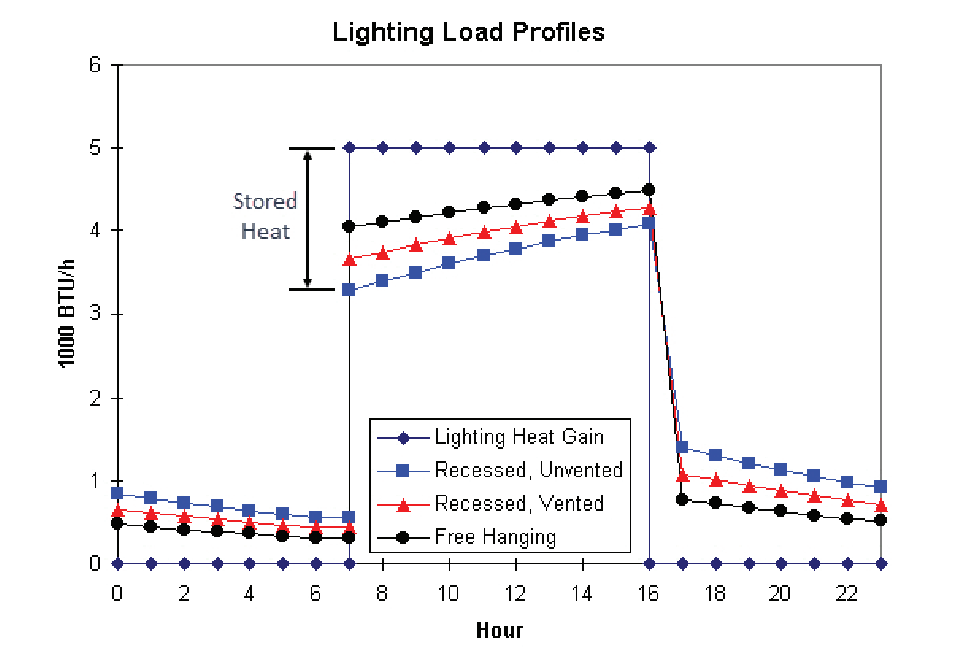

Figure 3. Lighting Load Profiles for Lighting Fixture Types Modeled in HAP v5.11

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long after lights are turned off at 1600 hrs. Again, this is due to the radiant heat and the heat storage effects. When the lights are turned off, some radiated heat from the previous nine hours is still stored in the room mass and continues to be convected to the room air over time. This build-up of heat in the room can sometimes result in a pull-down load first thing the next morning.

This is also why scheduled lights, where they are on for say 8-10 hrs per day then off the remainder of the time, can result in a condition whereby the peak lighting loads never reach 100% of the heat gain value over the full 24 hr day, in this case 5,000 BTU/h. The only way that peak lighting loads ever reach the lighting heat gain numerical values is when you utilize a 100% "on" lighting schedule for all hours. With continuous lights (on 24/7) the room mass eventually reaches equilibrium such that the heat gains equal the lighting loads.

Thus, this example illustrates that the Transfer Function Method models the transient build-up and discharge of heat in a building. This is an important consideration when trying to accurately estimate loads.

Electric Equipment: Typical electric equipment loads (aka plug loads) include computers, printers, copy machines, cash registers, kitchen appliances and industrial machinery. Like lights, the sensible load resulting from this equipment heat gain is calculated using separate convective and radiative components. The convective and radiative fractions of electric equipment heat gain vary with the type of equipment being evaluated, however for simplification HAP v5.11 assumes that ***75% is convective and 25% is radiative.*** These assumptions are appropriate for common types of office equipment and are based on research data published in the ASHRAE Handbook of Fundamentals.

The 75% convective fraction of the heat gain becomes a load immediately. The load due to the 25% radiative component is calculated using the ASHRAE room transfer function equation and appropriate coefficients. Figure 4 below shows equipment heat gain and total load profiles for a scenario in which a 5,000 BTU/h equipment heat gain occurs for a duration of 10 hours. Just like with the lighting example, the electric equipment load profile differs from the heat gain profile because a portion of the heat gain is radiative (stored in thermal mass) causing a time lag between the time the heat gain occurs and the time it is converted by convection into a space cooling load.

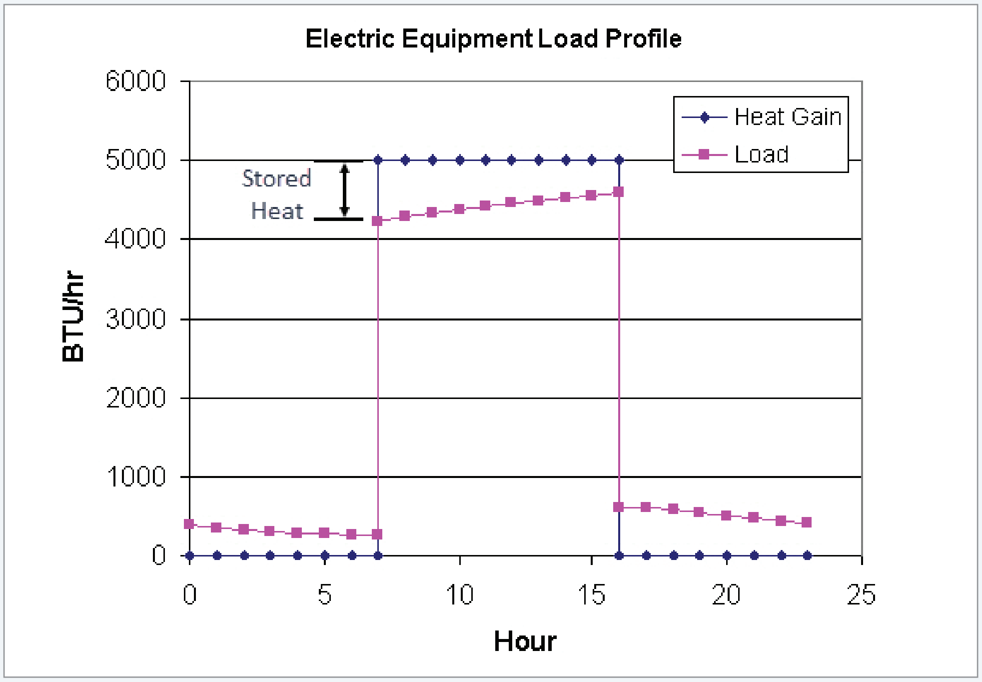

Figure 4. Lighting Load Profiles for Lighting Fixture Types Modeled in HAP v5.11

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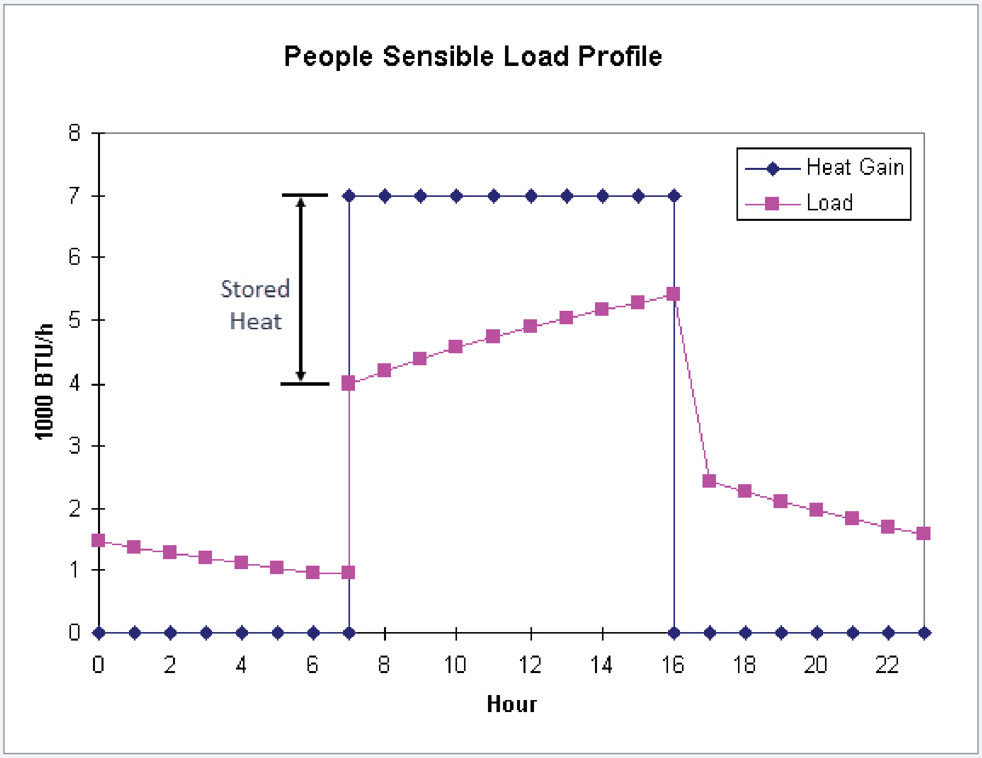

Figure 5. People Sensible Load Profile for HAP v5.11

Occupants: Cooling loads from people are the result of sensible and latent heat gain from people occupying a building. The latent component of the heat gain involves the transfer of moisture to room air and is thus immediately converted to a room latent load. For simplicity, latent loads are neglected in this discussion. The sensible component of the heat gain involves separate convective and radiative components and is evaluated using transfer function procedures. Using ASHRAE recommendations, the HAP program assumes an average value of ***30% convection and 70% radiation for people sensible loads.***

The 30% convective fraction of the heat gain becomes a load immediately. The load due to the 70% radiative component is calculated using the ASHRAE room transfer function equation and the appropriate coefficients. Figure 5 below shows people sensible heat gain and total sensible load profiles for a scenario in which a 7000 BTU/h sensible heat gain occurs for a duration of 10 hours. The large separation between heat gain and load profiles in this scenario is due to the fact that the majority of the heat gain is radiative and is therefore converted to load more slowly than if it was convective. At first this may seem counter-intuitive that people sensible loads are mostly radiative. But this is because people's bodies are warmer than their surroundings so they easily radiate heat to the colder room surfaces. If you have ever sat next to a cold window or wall and become chilled, even though the room temperature is warm, or if you have ever sat beneath a radiant heater outdoors in winter and felt comfortable even though the air temperature is cold then you have experienced the effects of radiant heat exchange.

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HAP v6.0

HAP v6.0 will utilize the ASHRAE ***Heat Balance (HB)*** Method, which uses pure physics and allows us to more accurately model the interaction of all heat flows for all surfaces in the building without requiring additional calculation times. While the Transfer Function Method, which is used in previous versions of HAP, has certainly served us well for many years (and will continue to be used in our industry) the HB method offers additional modeling capabilities. For example, building geometry and heat transfer surfaces (walls, ceilings, floors) and their relative positioning to each other involves 3D modeling. For the first time HAP v6.0 will know the relative positions of all building surfaces to each other and will allow more precise modeling of these relative heat flows from surface to surface. So even if one space is warmer than an adjacent space, HAP v6.0 will automatically account for this conductive load across the common (partition) wall connecting the two adjacent spaces. So, what this means is the use of partition walls, floors and ceilings that were often modeled in HAP v5.11 and earlier versions will no longer be necessary. This opens up some exciting new capabilities. As mentioned previously, a future *EXchange* article will cover the HB method extensively. We will only touch on a few fundamental HB concepts here, primarily as they pertain to internal sensible heat gains.

A Heat Balance cooling load calculation requires that a surface-by-surface conductive, convective and radiative heat balance calculation be solved for each surface in the room, plus a convective heat balance between all surfaces and the room air. Conductive heat transfer occurs across a surface whenever a temperature difference exists on both sides. One example of conductive heat transfer is across an outside wall to the inside, as illustrated in Figure 7 below where the outdoor temperature is 90F and the inside wall surface temperature is 82F.

As you can probably imagine, for a typical building with hundreds or even thousands of wall, floor and ceiling surfaces this involves potentially millions of calculations and significant computing power. Until fairly recently the HB method was impractical to use on most PCs. The advent of faster, more powerful computing hardware the past few years has made the HB method practical and feasible today on PCs, and without sacrificing any calculation time compared to simplified procedures used for many years, such as the ***Transfer Function Method.***

The Heat Balance Method involves modeling four interactive heat transfer components:

1. conduction through the building elements (both outside envelope and inside walls, floors, ceilings, partitions, etc.)
2. shortwave (SW) radiation absorption and reflectance
3. longwave (LW) radiant interchange between all surfaces
4. convection from all surfaces to the room air

So, what is SW and LW radiation? Figure 6 below illustrates the electromagnetic spectrum. Beginning with gamma rays on the left end, which have the smallest wavelengths, to radio waves on the other end, which have the longest wavelengths. Shortwave (SW) radiation begins within the upper ultraviolet (UV) spectrum (~0.1 µm) and encompasses the visible light (0.4-0.8 µm) spectrum and lower region of the infrared spectrum. Longwave (LW) radiation falls within the mid to upper (5-50 µm) infrared region of the spectrum, as indicated.

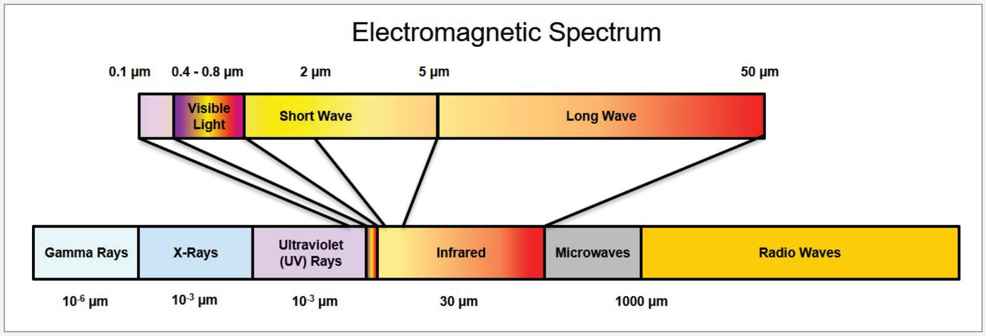

Figure 6. Electromagnetic Spectrum

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Incident shortwave (SW) radiation comes from the solar radiation entering the room through windows plus emittance from internal sources such as lights. The longwave (LW) radiation interchange includes the absorption and emittance of low temperature radiation sources, such as all room surfaces, electric equipment, and people. SW radiation contains a lot of energy. Solar energy enters earth's atmosphere as SW radiation in the form of UV rays (the same UV rays that can give us sunburn), visible light and infrared radiation. The sun emits SW radiation due to it being extremely hot and having an enormous thermal mass. Once this SW radiation reaches the earth's atmosphere, clouds and the earth's surface absorb all of this solar energy. This causes the ground to heat-up and it then re-emits energy as LW radiation in the form of infrared rays. The earth emits LW radiation because earth is cooler than the sun and has less thermal energy available to give off. Especially at night, when there are no clouds, the earth radiates a lot of LW radiation to the atmosphere, which is much colder, resulting in what is called the radiational cooling effect.

Figure 7 below illustrates how the LW radiative loads interact with all surfaces in the room and with the room air. Remember the fundamental law of heat transfer: heat always moves from a warmer surface to a colder surface. The inside surface of the outside wall is at 82F due to conduction from the warmer 90F ambient conditions. So, this 82F interior wall surface radiates LW radiation to the other room surfaces (ceiling, floor and interior wall), which have colder surface temperatures. The interior wall is 79F, which is warmer than the ceiling and floor so it also radiates LW energy to those colder surfaces. The ceiling is 78F, slightly warmer than the floor so it too radiates a small amount of LW radiation to the colder floor, which is at 77F. Finally, since the room air is 76F and all wall surfaces are warmer than the room air, therefore they all transfer heat by convection to the room air mass.

If there was a window in the outside wall with solar energy shining through into the space, we would also have additional SW radiative loads present; in this case we have simplified the example to not include solar effects, only internal loads.

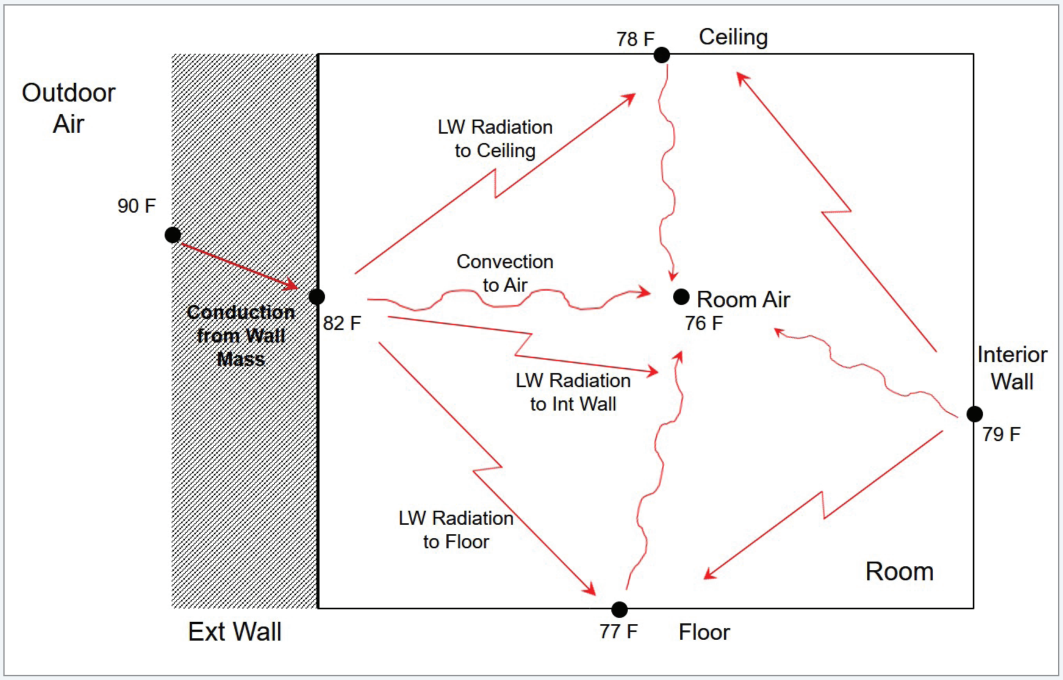

Figure 7. Heat Balance of Wall Surfaces and Room Air

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Next let's look at the internal load components of people and electric equipment to see how they interact in the room. People and electric equipment emit LW radiation to all surfaces in the room, as illustrated in Figure 8 below. People and electric equipment both convect heat directly to the room, however this happens at different rates. In HAP v6.0 occupant heat gains are assumed to be **70% radiant, 30% convective heat**. Heat gains from electric equipment are assumed to be **75% convective and 25% radiant heat**. These assumptions are exactly the same as those used in HAP v5.11.

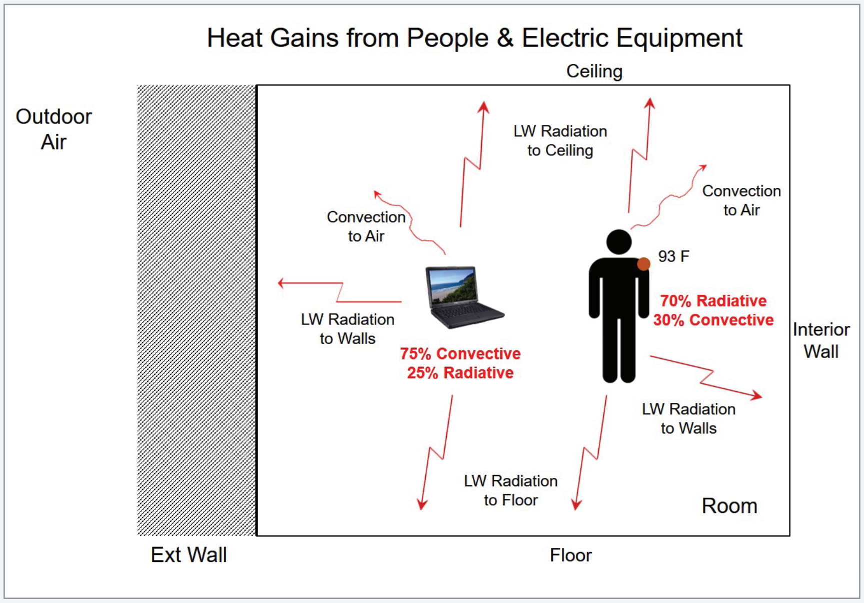

Figure 8. Heat Gain from Occupants & Electric Equipment

Finally, we will discuss lighting heat gains. Lighting heat gain calculations are a bit more complex in HAP v6.0 than in previous versions of HAP. HAP v6.0 models lighting heat gains more precisely based on several factors:

1. Fixture types:
    - a. fluorescent, recessed without lens, unvented
    - b. fluorescent, recessed without lens, vented
    - c. fluorescent, recessed with lens, unvented
    - d. fluorescent, recessed with lens, vented
    - e. fluorescent, downlight
    - f. fluorescent, free-hanging
    - g. free-hanging
    - h. LED, recessed, unvented
    - i. LED, downlight
    - j. LED, free-hanging
    - k. Incandescent, downlight
    - l. Incandescent, free-hanging
2. With ceiling space above
3. Without ceiling space above
4. Ducted return air
5. Ceiling plenum return air

These combinations of variables result in 33 different heat gain calculations. Specific radiant/convective splits for heat gains for all 33 of these applications will be included in the HAP v6.0 Help system and are not listed here. However, for illustration, several common lighting fixture types and their radiant/convective heat splits are shown in Figure 9 (page 9).

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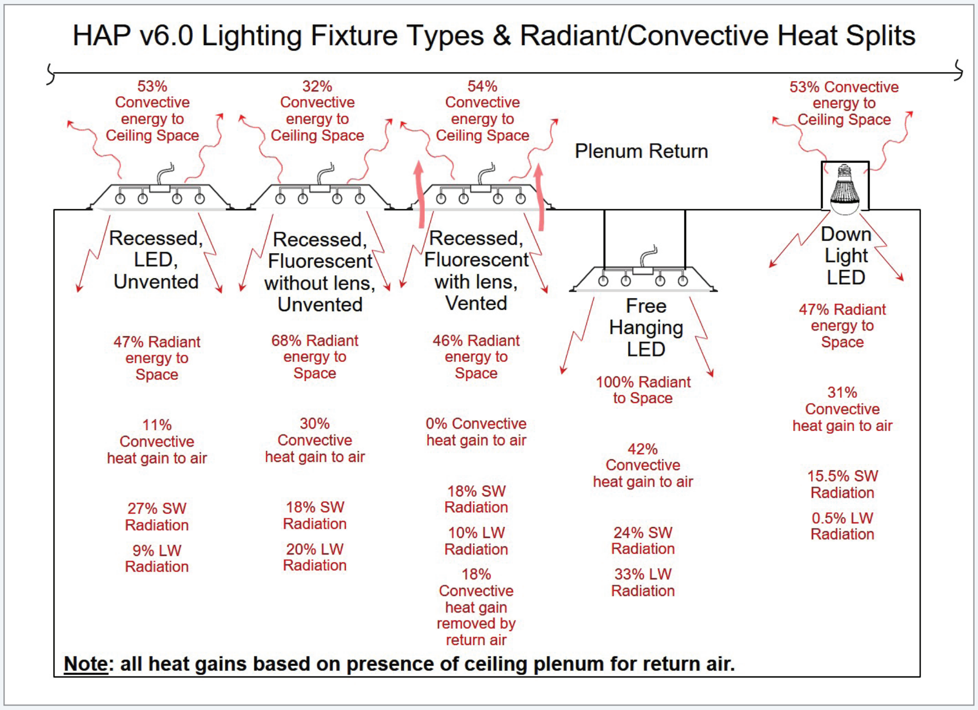

Figure 9. HAP v6.0 Common Lighting Fixture Types & Radiant/Convective Heat Splits

The five lighting types above illustrate how the convective heat is allocated to the ceiling plenum above and how much radiant heat is allocated to the space below. The use of a ceiling plenum return air sweeps-away this convective heat into the return airstream so this heat becomes a cooling coil load rather than a conductive room load. This has the effect of reducing the cooling airflow quantity (CFM) into the room necessary to meet the room load. There are some general observations to note regarding the use of a ceiling plenum:

With ceiling plenum: the amount of heat gain from the fixture that is allocated to the space and how much heat gain is allocated to the ceiling plenum above depends on whether or not the fixture is recessed, vented or free-hanging, the bulb type and if return air is ducted or ceiling plenum return is used. For vented fixtures 100% of the convective load from the lighting fixture is allocated to the ceiling plenum, while the radiant component is allocated to the space.

No ceiling plenum: for all fixture types, 100% of the radiative/convective light heat gain is allocated to the space below.

Conclusion

We have described the effects of space internal heat gains and how they are comprised of radiative and convective components and illustrated how the convective portion of the loads become instantaneous heat gains while the radiative components are stored in the thermal mass in the building and are released as convective loads over time. Because of the dynamic nature of radiative loads, the accurate hourly scheduling of these internal loads (lights, people and electric equipment) is paramount. When you create a new hourly schedule in HAP, the default schedule for the Design Day is 100% "ON" all hours (24/7), so unless you edit these defaults or use one of the pre-defined ASHRAE 90.1 schedules for your project you may discover that the presence of these internal loads all the time saturates the building's thermal mass with heat, which may create control problems such as large pull-down cooling loads the first hour of occupancy after a night setback/setup control period.

Frequently Asked Questions

FAQ #1: How does HAP v5.11 model below grade spaces? Since the underground soil is cooler than inside the space, I was expecting a credit for this against my space cooling load, but there is no cooling load credit. Why is this?

Answer: Figure 10 below is an illustration of a below-grade space with floor and walls partially underground. HAP does not perform load calculations for slab-on-grade and basement floors and walls for the design cooling condition. Per ASHRAE recommendations, slab and basement heat transfer is not included in the design cooling calculations since heat transfer is either negligible or constitutes a credit for summer conditions. For heat transmission through the basement walls, it is assumed the heat transfer path is circular between the basement wall and the soil surface (i.e. a 90-degree arc). The thermal resistance to heat flow depends on the R-value of the basement wall, wall insulation and the adjacent soil. The heat transfer path becomes longer as the depth below grade increases. The equation for one-dimensional heat transfer as a function of depth is integrated over the interval from grade level to floor depth below grade and is then solved to determine total heat transfer through the basement wall. When wall insulation is used, two separate calculations are performed. One is for the portion of the wall covered by insulation, and the other is for the uninsulated portion of the wall.

So, to summarize, this is how HAP v5.11 handles below grade calculations:

1. **Design cooling calculations** No calculation of ground heat loss or heat gain

2. **Design heating calculations** Calculation of ground heat loss only.

3. **Energy modeling** Calculate both ground heat gains and heat losses — whatever occurs based on hourly conditions.

In the upcoming HAPv6.0 release a 2D algorithm from *EnergyPlus*™ is utilized to compute below grade heat losses/gains. This algorithm considers not just the insulating value of soil but also the mass effect on heat storage/release in the soil. This can still result in heat gains or heat losses at different times, however the model is quite different from the calculation in HAP v5.11.

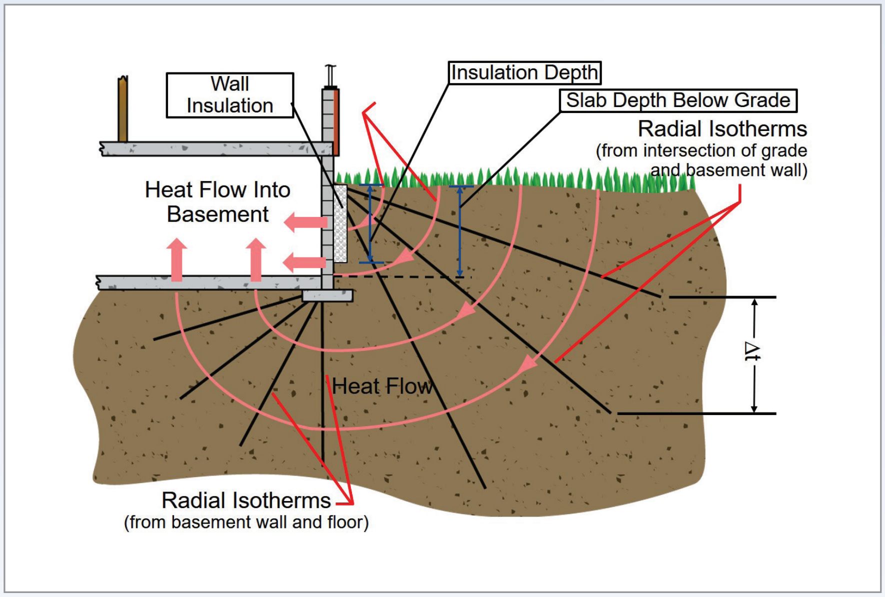

Figure 10. Heat Transmission for Below GradeSlab Floors & Walls

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FAQ #2: Why do I get more ventilation airflow than I asked for? I am designing an air system where the sum of outdoor airflows specified in the space inputs should be 3500 CFM. When I generate the Air System Design Load Summary, I see the ventilation airflow for the design cooling hour listed as 9000 CFM. Why do I get more ventilation airflow than I asked for?

Answer: There are three possible reasons for this:

1. Check your inputs to see if you specified an outdoor air economizer. If so, it is possible the economizer is operating for the hour whose data is displayed on the Air System Design Load Summary. To see if this is the case first check the supply airflow rate on the Air System Design Load Summary. If supply is equal to ventilation airflow, it's very likely the economizer is operating. Second, check the System Psychrometrics report for the same month and hour. Check temperature and humidity conditions to determine whether the economizer should be operating for this hour. For example, if you are using an integrated dry-bulb economizer, is the return air temperature warmer than the outdoor air temperature? If so, this is an hour when the economizer should operate.

2. The discrepancy may be due to a mistake when specifying "direct exhaust air". Edit the air system and go to the Zone Components tab > Thermostats data view. Check to see if "direct exhaust" air is specified. If it is, check to see if the "All zones the same" box is checked. If so, this quantity of "direct exhaust" air has been specified for all zones, not just one zone. Thus, if you have 500 CFM specified and 18 zones, you'll have a total of 9000 CFM of direct exhaust for the system. Because the system cannot exhaust more air than is entering the building as ventilation air, the program automatically adjusts the ventilation airflow to equal the direct exhaust.

   If you find this problem, there is a simple way to correct it:

   a. First change the direct exhaust value to zero.
   b. Next, uncheck the "all zones the same" box.
   c. Finally, scroll to the zone which has direct exhaust and specify the proper exhaust CFM. This way only that zone will have direct exhaust, not all zones in the system.

3. The final explanation also involves direct exhaust. If direct exhaust is correctly specified (only for the zones where it exists), but is greater than the outdoor ventilation air, then HAP will automatically increase the outdoor ventilation air to equal the direct exhaust airflow. A system cannot exhaust more air than enters as ventilation, so HAP must equalize these two airflow values.

FAQ #3: Why do I get less ventilation airflow than I asked for in a VAV system? I am designing a VAV air system in which the sum of outdoor airflows specified for spaces in the system is 3500 CFM. When I generate the Air System Design Load Summary report, I see in the design heating column that the ventilation airflow is only 1800 CFM. Why do I get less ventilation airflow than I asked for?

Answer: Make sure you specified "constant" control for the ventilation air. Without special controls outdoor ventilation airflow varies as a constant percentage of supply fan airflow. If ventilation air is 20% of supply airflow at the design cooling condition, it will be roughly 20% of design airflow at all other conditions as the VAV boxes close and the fan throttles. This is modeled by the "proportional" control option, which essentially means that ventilation air is not controlled. With this option you would have your specified 3500 CFM ventilation airflow when the VAV fan is at full airflow. If the VAV boxes close to 10% of design flow, you would have only 350 CFM of outdoor air when all VAV boxes were at their minimum position.

eDesign Suite Training

Load Calculation for Commercial Buildings	Energy Simulation for Commercial Buildings	Energy Modeling for LEED® Energy & Atmosphere Credit 1	Advanced Modeling Techniques for HVAC Systems	Engineering Economic Analysis	Block Load Basic
System Design Load HAP	*HAP*	*HAP*	*HAP*	*EEA*	*Block Load*

Please note: *Due to the global pandemic and concerns/restrictions regarding gatherings, all in-person training has been temporarily suspended. In lieu of classroom training, we have posted eDesign training videos on-line and are also conducting internet-based webinar training courses on-demand.*

*If you wish to discuss scheduling online training of any of the Carrier eDesign programs for your group, please contact us at **software.systems@carrier.com**.*

eDesign Suite Software Current Versions (North America)

Program Name		Current Version	Functionality
HAP	Hourly Analysis Program (HAP)	v5.11	Peak load calculation, system design, whole building energy modeling, LEED® analysis
BSO	Building System Optimizer	v1.60	Rapid building energy modeling for schematic design
BLK	Block Load	v4.16	Peak load calculation, system design
EEA	Engineering Economic Analysis	v3.06	Lifecycle cost analysis
RPD	Refrigerant Piping Design	v5.00	Refrigerant line sizing
SDL	System Design Load	v5.11	Peak load calculation, system design