Transfer Function Methodology (TFM)

The Transfer Function Methodology (TFM) is a dynamic means of accounting for heat transfer. Although there are other methods of accounting for heat transfer, Carrier's HAP program utilizes TFM in its calculations because it extends the analysis to account for specific system behavior to control the air temperature in the thermostat zones.

This article will review the calculation methodology of TFM to assist in interpreting the results of the HAP program. However, this article will not discuss the actual equations and formulas used. Such specific information can be found in the ASHRAE Fundamentals Handbook and in the HAP Help System, Chapter 27: Load Calculations. See Figure 1.

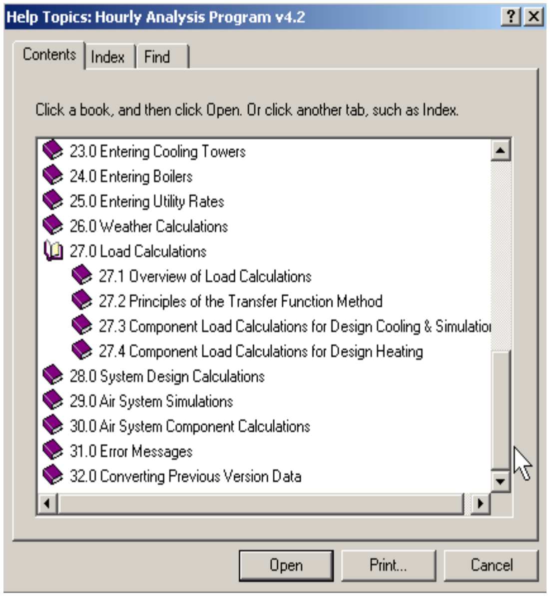

Figure 1 - HAP Online Help

HAP e-Help has noticed that users of HAP have encountered two issues that are preventing efficient use of the program. These issues are:

- Consideration of load estimating as a steady-state, instantaneous occurrence rather than a dynamic process
- Expectation of results based on previous experience with other load estimating programs that do not utilize TFM, especially those using simplifications to allow manual load calculations

TFM is a derivative of the Heat Balance Method. Calculation shortcuts and assumptions are used to reduce the volume and detail of required input, and to speed up calculations. (See Section 27.2 in the HAP Online Help System.) Reduced input and faster calculations make this method more efficient. For example, the coefficients in Transfer Function equations are derived directly from a Heat Balance analysis. The Heat Balance equations are used once to derive Transfer Function coefficients, and the coefficients are used repeatedly to quickly calculate loads. (TFM does not use U-values for walls and roofs.)

Conduction, convection, and radiation are the main drivers of heat transfer to or from the air in the room. The resulting room air temperature is calculated. The loads reported in HAP indicate how much cooling or heating is needed to maintain the room temperature within the throttling range. What is described below may be a new way of considering the effects of heat gain and cooling load compared to previous hand calculation methods adopted in the HVAC engineering community. The methods used by HAP align with ASHRAE calculation methodology.

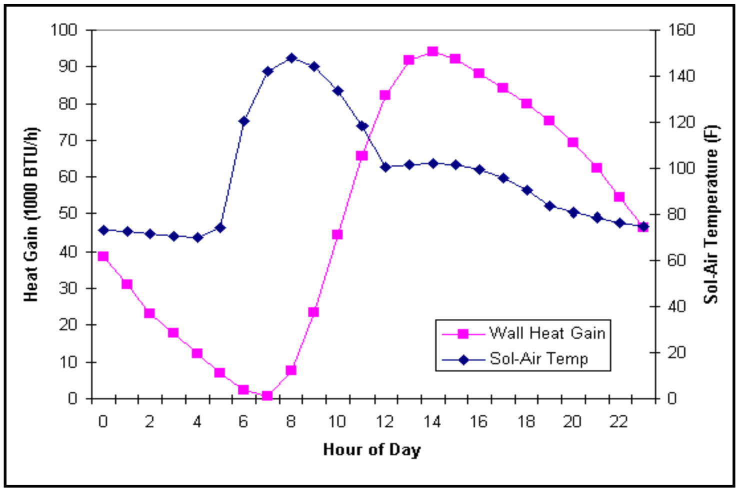

Figure 2 - Wall Heat Gain Example

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Transfer Function Methodology (TFM)

The dynamics of heat gain over time are best described graphically. Because an east-facing wall (See Figure 2) is used in the example, the sol-air temperature curve shows the effects of large morning heat gains due to solar radiation and smaller afternoon heat gains due to reduced sunshine but warmer outdoor air temperatures. The heat gain curve reveals the transient heat transfer processes involved. While the sol-air temperatures peak at 8 a.m., the interior wall heat gains for this medium-weight wall do not peak until 2 p.m. This reveals the time it takes for heat to be conducted through this specific type of wall construction.

Radiation heat gains from sources such as solar, lights and even people take time to become a load. The radiant heat must first heat up the building and contents and then be conducted and released over time to the room air by convection processes. This causes a delay between the time a heat gain occurs and the time its full effects as a cooling load appear.

Figure 3 shows the load and heat gains for lights turned on for six hours. Note that the 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.

Also note that cooling loads continue after lights are turned off and the heat gains cease. 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 six hours is still stored in the room mass and continues to be convected to room air over time.

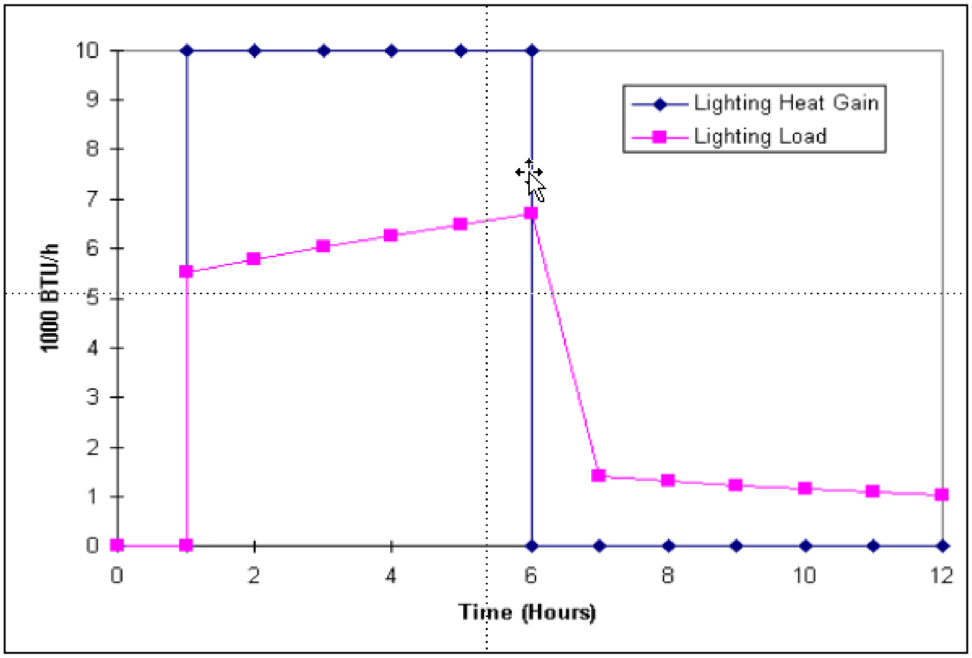

Figure 3 - Lighting Heat Gain Example

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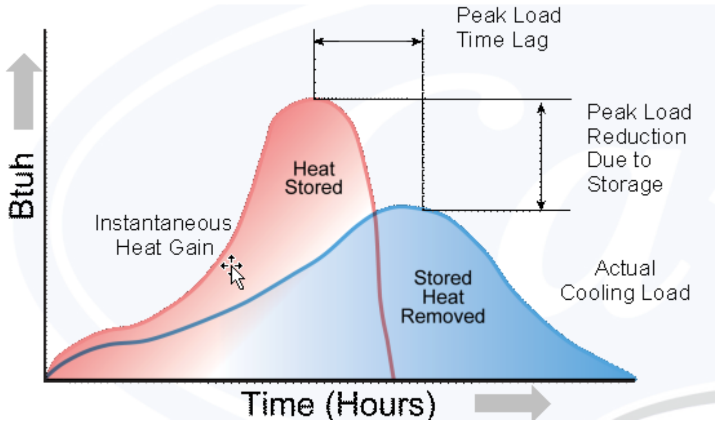
Transfer Function Methodology (TFM)

Figure 4 illustrates that the Transfer Function Method models the transient build-up and discharge of heat in a building.



The convection process is governed by the temperature difference between the mass and the room air. Convection decreases as the room air temperature rises and increases as the room air temperature decreases. Hand calculation methods assume a constant room air temperature at all hours to simplify this complex process. However, control systems have a throttling range, varying the room air temperature. Using night set up or not cooling during unoccupied times may cause an increase in room temperature and a decrease in convection, effectively storing heat for release. Later, on system start up, the room air temperature rapidly decreases and a connective rush of heat can occur. This is sometimes referred to as a pull down load. See Figure 5.

The TFM can calculate the effect of the changing room air temperature on the cooling and heating requirements. This is done using the Space Air Transfer functions referred to as Heat Extraction. This can be thought of as a thermostat and pulldown adjustment.

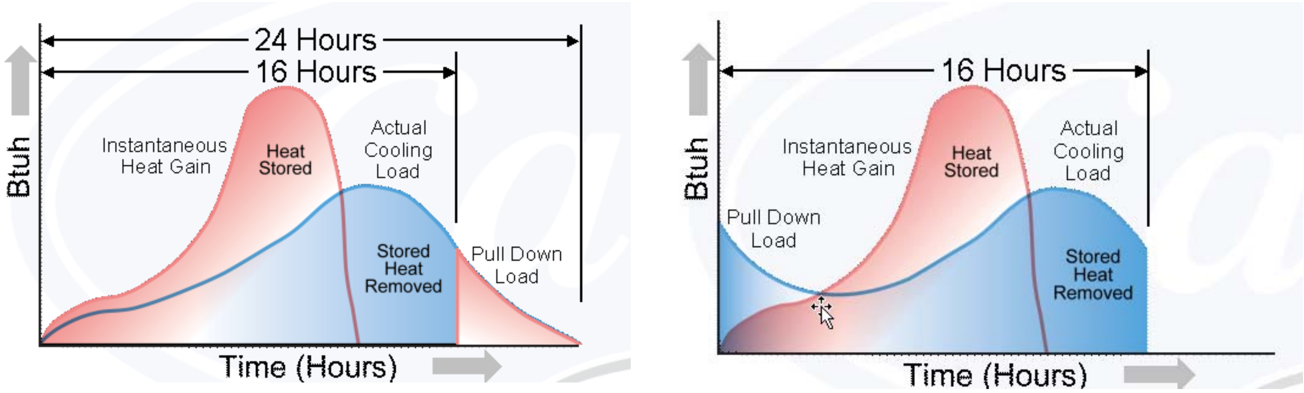


Figure 5 - Peak Loads: 24 Hours versus 16 hours

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Transfer Function Methodology (TFM)

The transfer function with heat extraction is implemented in three steps and two stages in HAP.

Stage One

Step One: The conduction equations are used to analyze the heat flow through walls and roofs.

Step Two: The room transfer functions are used to analyze the radiative, convective and heat storage processes of all components. Convective components are instantaneous and radiative components are stored and released over time.

Stage Two

Step Three: The space air temperature transfer functions (heat extraction equations) are used to analyze the effects of the changing room air temperature on convective heat flow from mass to room air that includes the behavior of the room thermostat.

In the **Stage One,** Steps One and Two are completed assuming a constant room air temperature 24 hours. The components, control zones, and the system are sized. These components comprise the Zone and Space Loads reported in HAP. See Figures 7, 8, 9, and 10.

In the **Stage Two,** Step three calculations are done. The system is simulated using the sizing from the first stage to correct the loads to what is needed to try to maintain set point. This is the "Zone Conditioning" reported in HAP (See Figures 7, 9, and 10.

To illustrate the results of this procedure, Figure 6 shows load, heat extraction, and room temperature profiles for a scenario in which HVAC equipment operates for the period 8 a.m. to 10 p.m., and is off for the remaining hours of the day. Figure 6 shows the cooling load profile calculated using the room transfer function procedures and assuming a constant room temperature. The actual room temperature profile shows that during the 8 a.m. to 10 p.m. operating period; the equipment maintains the zone within the thermostat throttling range of 72° F to 76° F. During the off hours, the zone temperature floats above the throttling range. During this period, heat is accumulated in the building mass. When the equipment operating period begins at 8 a.m., this accumulated heat is removed in addition to the hourly cooling loads. This results in a pulldown component of the load.

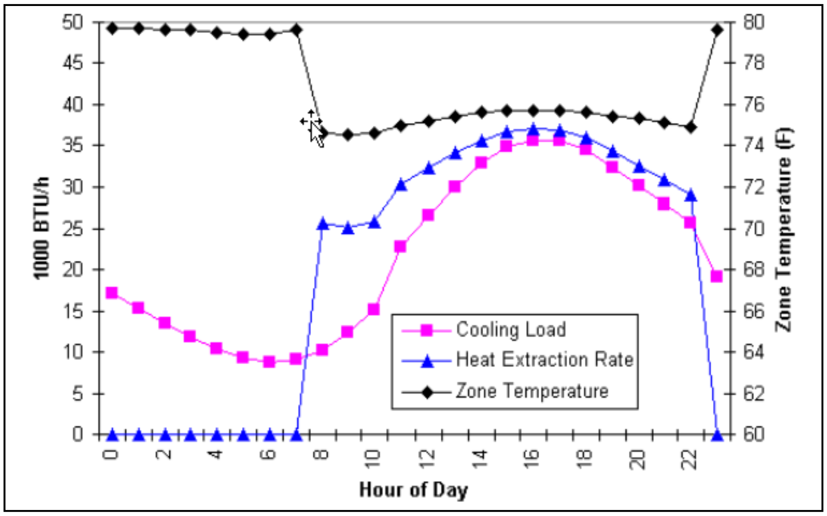

Figure 6 - Load, Heat Extraction, and Room Temperature Profiles

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Transfer Function Methodology (TFM)

The HAP report "**Air System Design Load Summary**" (Figure 7) shows the results of the two stages of the calculation procedure. The Total Zones Loads are the results of Stage One. The "Zone Conditioning" and "Total Conditioning" results are from the Stage Two calculation.

Air System Design Load Summary for D28 - RTU D2 - Classroom D101

Project Name: HAP42 Advanced Handout_03_01_05 07/1
Prepared by: 12

	DESIGN COOLING			DESIGN HEATING		
	COOLING DATA AT Aug 1500 COOLING OA DB / WB 94.5 °F / 75.9 °F			HEATING DATA AT DES HTG HEATING OA DB / WB 2.0 °F / 0.3 °F		
ZONE LOADS	Details	Sensible (BTU/hr)	Latent (BTU/hr)	Details	Sensible (BTU/hr)	Latent (BTU/hr)
Window & Skylight Solar Loads	96 ft²	3968	-	96 ft²	-	-
Wall Transmission	184 ft²	323	-	184 ft²	568	-
Roof Transmission	840 ft²	3395	-	840 ft²	3184	-
Window Transmission	96 ft²	1191	-	96 ft²	4229	-
Skylight Transmission	0 ft²	0	-	0 ft²	0	-
Door Loads	0 ft²	0	-	0 ft²	0	-
Floor Transmission	840 ft²	0	-	840 ft²	1101	-
Partitions	0 ft²	0	-	0 ft²	0	-
Ceiling	0 ft²	0	-	0 ft²	0	-
Overhead Lighting	2898 W	7911	-	0	0	-
Task Lighting	840 W	2548	-	0	0	-
Electric Equipment	840 W	2587	-	0	0	-
People	25	4185	3000	0	0	0
Infiltration	-	0	0	-	0	0
Miscellaneous	-	0	0	-	0	0
Safety Factor	0% / 0%	0	0	0%	0	0
>> Total Zone Loads	-	26109	3000	-	9081	0
Zone Conditioning	-	29034	3000	-	8611	0
Plenum Wall Load	0%	0	-	0	0	-
Plenum Roof Load	0%	0	-	0	0	-
Plenum Lighting Load	0%	0	-	0	0	-
Return Fan Load	1384 CFM	0	-	1384 CFM	0	-
Ventilation Load	400 CFM	8389	9169	400 CFM	28562	0
Supply Fan Load	1784 CFM	1322	-	1784 CFM	-1322	-
Space Fan Coil Fans	-	0	-	-	0	-
Duct Heat Gain / Loss	0%	0	-	0%	0	-
>> Total System Loads	-	38746	12169	-	35851	0
Central Cooling Coil	-	38746	12169	-	0	0
Central Heating Coil	-	0	-	-	35851	-
>> Total Conditioning	-	38746	12169	-	35851	0

Stage one

Stage Two

Figure 7 - Air System Design Load Summary

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Transfer Function Methodology (TFM)

The **Zone Design Load Summary** and **Space Design Load Summary** reports (Figure 8) show the detail of the Stage One results.

Zone Design Load Summary for D28 - RTU D2 - Classroom D101

Project Name: HAP42 Advanced Handout_03_01_05 07/13
Prepared by: 12:

Zone 1	DESIGN COOLING			DESIGN HEATING		
	COOLING DATA AT Jun 1500 COOLING OA DB / WB 91.5 °F / 73.9 °F			HEATING DATA AT DES HTG HEATING OA DB / WB 2.0 °F / 0.3 °F		
	OCCUPIED T-STAT 72.0 °F			OCCUPIED T-STAT 70.0 °F		
ZONE LOADS	Details	Sensible (BTU/hr)	Latent (BTU/hr)	Details	Sensible (BTU/hr)	Latent (BTU/hr)
Window & Skylight Solar Loads	96 ft²	4344	-	96 ft²	-	-
Wall Transmission	184 ft²	315	-	184 ft²	568	-
Roof Transmission	840 ft²	3530	-	840 ft²	3184	-
Window Transmission	96 ft²	1005	-	96 ft²	4229	-
Skylight Transmission	0 ft²	0	-	0 ft²	0	-
Door Loads	0 ft²	0	-	0 ft²	0	-
Floor Transmission	840 ft²	0	-	840 ft²	1101	-
Partitions	0 ft²	0	-	0 ft²	0	-
Ceiling	0 ft²	0	-	0 ft²	0	-
Overhead Lighting	2898 W	7911	-	0	0	-
Task Lighting	840 W	2548	-	0	0	-
Electric Equipment	840 W	2587	-	0	0	-
People	25	4185	3000	0	0	0
Infiltration	-	0	0	-	0	0
Miscellaneous	-	0	0	-	0	0
Safety Factor	0% / 0%	0	0	0%	0	0
>> Total Zone Loads	-	26425	3000	-	9081	0

Stage One

Space Design Load Summary for D28 - RTU D2 - Classroom D101

Project Name: HAP42 Advanced Handout_03_01_05 07/13
Prepared by: 12:

TABLE 1.1.A. COMPONENT LOADS FOR SPACE " D101-Classroom " IN ZONE " Zone 1 "						
	DESIGN COOLING			DESIGN HEATING		
	COOLING DATA AT Jun 1500 COOLING OA DB / WB 91.5 °F / 73.9 °F OCCUPIED T-STAT 72.0 °F			HEATING DATA AT DES HTG HEATING OA DB / WB 2.0 °F / 0.3 °F OCCUPIED T-STAT 70.0 °F		
SPACE LOADS	Details	Sensible (BTU/hr)	Latent (BTU/hr)	Details	Sensible (BTU/hr)	Latent (BTU/hr)
Window & Skylight Solar Loads	96 ft²	4344	-	96 ft²	-	-
Wall Transmission	184 ft²	315	-	184 ft²	568	-
Roof Transmission	840 ft²	3530	-	840 ft²	3184	-
Window Transmission	96 ft²	1005	-	96 ft²	4229	-
Skylight Transmission	0 ft²	0	-	0 ft²	0	-
Door Loads	0 ft²	0	-	0 ft²	0	-
Floor Transmission	840 ft²	0	-	840 ft²	1101	-
Partitions	0 ft²	0	-	0 ft²	0	-
Ceiling	0 ft²	0	-	0 ft²	0	-
Overhead Lighting	2898 W	7911	-	0	0	-
Task Lighting	840 W	2548	-	0	0	-
Electric Equipment	840 W	2587	-	0	0	-
People	25	4185	3000	0	0	0
Infiltration	-	0	0	-	0	0
Miscellaneous	-	0	0	-	0	0
Safety Factor	0% / 0%	0	0	0%	0	0
>> Total Zone Loads	-	26425	3000	-	9081	0

Stage One

Figure 8 - Space Design Load Summary and Zone Design Load Summary Reports

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Transfer Function Methodology (TFM)

The **Hourly Zone Loads** report (Figure 9) shows the hourly results of the Stage One and Stage Two calculations as well as the varying hourly zone air temperature achieved.

Hourly Zone Loads for D28 - RTU D2 - Classroom D101

Project Name: HAP42 Advanced Handout_03_01_05 07/13/20
Prepared by: 12:50

ZONE: Zone 1
DESIGN MONTH: JULY

Hour	OA TEMP (°F)	ZONE TEMP (°F)	RH (%)	ZONE AIRFLOW (CFM)	ZONE SENSIBLE LOAD (BTU/hr)	ZONE COND (BTU/hr)	TERMINAL COOLING COIL (BTU/hr)	TERMINAL HEATING COIL (BTU/hr)	ZONE HEATING UNIT (BTU/hr)
0000	81.1	83.3	-	0.0	6012.7	0.0	0.0	0.0	0.0
0100	80.0	83.3	-	0.0	5509.1	0.0	0.0	0.0	0.0
0200	79.1	83.3	-	0.0	5058.4	0.0	0.0	0.0	0.0
0300	78.2	83.3	-	0.0	4636.4	0.0	0.0	0.0	0.0
0400	77.4	83.3	-	0.0	4256.0	0.0	0.0	0.0	0.0
0500	76.9	83.3	-	0.0	3916.3	0.0	0.0	0.0	0.0
0600	76.7	73.5	70	1783.8	4014.2	16843.2	0.0	0.0	0.0
0700	77.1	73.5	70	1783.8	5948.0	16315.3	0.0	0.0	0.0
0800	78.0	74.3	64	1783.8	13978.6	21698.5	0.0	0.0	0.0
0900	79.6	74.1	63	1783.8	15567.0	22582.5	0.0	0.0	0.0
1000	82.0	73.8	62	1783.8	16524.1	22926.5	0.0	0.0	0.0
1100	84.8	73.9	63	1783.8	17046.0	22436.0	0.0	0.0	0.0
1200	87.9	74.1	64	1783.8	17240.6	21496.4	0.0	0.0	0.0
1300	90.8	74.1	64	1783.8	17704.8	21256.1	0.0	0.0	0.0
1400	93.0	74.0	64	1783.8	18078.7	21389.6	0.0	0.0	0.0
1500	94.5	74.0	64	1783.8	18245.2	20958.6	0.0	0.0	0.0
1600	95.0	74.1	65	1783.8	18167.2	20361.1	0.0	0.0	0.0
1700	94.5	82.7	-	0.0	12680.9	0.0	0.0	0.0	0.0
1800	93.2	83.3	-	0.0	11701.9	0.0	0.0	0.0	0.0
1900	91.2	83.4	-	0.0	10466.9	0.0	0.0	0.0	0.0
2000	88.8	83.3	-	0.0	9172.5	0.0	0.0	0.0	0.0
2100	86.4	83.3	-	0.0	8099.5	0.0	0.0	0.0	0.0
2200	84.4	83.3	-	0.0	7275.1	0.0	0.0	0.0	0.0
2300	82.6	83.3	-	0.0	6594.8	0.0	0.0	0.0	0.0

Zone Temp

Stage One

Stage Two

Figure 9 - Hourly Zone Load Report

Transfer Function Methodology (TFM)

Graphing the column of numbers from the two stages can be done from the **Hourly Zone Design Day Loads** (see Figure 10). The magnitude of the pull down load can be seen at 6 am. The extra amount of "conditioning" represents the true demand for cooling needed for running 11 hours instead of 24 can easily be seen.

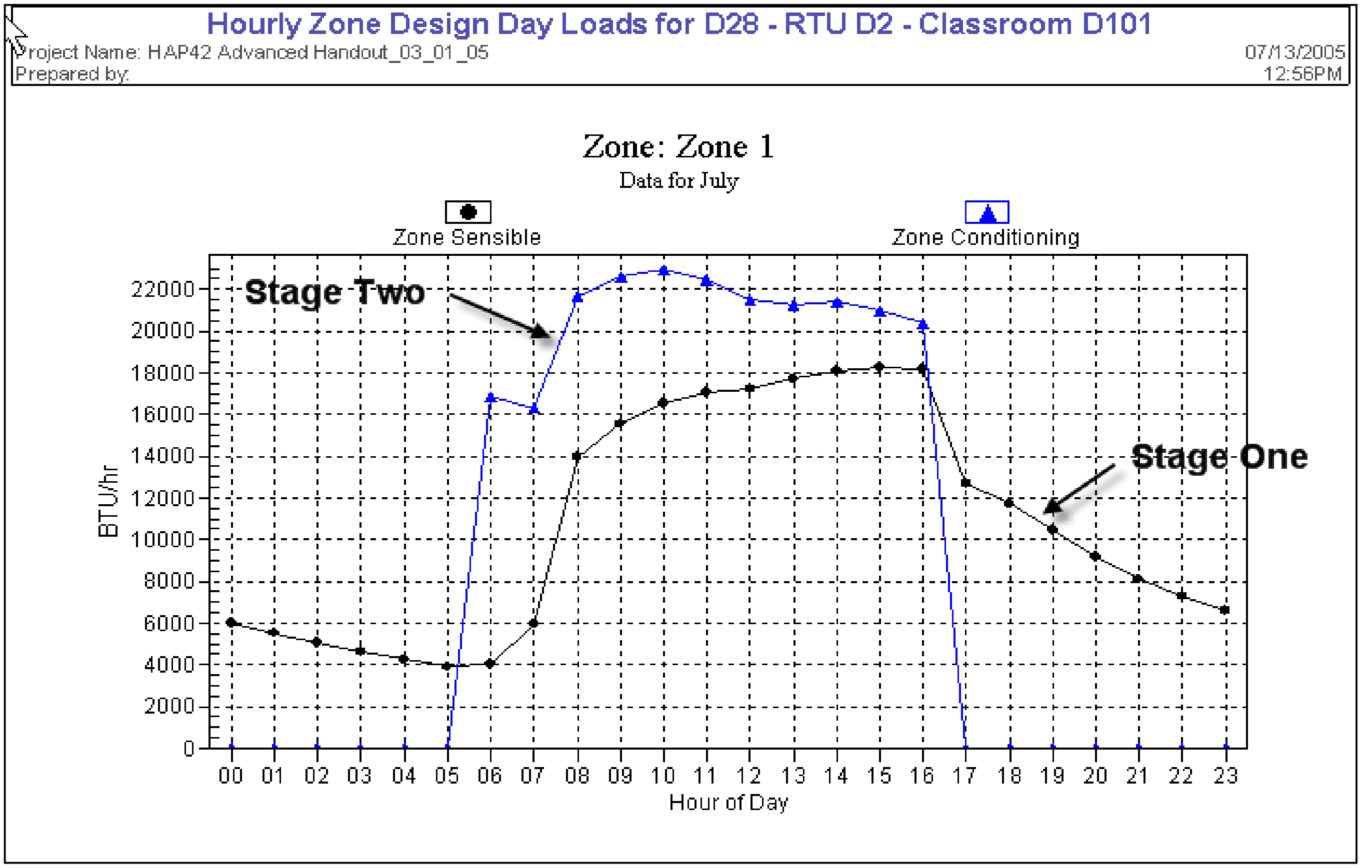

Figure 10 - Hourly Design and Day Loads

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Transfer Function Methodology (TFM)

As a review, when performing calculations to determine required airflow rates, supply terminal characteristics, and coil capacities for HVAC systems, HAP uses the following general eight-step procedure:

1. Compute sensible and latent loads for all zones served by the HVAC system.
2. Sum zone loads to obtain sensible and latent loads for the HVAC system.
3. Determine required zone airflow rates.
4. Compute required sizes for terminal reheat coils as necessary.
5. Determine required system airflow rates. This includes sizing all fans and outdoor ventilation airflow rates.
6. Simulate HVAC system operation. Based on the required airflow rates determined in Steps 3 through 5. Operation of the HVAC system is mathematically simulated to produce profiles of loads on central cooling and heating coils.
7. Identify peak coil loads. Cooling and heating coil load profiles from Step 6 are inspected to identify maximum loads.
8. Report results.

The results of these calculations can yield important benefits such as the ability to analyze the realistic transient heat transfer that occurs in all buildings. Loads can also be accurately computed for any heat gain sequence and wall or roof construction. Consequently, resulting loads are specific and customized for each application analyzed, accounting for local weather conditions, building construction and operating schedules. The value of these benefits is obvious for HVAC design work.

Further articles in this series of HAP e-Help will build upon this discussion and explore how the HAP software can assist system design rather than just load calculation.

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