Carrier heat load calculation manual

I'm not robot!

LOAD ESTIMATING Load Estimating Level 2: Fundamentals Technical Development Programs (TDP) are modules of technical training on HVAC theory, system design, equipment selection and application topics. They are targeted at engineers and designers who wish to develop their knowledge in this field to effectively design, specify, sell or apply HVAC equipment in commercial applications. Although TDP topics have been developed as stand-alone modules, there are logical groupings of topics. The modules within each group begin at an introductory level and progress to advanced levels. The breadth of this offering allows for customization into a complete HVAC curriculum – from a complete HVAC design course at an introductory-level or to an advancedlevel design course. Advanced-level modules assume prerequisite knowledge and do not review basic concepts. The fundamentals of commercial load estimating are needed to understand the various load components that go into making a practical estimate of the amount of heating and/or cooling energy needed to condition a building. Done properly, a load estimate provides the data necessary to select heating and cooling equipment that can condition the spaces within a building. If the characteristics of the load components for the building and the HVAC system are known, then an analysis of the application can be used to come up with the correct load and equipment selections to complete the design. Along with psychrometrics, load estimating establishes the foundation upon which HVAC system design and operation occur. Load Estimating, Level 2: Fundamentals is the second in a four-part series on load estimating. It is preceded by an overview of the topic and followed by two TDPs that review the procedures for completing block and zone load estimates and refinements required for preparing a system-based design load estimate. Printed in Syracuse, NY CARRIER CORPORATION Carrier Parkway Syracuse, NY 13221, U.S.A. Table of Contents LOAD ESTIMATING, LEVEL 1: FUNDAMENTALS Introduction This Technical Development Program (TDP) on commercial load estimating presents the fundamentals needed to understand the various load components that go into making a practical estimate of the amount of heating and/or cooling energy needed to provide comfort conditioning of a building. Once a project begins to take shape, the job requirements (a scope of work) can be tabulated for the HVAC portion. Given this data, it is possible to perform a load estimate for the selection of the heating and cooling equipment that will condition the various rooms, or spaces, to maintain the temperature, humidity, or CO_2 set points. If the designer knows the elements of the loads for the building and the features of the HVAC system, then the application can be analyzed regardless of the calculation method used, and correct equipment selections can be made to complete the design. If a simple, rule of thumb load estimate has been used during preliminary design, then later on in the design process the building and HVAC loads should be calculated in detail. When completed, all the necessary parameters for sizing the selected packaged equipment (rooftops units and split systems) or applied equipment (chillers, boilers, and air handlers), along with terminals and air diffusion devices will be available to the designer. Importance of Load Estimating An accurate load estimate is needed to get the process of designing, installing, and operating a project off to a good start. The load estimate numbers provide the data for a host of subsequent calculations, selections, and decisions. Among these items are: HVAC system selection; equipment selections for fans, coils, and pumps; duct and electrical feeder sizing; and water piping design. An accurate estimate will provide the correct cooling and heating requirements, offer options for load reductions at the least incremental cost, provide properly sized equipment, and yield efficient air, water, and electrical distribution designs. Load Estimate versus Load Calculation One often hears load estimate and load calculation used synonymously. A load estimate is an approximation based on methods that are not detailed, such as a rule of thumb, check figures, or quick hand calculation based on assumptions. Check figures and rules of thumb have been derived for common applications by HVAC designers and are often compiled for ease of use. Some 2 2 common check figures represent cooling in ft /ton and people density as ft /person. A load calculation is a more detailed analysis of load components based on actual building design knowledge and is usually performed by computer software spreadsheets and programs. Even though a load calculation is considered more accurate, not all the details of the inputs required by the software are known. The user must still rely on good judgment, so the word "estimate" is still appropriate for the results. Current calculation models have increased the accuracy of software programs. However, simplifying assumptions are a part of these methods too, so as far as trying to approach the reality of nature, it is still an estimate, but at increasingly higher levels. Load Estimating 1 LOAD ESTIMATING, LEVEL 1: FUNDAMENTALS Types of Load Estimating Proper load estimating requires gathering enough details to obtain the level of accuracy required. Preliminary HVAC load estimates can be performed through minimal project knowledge by use of rules of thumb and check figures, since order of magnitude for preliminary budgets and rough schematics are the goals. As a project progresses in the design process, more information becomes available and the load estimates must be refined. The methodologies used for the detailed sizing calculations or system modeling often will dictate the type and depth of information that is needed for input into various software programs. These more in-depth subjects will be covered in the two remaining Figure 1 load estimating TDPs. Load estimates are the Cooling Estimate Load Components summation of heat transfer elements into (gains) or out of (losses) the spaces of a building. Each heat transfer element is called a load component. Load components represent sensible and latent heat transfers (in Btuh) from a multitude of sources, but all can be assembled into one of these basic groups, external space loads, internal space loads, and system loads. Each will be covered in detail in a separate section of this TDP. The Appendix contains a terms list for the abbreviations found in the figure. To properly understand the workings of the various external, internal and system load components, details regarding the following items will need to be gathered from a set of plans, existing building surveys, or occupant interviews: • Occupancy of the entire building (office, health care, retail store, educational, etc.) • Orientation of the building (sun effects on surfaces) • Weather data (design conditions, heat transfer Δt) • Use of the spaces within the building (offices, conference room, lab, data center) • Hours of operation (occupied and unoccupied) • Thermostat set points (main comfort parameter) • Dimensions of walls, roofs, windows, and doors • Construction materials (gather densities, external color, and U-factors, or describe material type layer-by-layer (R-values) • Stairways and elevators (floor-to-floor openings) • People occupancy and activity, and when they are present • Lighting intensity and hours used • Motor and appliance sizes or kW, and times they are used • Ventilation needs (IAQ and exhaust makeup) While many of these items will be explored as this module progresses, the Load Estimating TDP on Block and Zone Loads needs to be consulted for a full building load takeoff example. Load Estimating 2 LOAD ESTIMATING, LEVEL 1: FUNDAMENTALS Types of Load Estimating There are many types of load estimating and calculation procedures. They range from fast and easy hand calculations to detailed descriptions for advanced computerized load estimates. Rules of Thumb There are many types of rules of thumb available for use in commercial buildings. One such compilation is found in the Carrier Commercial Systems Quick Reference (CSQR). These are reproduced in the Appendix of this manual. The Cooling Check Figures allow for approximation of total cooling needs (building 2 gross area • cooling ft /ton), electrical load (gross square footage • lighting + equipment Watts/ft), and outdoor air ventilation requirements (building gross area • people 2 ft person • ventilation cfm/person). The Approximate Design Air Distribution cfm (Cooling) table allows early approximation of the zone primary supply air needs for terminal selection and ductwork space evaluation. Rules of Thumb These ballpark numbers are very useful in preliminary design phases and are good check points for comparing with the results of more detailed procedures to see if any gross input errors were made. Manual vs. Software Generated Going beyond the rules of thumb method, the designer now has to do a load takeoff and provide a level of detail on the project that allows individual computations for the major and hopefully important minor load components. A manual method can use a tabular form like the Carrier E-20A, Air Conditioning Load Estimate form (see Appendix), or a computer spreadsheet like Excel or Lotus. In one, a pencil and a calculator are used to run a load estimate for a simple building or to study unusual space or zone requirements. In the other, input is still manual, but the computer spreadsheet tabulates the many calculations required for larger multi-room systems with extensive zoning or multiple central equipment selections to be sized. Manual methods will take a lot of time, especially in the early stages of design, and when a quick calculation is needed to check sizing requirements or the magnitude of load change created by a change in a takeoff value. Larger commercial jobs, especially ones with unusual load components, should have the cooling and heating loads estimated using one of the many software load estimating programs available to designers. This method proves to be efficient whenever a change in the takeoff at the later stages of design requires a recompilation of the load estimate. Load Estimating 3 LOAD ESTIMATING, LEVEL 1: FUNDAMENTALS The computer printed outputs generally organize the data very well (Figure 2), and in some cases can provide graphical outputs of the detailed calculations, such as a psychrometric plot of the system points (Figure 3). Softwaregenerated load estimates run the gamut from simple spreadsheets to full computer energy simulation derived from detailed inputs that include full system and component descriptions. The energy calculation modeling is described in the energy estimating TDP. Air System Design Load Summary for Top Floor Project Name: Chicago Office Building (TDP-301) 09/09/2004 Prepared by: ZONE LOADS Window & Skylight Solar Loads Wall Transmission Roof Transmission Window Transmission Skylight Transmission Door Loads Floor Transmission Partitions Ceiling Overhead Lighting Task Lighting Electric Equipment People Infiltration Miscellaneous 08:40AM DESIGN COOLING DESIGN HEATING COOLING DATA AT Jul 1500 HEATING DATA AT DES HTG COOLING OA DB / WB 91.0 °F / 74.0 °F HEATING OA DB / WB -6.0 °F / -7.2 °F Sensible Latent Sensible Details [illegible] Safety Factor • Total Zone Loads Zone Conditioning Plenum Wall Load Plenum Roof Load Plenum Lighting Load Return Fan Load Ventilation Load Supply Fan Load Space Fan Coil Fans Duct Heat Gain / Loss • Total System Loads Central Cooling Coil Preheat Coil Terminal Reheat Coils • Total Conditioning [illegible] Figure 2 System Block Load Space, Zone, and Block Loads for Equipment Sizing Each of the load types, space loads, zones and block loads are all used for equipment sizing, and can be obtained from almost any load estimating software and manual calculation method. The purpose is to get the Btuh and fluid quantities (cfm and gpm) for selecting diffusers, sizing fans, and determining the cooling and heating capacities for the equipment. A total building or project block load is useful for sizing central cooling and heating plant equipment such as chillers and boilers. A system level block load (Figure 2) provides fan and coil sizing details for the central airhandling units. Figure 3 Psychrometric Plot of an HVAC System Load Estimating 4 LOAD ESTIMATING, LEVEL 1: FUNDAMENTALS A zone load provides the information to select units such as CV and VAV terminals and terminal heating coils (Figure 4), and room air diffusers (Figure 5). The peak block load and zone loads may occur at different times of the day and at different months, so each is usually run. The Carrier Block Load and program and the Hourly Analysis Program (HAP) are examples of this type of software. Zone Sizing Summary for Top Floor Project Name: Chicago Office Building (TDP-301) 09/09/2004 Prepared by: 08:40AM Air System Information Air System Name .... Top Floor Equipment Class .... CW AHU Air System Type .... VAV Number of zones .... 9 Floor Area .... 15752.0 ft2 Location .... Chicago IAP, Illinois Sizing Calculation Information Zone and Space Sizing Method: Calculation Months .... Jan to Dec Sizing Data .... Calculated Zone CFM .... Peak zone sensible load Space CFM .... Individual peak space loads Zone Sizing Data Zone Name North West Corner Top North East Corner Top North Side Top North West Corner Top East Side Top West Side Top Interior Top Maximum Cooling Sensible (MBH) [illegible] Figure 4 Terminal Sizing Summary Space Manual, Part 1, and two User Guides [illegible] Zone Sizing Summary for Top Floor Project Name: Chicago Office Building (TDP-301) 09/09/2004 Prepared by: 08:40AM Air System Information Air System Name .... Top Floor Equipment Class .... CW AHU Air System Type .... VAV Number of zones .... 9 Floor Area .... 15752.0 ft2 Location .... Chicago IAP, Illinois Sizing Calculation Information Zone and Space Sizing Method: Even more important is the cooling supply air requirement that is used in the calculations. This is needed to select the equipment that will meet the load requirements, and perform as expected on startup. Applied equipment has many more choices than packaged equipment for selecting coil rows, fins, and circuiting; so a 55° F supply air temperature for various system applications can be Figure 5 easily achieved. The lower supply air set point gives bet- Space Sizing Summary for part load dehumidification, very important in Note: limiting room IAQ issues Most packaged equipment and room fan coils have limited around moisture damage and coil geometry options and, as a general guideline, deliver a mold growth. supply air temperature of about 58° F to 59° F. Calculation Months .... Jan to Dec Sizing Data .... Calculated Zone CFM .... Peak zone sensible load Space CFM .... Individual peak space loads Space Loads and Airflows Zone Name / Space Name North West Corner Top Mult. North West Corner Top North East Corner Top North Side Top North Typical Top East Side Top East Typical Top South Side Top South Typical Top West Side Top West Typical Top Interior Top Interior Typical Top South East Corner Top South East Corner Top South West Corner Top South West Corner [illegible] Load Estimating 5 LOAD ESTIMATING, LEVEL 1: FUNDAMENTALS Safety Factors A safety factor should be a function of the designer's confidence in his or her load survey and the details gathered on the project's construction materials. There is usually a built in creeping safety factor as the HVAC design is through the design method and equipment sizing procedures. For instance, assume the room airflow requirement is 108 cfm of conditioned supply air. This value was then increased to 113 cfm based on a 5 percent sensible load safety factor. The equipment selected to deliver air to the room would probably then be rounded up and selected for 125 cfm. This is a 10 percent Figure 6 increase on top of the original 5 percent calculation safety Creeping Safety Factor factor. Then the total load is calculated for the cooling equipment at 105,445 Btuh (8.79 tons), again based on a safety factor. However, the piece of equipment selected to do the job only comes in discreet sizes such as 5, 7½ and 10 tons. So a 10-ton unit is installed, which is over capacity by 10 percent on a load that already contained multiple safety factors. In fact, for more favorable outside conditions than the standard rating values (80° F db/67° F wb), the unit capacity can be even more overcrowded. Minimal Safety Factors The use of safety factors in the cooling load estimate is discouraged. An accurate takeoff and double-checking of entry values in load forms or computer software is encouraged. This over-conservative approach to cooling sizing causes over-sized equipment to be installed. This results in less efficient operation and difficulty in controlling room conditions, especially relative humidity and the associated IAQ (indoor air quality) problems. Designers should examine the results of the calculations, understand where the numbers come from, and satisfy themselves that the resulting numbers make sense. Because beginners may be unsure of the calculation methods and output values, the tendency is to use safety factors as insurance. If one feels that this insurance is needed, a factor of a few percent, but not to exceed 5 percent, is suggested for cooling. As you will see later in the heating section, a spring safety factor to cover warm-up loads is often quite large (up to 25 percent) in cold climates. Load Estimating 6 LOAD ESTIMATING, LEVEL 1: FUNDAMENTALS Loads Run for HVAC System Modeling Now that software models are available to size and select HVAC systems and components in more detail than basic block and zone load software. This modeling software allows the designer to do system-based design because the inputs describe schedules, set points and equipment operation unique to the selected HVAC system. For programs like Carrier's HAP, by building on the information already used for the detailed load estimate, an annual energy analysis simulation can also be done. Additional items needed beyond the typical load estimate inputs include hourly weather data for the entire year, comprised of 8760 instances of dry bulb, wet bulb, and solar data, electric and fuel rate costs, and equipment efficiencies. With this degree of input data and program computational methods, detailed life cycle costs for alternative HVAC designs can easily be compared. Energy Code Requirements Now that various model building codes across the United States have been unified into the International Codes Council family of codes, it is easy to discuss energy code requirements by referring to the International Energy Conservation Code 2003 requirements. As the design progresses, the designer should make sure that the following items are completed: • Read over the Administrative and Definitions chapters to coordinate those requirements with the specific project being worked on. • Determine exterior design conditions (dry and wet bulb temperatures, and degree days) from ASHRAE (American Society of Heating, Refrigerating, and Air-Conditioning Engineers) and NOAA (National Oceanic and Atmospheric Administration) references. • By direct reference, all commercial buildings follow ASHRAE Standard 90.1-2001, Energy Standard for Buildings Except for Low-Rise Residential Buildings. While most items in Section 6 (Heating, Ventilating, and Air-Conditioning) of ASHRAE 90.1 relate to system design and operating efficiency (see 90.1 summary in Appendix), paragraph 6.2.2 requires running heating and cooling load estimates before selecting equipment. • Chapter 8, which provides an alternative to ASHRAE 90.1 for architects who want to follow "acceptable practice" tables for building exterior envelope heat transfer U-factors and Rvalues. • Model Codes can always be superseded by the AHJ (local Authority Having Jurisdiction, or code official). The designer needs to review critical issues (e.g. will the simplified approach option, paragraph 6.1.3, be allowed for your project?) with local standards and/or ask for interpretation from the AHJ directly. Load Estimating 7 LOAD ESTIMATING, LEVEL 1: FUNDAMENTALS Load Estimating Methods Over time, load estimating has become more sophisticated. The early methods, like instantaneous method and storage load factor/ETD method, use hand calculations that were not quick and easy, even with the simplifying assumptions and look-up tables. Doing an entire building makes for lengthy calculations. Working up to the current methods, which try to track actual heat transfer within a building, only the use of computer software allows executing the millions of calculations required to complete a load estimate. Load estimating today can still be done manually using hand calculations or software spreadsheets, but these methods are usually reserved for early design rough approximations, or studies of special zones or material options effects. Running a final load for a large multizone building requires doing away with as many simplifying assumptions as possible, and using the HVAC system modeling techniques and refinement of heat transfer calculations of the transfer function and radiant time series methods. Figure 7, plots relative accuracy vs. complexity for many common methods. The two extreme methods on the ends are instantaneous and heat balance. Instantaneous is the fastest and easiest to use, however, it is now only used for heating load calculations; it is too simple in the assumptions used to be used for cooling loads. The method does not take into account the storage and release of heat over time within the building material and furnishings. The heat balance method at the other end of the chart uses the least amount of simplifying assumptions, making it the most accurate method, but it must be done using computer software. All the load components Figure 7 (solar, wall, roofs, people, Accuracy vs. Complexity lights etc) interact dynamically with each other. This method calculates these interactions simultaneously and yields very precise results. Since the load components are calculated interactively, the method cannot provide output on how much of the load comes from walls, windows, roofs, people, lights etc. Since one of the main uses of load calculations is for designers to determine the individual load component contributions, this method is not used very much for actual load estimates. The heat balance method is very good for doing energy simulations, which is a topic for the Energy Estimating TDP. Carrier's SDM-1 storage load factors/ETD manual load estimating method is still available, along with Block Load and Hourly Analysis Program computer software programs, both of which currently use the transfer function method. Plans are underway to convert these programs over to the current ASHRAE radiant time series method. Load Estimating 8 LOAD ESTIMATING, LEVEL 1: FUNDMENTALS Storage Load Factor/ETD Method The Carrier E20 method (storage load factor/ equivalent temperature difference method) was developed before ASHRAE became the industry source. In this method, a way for hand calculating the effects of storage and release of heat over time was put into tables to determine the appropriate storage factor. The method is covered in complete detail in Carrier's System Design Manual, Part 1, and two User Guides that cover the use of the E-10A (heating) and E-20A (cooling) forms for load estimating Figure 8 and coil performance. Peak Solar Gain through Glass (from Carrier SDM-1, Chapter 3) When determining actual cooling loads, Table 6 from SDM-1 is used to determine the peak solar heat gain figures. This table represents the monthly maximums. The variation of solar intensity and movement of heat into and out of the building mass is taken care of through the storage load factor tables. To demonstrate some of load estimating procedures we will begin creating an example building, and continue with its use throughout the remaining load estimating TDPs. The example building, the Chicago Office Building, has a 12hour schedule of occupied operation. Figure 9 shows a portion of SDM-1 Table 11, which would be used to determine the appropriate storage factors. Other tables deal with different equipment operating hours. Figure 9 Solar Glazing Storage Load Factors (from Carrier SDM-1, Chapter 3) Load Estimating 9 LOAD ESTIMATING, LEVEL 1: FUNDAMENTALS As an example, lets look at a typical east-facing window. Chicago is approximately 40° N 2 latitude, so looking at July, Table 6 (Figure 8) indicates a peak solar heat gain of 164 Btuh per ft . Going to Table 11 (Figure 9), and using the east exposure with a building weight of 100 pounds 2 per ft and internal shading, the peak storage load factor would be 0.73 at 8 a.m., reducing the solar heat gain to 164 ∗ 0.73 = 120 Btuh/ft2. By contrast, if there was no shading, the load factor would drop to a peak of 0.58 at 9 a.m., and the load profile is more leveled, demonstrating the heat storage effect. Cooling Load Temperature Differential/Cooling Load Factor (CLTD/CLF) Methods In the 1970s, ASHRAE published the CLTD/CLF Methods. These hand calculation methods were derived from the dynamic heat balance method using transfer functions on computer runs to derive location-specific tables that could be used in hand calculations. As hand calculation procedures, both methods (CLTD and CLF) did a good job of balancing complexity (and therefore effort) with accuracy, however, both methods lacked flexibility. Building loads are affected by a wide variety of factors involving design, construction, environment, and building use. Table-based hand calculation methods typically deal with a fixed set of basic conditions (such as envelope loads for July 40 degrees North latitude) and then attempt to handle other conditions via correction factors. Ultimately, this approach introduces error and reduces accuracy when compared with methods that are more detailed. Some way of calculating loads specific to each design application was needed, which lead to the use of later methods that can best be done or only be done on a computer. Neither method is used currently since the transition from manual calculations to software-based load estimating has been successfully completed. Transfer Function Method The transfer function method is a simplification of the heat balance method that requires computer software to use. The transfer function method uses mathematical Laplace transformations to simplify the heat balance solution process, thereby yielding calculation times that are faster than those of the heat balance method without sacrificing too much of its accuracy. The dynamics of calculating heat gain over time are retained, but individual load components can be calculated and then summed to get total loads. This allows the designer to gain element contribution values. For example, in Figure 10, the lights are turned on for 5 hours. The heat from the lights is split between convective (instantaneous) and radiant (heat storage) portions. The radiant portion is stored and released over time, just like solar load coming through a window. Therefore, as the lights remain on, the resultant load is Figure 10 Lighting Load Transfer Function Load Estimating 10 LOAD ESTIMATING, LEVEL 1: FUNDMENTALS A mixture of convective from instantaneous light heat and released radiant heat from storage. Note that after the lights are off, there is still the residual stored heat to be removed. In the transfer function method, loads are calculated over a 24-hour period to allow for the heat storage dynamics. In that way, the transfer function method accounts for loads that occur during the unoccupied period which affect the loads during the occupied period. The temperature of the room air is tracked for both occupied and unoccupied periods, and the effects of set point changes, and the magnitude of thermostat response to offset from set point are considered. Looking at Figure 11, there are three items graphed: cooling loads, heat extraction rate, and zone temperature. The first step of the transfer function procedure is to use the conduction and room transfer equations to calculate the cooling load, assuming a constant room air temperature over 24 hours. The next step uses the equipment sizing derived in the first step, along with the control system characteristics to simulate the way the room would be conditioned. From this, the true amount of heat that Figure 11 needs be extracted to maintain the room air temperature set point is de- Transfer Function Elements termined. These calculations take into account the temperature during the unoccupied time. The graph shows that the system starts up early in the morning. The pulldown load on the air conditioning equipment can be readily seen. The system then operates during the course of the occupied period until it shuts off late in the evening. The zone air temperature achieved is also plotted. During the occupied time, the thermostat set point is traditionally about 75° F, and the unoccupied set point will often climb up to around 85° F. Because the transfer function method retains the dynamics of the heat balance method, it can be used for energy analysis as well. Load Estimating 11 LOAD ESTIMATING, LEVEL 1: FUNDAMENTALS Radiant Time Series Method The radiant time series method, as you may expect by now, is a further simplification of the heat balance method, reducing the computation burden of the transfer function method. The term "radiant time series" refers to a set of factors that define the fraction of a heat gain converted to cooling load during a series of hours. The results from this method are similar to the first step of the transfer function method. It calculates a load based on a constant zone air temperature over 24-hours. It is not applicable for doing energy analysis calculations, but is Table 19 Convective and Radiant Percentages of easier to interpret pure load calculaTotal Sensible Heat Gain tion results. Radiant Convective Heat Gain Source Heat % Heat % For walls and roofs, a solar air 0 100 Transmitted solar, no inside shade temperature is derived. This is a tem- Window solar, with inside shade 37 63 perature that has the combined effects Absorbed (by fenestration) solar 37 63 33 67 of solar intensity, external color, and Fluorescent lights, suspended, unvented 41 59 Fluorescent lights, recessed, vented to return air actual dry bulb temperature. It repre81 19 Fluorescent lights, recessed, vented to return air sents the effective temperature on the and supply air 20 80 outside of the wall. Then, each load Incandescent lights element for each of 24-hours is split People 37 63 Conduction, exterior walls into convective (instantaneous) CTS Conduction, exterior roofs 16 84 (Conduction Time Series) and radiant Infiltration and ventilation 100 0 80 to 20 20 to 80 RTS (Radiant Time Series) portions. Machinery and appliances (see Table 13) A sample of the radiant and convec- Sources: Pederson et al. (1998), Hosni et al (1999). tive splits used by some components is listed in Figure 12. The items are then summed up for each hour to get a Figure 12 total for any hour of the day. Radiant/Convective Splits (from ASHRAE 2001 Fundamentals Handbook, Chapter 29) Choosing Which Method to Use No single load estimating method is best. Each method is appropriate for a specific application, depending on the point in the design process, time available to run the calculations, the sophistication of the user, and the desired level of accuracy in the results. The following recommendations are meant to guide the beginning designer as they become familiar with the various methods available. • Preliminary design rough loads – rule of thumb check figures • Schematic building loads – manual methods like storage load factor/ETD or simple block load software using transfer function or radiant time series • Final loads for equipment selection – space, zone, and system loads using block load or system-based design software (HAP) using transfer function or radiant time series With the release of the 2001 Fundamentals Handbook, ASHRAE began promoting the heat balance method for energy analysis and radiant time series method for pure load calculations. Load Estimating 12 LOAD ESTIMATING, LEVEL 1: FUNDMENTALS External Space Loads Earlier, when load components were first presented in Figure 1, external space loads were shown to include everything that directly caused the room temperature to vary, either above (heat gain), or below (heat loss) the set point. These loads can be further broken down into three subgroups: • Weather-Related – made up of predominantly solar gain through glass, along with solar and transmission gains through walls and roof. • Infiltration-Related – not directly weatherrelated, though outside wind speed affects the amount of airflow Figure 13 through the exterior External Space Load Components envelope of the building. Infiltration (and exfiltration) occurs through any opening in the building envelope, whether it is planned like a window, door or HVAC unit sleeve, or unplanned gaps due to poor construction or building component deterioration. • Adjacent-Space Related – made up of heat transfer across any interior partition with a temperature differential across the material assembly. Traditionally these have been thought of as walls, but horizontal assemblies that separate the floors in a building often have the required temperature differential to cause heat transfer. These heat gains and losses, which cause the space temperature to vary from set point, are the same no matter what kind of system is used, whether it is a window unit or a VAV terminal. Later in this TDP we will see that the system chosen will impact the load. Design Conditions As had been discussed, a temperature difference (Δt) is needed for heat to flow. So, some way to determine the peak or extreme outside air temperatures, along with the inside design temperatures, is needed to calculate the maximum heat flows through the building exterior envelope. The load estimating methods also need to calculate heat flow over time, so a means of determining a daily profile of hourly temperatures is needed. Climatic Design Conditions The designer is concerned about both cooling and heating; so two groups of climatic design data are needed. The most current ASHRAE Handbook of Fundamentals is the best source of outside weather data for design conditions across the globe. Tables are available for the United States, Canada, and other world locations. Load Estimating 13 The inside design temperatures are the comfort design conditions; generally 74 to 78˚ F db for cooling and 70 to 74˚ F db for heating. LOAD ESTIMATING, LEVEL 1: FUNDAMENTALS Data is presented for dry-bulb dependent comfort cooling applications, wet-bulb dependent evaporation equipment (cooling towers, evaporative coolers, and fresh air ventilation systems) and dew point extreme conditions that often occur during months of moderate dry bulb temperatures. Cooling In the ASHRAE Climatic Design Data tables, there are three temperature variance choices, 0.4%, 1%, and 2%. These percent values indicate the number of hours in a year that the indicated temperatures may be exceeded. For instance, 0.4% db/mwb means that for 0.004 ∗ 8760 hours/year = 35 hours per year the 0.4% cooling design dry bulb temperature for Chicago of 91º F may be exceeded. It is common for designers to use their best judgment when selecting which design conditions to use. However, beware of the creeping safety factor problem. Consult with your owner to see if being uncomfortable by only a couple degrees inside on those really hot days that do not occur every summer are worth the savings in both first cost and yearly cooling operating costs. Remember, going from the 0.4% column to the 1.0% column means only 53 additional hours per year, or only 7 to 10 occurrences a season, assuming approximately 6 hours of temperature overage on an above-design day. Therefore, a reduction of 3º F in the maximum outside temperature represents nearly a 20 percent drop in the Δt used to calculate the transmission heat transfer (88º F - 75º F, versus 91º F - 75º F). TABLE 2–CORRECTIONS IN OUTDOOR DESIGN TEMPERATURES FOR TIME OF DAY (For Cooling Load Estimates) DAILY RANGE OF TEMPERATURE* (F) DRYOR WETBULB SUN TIME AM PM 8 10 12 2 3 4 6 8 10 12 10 Dry-Bulb Wet-Bulb –9 –2 –7 –2 –5 –1 –1 0 0 0 –1 0 –2 –1 –5 –1 –8 –2 –9 –2 15 Dry-Bulb Wet-Bulb –12 –3 –9 –2 –5 –1 –1 0 0 0 –1 0 –2 –1 –6 –1 –10 –3 –14 –4 TABLE 3–CORRECTIONS IN OUTDOOR DESIGN TEMPERATURES FOR TIME OF YEAR (For Cooling Load Estimates) YEARLY RANGE OF TEMPERATURE(F)* DRY- OR WET-BULB March April May June July August 8 Oct. Nov. 100 Dry-Bulb Wet-Bulb –29 –14 –19 –10 –10 –5 –3 –2 0 0 0 0 –6 –3 –16 –8 –27 –14 95 Dry-Bulb Wet-Bulb –29 –14 –19 –10 –10 –5 –3 –2 0 0 0 0 –6 –3 –16 –8 –27 –14 TIME OF YEAR Figure 14 Outdoor Temperature Corrections (from Carrier SDM-1, Chapter 2) Cooling is a time-dependant series of calculations. Many of the methods require a full day's time frame for the dynamics of the procedures. The practical reasons are that different thermal loads peak at different times. For example, the east peaks in the summer morning, while the west peaks in the summer afternoon (Figure 16 shows this graphically). The south side may peak in the fall because of the influence of the solar load created by the sun's lower position in the sky. However, when the system or coil load is determined, it may be in the summer mid-afternoon because of the effect of the high enthalpy (sensible and latent heat content) outdoor air. Figure 14 shows portions Load Estimating 14 LOAD ESTIMATING, LEVEL 1: FUNDMENTALS of tables from SDM-1 that can be used to determine peak cooling temperature for various sunlit hours for a hot day in each month of the year. The tables are based on the daily range and the annual range (full tables are in the Appendix). Figure 15 shows a graphical representation of a design day for Chicago in August. Figure 15 Design Temperature Profiles - August Heating Design heat loss is a simple calculation involving the design minimum outside air temperature. It is usually based on the ASHRAE 99.6 percent value or the judgment of the designer. For Chicago, the number is -6º F. When performing design heat loss calculations, there are no credits taken for any internal loads or solar heat gains. This is because the maximum heating losses usually occur in the morning hours, often before the building is occupied, meaning offsetting loads from lights, people, equipment, and even solar would not be present. When selecting climatic design temperatures, the addition of a few degrees to the ASHRAE design data may be the first of many additive safety factors that creeps up on the designer. Solar To go along with the cooling design temperature profiles, a means of calculating peak effects from the sun is needed to figure out the solar loads through the glass. The solar load component represents the amount of radiant energy transmitted to the space through ordinary single pane glass. Hand calculation methods use tables of data, while computer software programs make this 2 data ready to use for the site city. The solar data is in Btuh per ft of glass area, comprised of both beam radiation (direct) and diffuse radiation (indirect, or scattered). Load Estimating 15 LOAD ESTIMATING, LEVEL 1: FUNDAMENTALS The compass points and number of exposures have an impact on the solar loads. The position of the sun not only varies with time of day, but significantly with time of year, which is determined by the latitude (angle of the sun) and longitude (sun time versus time of day) of the building site. For example, an east exposure has a morning peak in the summer. The south side has a peak around noon and it may be in the fall. The west glass peaks late afternoon in the summer, while the north glass receives only scattered diffuse sunrays in northern latitude locations like the United States. Occasionally, a cooling load study is done based on the building site orientation, especially if a large amount of glass is to be used. Since radiant energy is not a heat gain until it strikes some object and is absorbed, this does not represent the amount of heat to be removed by the Figure 16 air conditioning equipment. Glass Solar Heat Gain types, special coatings, and internal and external shading all cut back on the amount of solar energy that comes into the room. Coefficient Conversion You can convert from one to The value that is eventually derived to modify the so- another. SHGC = (0.87) * SC lar heat gain value is called either a shade coefficient (SC) or a solar heat gain coefficient (SHGC). The SHGC is the current rating method used for both the transfer function and radiant time series methods. These two coefficients are not the same. The shading coefficient should be used if the CLTD/CLF method is utilized. Window and Glazing Types The National Fenestration Rating Council (NFRC) is a good source for detailed information on windows and glazing types (simply called "glass"). Most manufacturers of windows and glass also offer technical information for computing solar heat gain when using their products. Energy codes have all but done away with single pane 1/8-inch clear glass. Double-pane windows using two layers of glazing are most common, and on occasion in very cold climates triple-pane glazing assemblies are used. Glass comes in different thickness, 3/16 in., 1/4 in., and 1/8 in. Between the panes, there Figure 17 Window and Glazing Types Load Estimating 16 LOAD ESTIMATING, LEVEL 1: FUNDMENTALS can be different gaps 1/4 in. and 1/2 in., filled with air, krypton, or argon. These refinements all reduce the SHGC and affect the overall U-factor. The frame types, such as aluminum, wood, or vinyl, with or without thermal breaks, greatly affect the thermal performance and comfort for those seated near the windows. Coatings Further refinements in glazing performance come from inner and outer panes that have both tinting such as bronze, gray, or blue-green, and reflective coatings to reduce the transmission of solar energy with limited reduction of the visible light portion of the spectrum. Low-emission glass (low-e) is a clear glass that has a microscopically thin coating of metal oxide. This allows the sun's heat and light to pass trough the glass into the building. At the same time it blocks heat from leaving the room, reducing heat loss considerably. Buildings no longer need to excessively limit the glazing area to meet the energy conservation codes. Shading - Internal, External, and Adjacent Buildings One way to cut down on the amount of solar beam energy is to reduce the effective glass area and/or reflect some radiation back to the outside. Internal shade type describes the type of drapes, shades or Venetian blinds used with the window. The presence of interior shades, and the characteristics of the shading device, affects conductive and convective heat flows through the window assembly, as well as the transmission of solar radiation into the building. Shade properties therefore influence the calculation of the overall window U-factor, the shading coefficient, and the transmission and solar loads for the window. Internal shades, depending on color, reflect a portion of the solar radiation back out the window, reducing the SC. Light colors reflect solar more than dark colors. For example, the windows in the Chicago example building have a U of 0.650 and an SC of 0.658, without internal shades. With an open weave light-colored fabric, the U is improved to 0.544 because of the additional insulation, and the SC is lowered to 0.496. With a medium colored fabric, the U is unchanged but the SC is larger at 0.547. Because this is radiant heat, the way the solar is accounted for is affected. If the shades are drawn, the radiant solar energy strikes the shades and is absorbed because the shade material is lightweight the heat is released to room almost immediately. If the shades are not drawn, the solar comes into the room that has much more mass and the solar heat is absorbed and released later and at a slower rate, lowering the value of the peak load and shifting it to later in the day. External shading is commonly done with fins, overhangs, and reveals that are described in relation to the window. They reduce the area through which the sun directly shines. Hand Figure 18 calculation methods do not provide External Shading Load Estimating 17 LOAD ESTIMATING, LEVEL 1: FUNDAMENTALS accurate results for external shading. However, computer software can do the job with all the calculations needed to get hour-by-hour shading from exact solar angles, just as latitude and longitude are accounted for. Shading (or even bounce light from reflective surfaces) from adjacent buildings is very difficult to calculate unless it shades surfaces all day. Then, just diffuse radiation can be assumed and a "north" exposure can be used to model this situation. Computer methods would need to reference the relationships of the adjacent building to walls and windows in the subject building in x-, y-, and z-coordinates. This would be very user-intensive and prohibitive from a practical standpoint. Therefore, designers will have to wait until these building interrelationships can be gained by CAD software communicating with load estimating software. Transmission If a temperature difference exists between the inside and outside surfaces, heat will flow by conduction to the cooler side. These are called transmission losses. There are varieties of surfaces that need to be accounted for in a cooling or heating load estimate to calculate all the conduction thermal loads. Remember, the equivalent temperature difference is used to account for the impact of solar loading on walls and roofs. Wall and Door Wall calculations can be performed manually using a U-factor for the wall materials assembly most closely matching the building design. There are tables of transmission coefficients (Ufactor) in SDM-1 or older ASHRAE Fundamentals Handbooks that allows the user to select the most appropriate U-factor. The ASHRAE Fundamentals Handbook no longer has these tables since current methods like radiant time series use heat transfer coefficients layer-by-layer. The transfer function method uses the same method to calculate heat transfer as radiant time series. However, quick comparisons of the overall U-factors will generally indicate relative resistance to heat flow of various assemblies. As discussed earlier, U-factors can be derived from tables of material R-values. Door transmission gains or losses in commercial load estimates are sometimes ignored because they represent a very small fraction of the total load. If they are to be considered, a simple U-factor calculation is sufficient. This would not be the case if the doors were mostly glass, in which case they could be considered a separate window type. Roof The roof on a commercial building is usually horizontal and receives a lot of sunlight. Therefore, the effective temperatures are relatively high. If the roof is sloped, the area to be used in the transmission calculation is determined by measuring the area of the insulation layer at its location, either along the slope line or at the horizontal plane of the attic. The heat flow path starts with the ceiling material, then the air space above, all the way through the insulation and roof material assembly to the outside surface. Manual load calculations will require deriving the U-factor, or coefficients are internally computed for current software methods. Load Estimating 18 LOAD ESTIMATING, LEVEL 1: FUNDMENTALS Windows and Skylights Besides the solar load component, glass also has a transmission component. Similar to walls and roofs, the overall U-factor is used for this calculation. On Grade and Below Grade The temperature of the ground complicates calculation of the heat gain through the on grade floor or through basement walls below grade. The ground temperature near the surface is close to the outside air temperature, but further down the ground temperature approaches a rather constant value of from 45º F to 65º F, depending on the geographical area. There is very limited impact on the cooling load from the earth as most of the heat transfer is a heat loss. Heating loads, which will be dis- Figure 19 cussed later, are much larger. Transmission Below Grade Infiltration In addition to the other sources of heating or cooling loads, another tricky component is the effect of infiltration. These unplanned airflows must be heated or cooled to room conditions, often adversely affecting perimeter spaces. Experienced designers will say that estimating infiltration is like sticking a wet thumb in the air to estimate wind velocity. Modern construction techniques result in tightly constructed buildings with minimal envelope infiltration. In low-rise buildings with fixed windows, and in those facilities operated under a slight positive pressure, infiltration can often be ignored. Most designers simply add a small safety factor to the load estimate to account for infiltration. The exceptions are high-rise buildings and those expected to be subjected to high wind loads. Load Estimating 19 Some old rules of thumb that have been used for older buildings are 1 air change per hour in the summer and 2 air changes per hour in the winter. LOAD ESTIMATING, LEVEL 1: FUNDAMENTALS Wind and Stack Effects The pressure of the wind causes air to enter (infiltrate) the windward side of a building and leave (exfiltrate) the opposite (leeward) side. Stack effect, often called buoyancy, is caused by air density differences due to temperature and relative humidity differences between the indoor and outdoor air. Stack-effect induced airflow can be significant in tall buildings that are not sealed tightly at the floorline. The relative importance of the wind and stack pressures in a building depends on building height, internal resistance to vertical airflow, location and flow resistance characteristics of exterior envelope openings, local terrain, and the immediate shielding of the building. Figure 20 Stack Effect for an Idealized Building Sensible and Latent Components The infiltration air, when it is at a different temperature or moisture content, will impose additional space loads on the heating and cooling system. Infiltration is treated as a space thermal load. The difference in air temperatures is a sensible load addition. Figure 21 Infiltration, Sensible Component The difference in moisture content is a latent load addition. Figure 22 Infiltration, Latent Component Load Estimating 20 LOAD ESTIMATING, LEVEL 1: FUNDMENTALS Partitions, Floors, and Ceilings Some conditioned spaces in a building may be adjacent to unconditioned or partially conditioned spaces. When this occurs, heat is conducted by the temperature differences across the dividing material assemblies. It may be an interior wall (partition) next to a minimally heated warehouse. On the other hand, it may be a floor above an unconditioned parking garage or a ceiling that has a hot attic above it. All that is needed, of course, for a hand calculation is the Ufactor, Δt, and area. Computer software may offer ways to change the temperature on the unconditioned side in some relationship with outside air to account for the dynamics over time. Internal Space Loads In non-residential buildings, the internal loads are a significant item in the load calculations. The designer must estimate the peak usage of lights, number of people, electric equipment, and plug load. The other item of judgment, besides how much, is when. The current dynamic methods used in computer software need the amount during the unoccupied hours as well to estimate the magnitude of pulldown loads. In some industrial applications items such as electric motors, exposed piping, tanks, and other process items need to be Figure 23 Internal Space Load Components included in the calculation. People Heat is generated within the human body by oxidation − commonly called metabolic rate. This heat is carried to the surface of the body and dissipated by: 1. Conduction from the body to the objects the person touches and to the air surrounding them. Figure 24 Heat Transfer from People Load Estimating 21 LOAD ESTIMATING, LEVEL 1: FUNDAMENTALS 2. Convection from the body and respiratory tract into the air close to the person. Since warm air is lighter, or less dense, than cool air, the warm air floats upward. The warm air is replaced by cooler air, and the process continues. 3. Radiation from the body to the surrounding colder surfaces. 4. Evaporation of moisture from the body surface and in the respiratory tract to the surrounding air. This chart shows representative values for latent and sensible heat gain from people. The values depend on room temperature and size (male, female or child). ASHRAE has tables and correction factors and computer software may have additional activity levels available for the designer. A quick rule of thumb is 100 people represent 3 to 4 tons of total cooling load. Figure 25 Heat Gain from People Lighting Lights generate sensible heat by the conversion of electrical power, or Watts (W), into light and heat. The energy is dissipated by radiation to the surrounding surfaces, by conduction into adjacent materials, and by convection to the surrounding air. Lights as a load component are typi2 cally referred to as lamp Watts per ft of floor area. The radiant energy from lights is stored in the mass of the building and appears later as a load in the space. This is the same process that occurs with solar radiant energy, and current software methods factor this into the calculations. Incandescent lamps convert approximately 10 percent of W into light. The remaining 90 percent of W turns into heat within the lamp. This heat then transfers into the space, 80 percent by radiation and 10 percent by conduction plus convection. This kind of light is used for task lighting, where its application reduces the need for higher overall lighting levels. Figure 26 Lighting, Incandescent Load Estimating 22 LOAD ESTIMATING, LEVEL 1: FUNDMENTALS Fluorescent light fixtures are more commonly used in commercial buildings for general lighting. Since about 23 percent of W is converted into light by fluorescent lamps, they are more efficient than incandescent lamps. Even though more efficient, a full 45 percent of W dissipates by conduction and convection to the space. Additionally, the final 10 percent of the input power turns into heat in the electronic ballast feeding the lamps. Figure 27 Lighting, Fluorescent Electric Equipment (Plug Load) Other devices such as computers, printers, copy machines, and appliances use electrical energy. Sometimes they are all lumped into a category of miscellaneous electrical equipment or plug load. Carrier SDM-1 or ASHRAE has tables of information for many kinds of appliances. For instance, a 12-cup coffee maker with two burners is 3750 Btuh sensible and 1910 Btuh latent. Just taking the nameplate data and adding them up gives too large a plug load. In an article in the ASHRAE Journal (June 2000, Heat Gain from Office Equipment), it was reported that the average nameplate Watts for tested computers was 391, while the average heat dissipation was 2 only 55 Watts. It was also found that heat gain was between 0.44 Watts per ft to 1.05 Watts per 2 2 ft , with an average of about 0.81 Watts per ft . The more unique the equipment or specialized the usage, i.e. medical laboratory, it is best to use published heat dissipation values for the actual equipment from the manufacturer (or installation and service manuals). Electric Motors Electric motors contribute sensible heat to a space by converting the electric power input (Watts or horsepower) to heat. Heat gain from electric motors depends on many factors, including motor horsepower, motor efficiency, motor hours used within a time period, how heavily the motor is loaded, and whether or not the motor and driven equipment is located inside or outside of the conditioned space or airstream. Motor Nameplate or Rated Horsepower Standard Efficiency EPACT Min. Efficiency Premium Efficiency 1/20 1/12 1/8 1/6 1/4 1/3 1/2 3/4 1 1 1/2 2 3 5 7 1/2 10 15 20 25 30 40 50 60 75 100 125 150 200 250 35.0 35.0 35.0 35.0 54.0 56.0 60.0 72.0 75.0 77.0 79.0 81.0 82.0 84.0 85.0 86.0 87.0 88.0 89.0 89.0 89.0 89.0 90.0 90.0 90.0 91.0 91.0 91.0 82.5 84.0 84.0 86.5 87.5 88.5 89.5 91.0 91.0 91.7 92.4 93.0 93.0 93.6 94.1 94.1 94.5 95.0 95.0 95.4 89.5 89.5 91.7 91.7 93.0 93.0 93.6 93.6 94.5 94.5 95.0 95.4 95.4 95.4 95.8 96.2 96.2 NOTES: Electric Motor Efficiencies 23 364 606 909 1,212 1,178 1,515 2,121 2,651 3,393 4,958 6,443 9,426 15,518 22,723 29,941 44,390 58,506 72,301 85,787 114,382 142,978 171,573 212,083 282,778 353,472 419,505 559,341 699,176 127 212 318 424 636 848 1,273 1,909 2,545 3,818 5,090 7,635 12,725 19,088 25,450 38,175 50,900 63,625 76,350 101,800 127,250 152,700 190,875 254,500 318,125 381,750 509,000 636,250 236 394 591 788 542 667 848 742 848 1,140 1,353 1,791 2,793 3,636 4,491 6,215 7,606 8,676 9,437 12,582 15,728 18,873 21,208 28,278 35,347 37,755 50,341 62,926 Ratings for open, drip-proof type, 4-pole, 1800 rpm motors Totally-enclosed, fan-cooled (TEFC) motor ratings slightly higher Consult motor manufacturer's ratings for specific data Figure 28 Load Estimating Heat Gain From Standard Eff. Motor in Location Btu/hr A B C LOAD ESTIMATING, LEVEL 1: FUNDAMENTALS If the building is an industrial application, then the motors driving the process machinery also are a source of internal heat gain. There are sources beyond Figure 28 for data used in calculating motor heat loads, including manufacturers, ASHRAE 90.1 Energy overall loads can be related to the outside temperature and solar loading, much in the Figure 34 same way the HVAC system capacity responds Example Building Load Data (Top Floor) to the changing outdoor air load conditions. Building the Profile The first step is to set up a grid of the outside dry bulb temperatures that cover the annual range for the subject building or zone on the horizontal axis. Sensible load values are plotted vertically in Btuh, both as positive heat gains (cooling), and negative loads or losses (heating). The transmission peak loads are first plotted on the design heating and cooling temperature lines, using the data from the completed load estimate, in this case the top floor of the Chicago Office Building (Figure 34). Then a line is drawn between the design conditions to establish the slope of the load profile (Figure 35). The line crosses zero Btuh at the room set point. This uses the simplifying assumption of steady Figure 35 Completed Space Load Component Profiles Load Estimating 31 LOAD ESTIMATING, LEVEL 1: FUNDAMENTALS state heat flow. The slope of this line will change with different glass ratios, becoming steeper as the amount of glass increases. It can be seen that the net heating is less when it is cold outside and net cooling is greater when it warm outside. Next, design cooling condition points should be established for lights, people, and miscellaneous electric (plug load). These internal loads are always cooling loads. Lines are drawn through each point parallel to the base profile line established by the transmission load. Without the addition of the transmission sloping line, these items would be straight horizontal lines as they are cooling loads at all temperatures. Adding the solar data completes the load profile (Figure 35). Here, a straight line based on the design cooling condition represents the solar data. In actuality the solar load varies significantly, both by time of day and time of year, requiring more complexity than a manual profile warrants. Balance Points Load profile balance points are those temperatures where the load lines cross over from cooling to heating. Looking at the completed profile, heat gain from lights will be offset by transmission losses when it is 44º F or lower outside. Adding people load causes the balance point to decrease to 40º F. When miscellaneous electrical loads are added, balance point drops even further to 27º F. As noted, the solar loads are highly variable, but it is easy to see how a building might require cooling even below freezing conditions outside. The Chicago Office Building example shows the internal loads offsetting the transmission losses all the way down to 6° F. This extreme condition should be tempered with the infiltration load and the fact that not every light will be turned on or every person occupying the building. A more reasonable statement would be that our example building would most likely be in cooling down to the 30s, possibly even to below freezing. The eventual system selected for the building needs to accommodate this need for cooling during lower outside temperatures, either with an economizer cycle or through equipment selected to operate at the reduced temperatures. Plotting on the Psychrometric Chart A psychrometric plot of the system under design is necessary for a thorough understanding of the process and perhaps troubleshooting potential problems. If hand calculations are done, the process must be plotted manually on a psychrometric chart to assist in the design of the system. Some software load estimating programs can create these as part of the output. Load Estimating 32 LOAD ESTIMATING, LEVEL 1: FUNDMENTALS State Points When any two properties of an air-water mixture are known, the exact condition of the air can be located on the psychrometric chart, then all other properties can then be found from this one point. Such a point is referred to as a state point. There are a number of state points that can be determined from running a cooling load estimate for an HVAC system. The simplest two are the room cooling set point and outside air design climatic condition. A third state point is the supply air temperature entering the space. This number is not needed for a basic manual load estimate, but is a common input for load estimating software. Efforts to model the HVAC system to refine the load require it as an input or it is a system data output when the designer uses other defining parameters such Figure 36 as airflows for either the State Points and RSHF Line air handler or the zone terminals/diffusers. Room Sensible Heat Factor (RSHF) Line The room sensible heat factor is the ratio of the room sensible heat to the summation of room sensible and room latent heat. This ratio for a typical Chicago Office Building space is calculated as follows: RSHF = RSH 6072 Btuh = = 0.97 RSH + RLH 6072 Btuh + 160 Btuh The RSHF line is drawn through the room set point on Figure 36 as a line parallel to a sensible heat factor line of the same value (using the reference point on the chart). When adequate conditioned air is supplied to offset the room loads, the room set point will be satisfied, provided both the dry bulb and wet bulb temperatures of the supply air fall on the RSHF line. Colder air would need less airflow and warmer air more airflow. Load Estimating 33 LOAD ESTIMATING, LEVEL 1: FUNDAMENTALS System Lines The psychrometric chart shown here has completed the circle by showing the effects of system loads and the performance of the cooling coil. The effect of fan heat (point 1 to 2), supply duct heat gain (point 2 to 3) are shown, along with point C, which is the effect of mixing outdoor air with the return air to arrive at the coil entering conditions. These advanced load-estimating concepts for system-based design will be covered in Figure 37 both the third and fourth System Lines TDPs in the Load Estimating series. Heating Load Estimate Heating loads are a simplified version of cooling loads. Figure 38 shows that the envelope heating load losses are derived from steady state transmission and infiltration losses, while loads like ventilation outdoor air are most often system load components, which also apply to heating loads. The methods involved in calculating the loads have already been discussed in previous sections of this TDP. Determining the heat loss through basements and slab on grade floors becomes a little more complex than the simple $q = U * A * \Delta t$ transmission equation. The manual method, presented in detail in SDM-1, utilizes Form E-10A (found in Appendix). Most computer software load estimating methods automatically per- Figure 38 form a heating load when Heating Load Components calculating a cooling load. Load Estimating 34 LOAD ESTIMATING, LEVEL 1: FUNDMENTALS Design Conditions To determine the temperature difference to be used across the exterior walls, the climatic design conditions need to be established first. From the ASHRAE Fundamentals Handbook, the heating 99.6 percent column value (reversal of 0.4 percent column used for cooling) for Chicago is -6º F. The room set point depends on the application. Comfort for an office building may be 70º F, while a warehouse may be only 45º F. Healthcare projects are applications that may require a wide range of set points in some areas, so you may need to design for 68º F cooling and 80º F heating. Transmission Transmission losses are normally the major heat transfer values in a space heating load estimate. The building walls, roof, glass, and foundation / basement comprise the load components. The temperature differences used are the differences between the room set point and the temperatures on the other side of the appropriate structural barrier (heating design climatic data, adjacent room temperature, or soil temperature). Heat loss through walls above grade is determined in the normal steady state transmission equation fashion. Floor and Basement Heat Losses For slab on grade and partially below-ground construction, the major heat loss takes place around the perimeter. The International Energy Conservation Code and ASHRAE 90.1 Energy Code require good levels of insulation along the full perimeter, extending down into the upper level of the soil, usually the first couple of feet, but no greater than the frost depth. The standard transmission equation is used to calculate the heat loss. While the floor loss is a minor percentage of the total heat loss, it is quite important for comfort, since cold floors mean an improperly heated building. The heat loss from a full-depth basement is the result of a complex heat transfer process. The complexity is due to the variable ground temperature surrounding the basement. Below 8-ft, the ground is an excellent heat sink and can absorb large amounts of heat with little appreciable change in soil temperature. Above the 8ft level, a temperature gradient exists due to the influence of the outside air temperature. The greatest variation exists at the surface and decreases down to the 8-ft level. In order to simplify the heat loss calculation, Figure 39 shows four possible calculations that could be involved. Figure 39 Basement and Floor Heat Losses Load Estimating 35 LOAD ESTIMATING, LEVEL 1: FUNDAMENTALS Basement Floor The heat loss through a basement floor is normally small and relatively constant year round because the ground temperature under the floor varies little throughout the year. SDM-1 Table 37 shows the TABLE 37—GROUND TEMPERATURES ground temperature to vary only FOR ESTIMATING HEAT LOSS THROUGH BASEMENT LOSSES 25º F while the outside air temperature varies 50º F (from -30º F to +20º –30 –20 –10 0 +10 +10 Outdoor Design Temp (F) F). SDM-1 Table 35 also shows the Ground Temp (F) 40 45 50 55 60 65 transmission coefficient (U) for an uninsulated masonry floor of any Figure 40 thickness to be approximately Ground Temperatures (from SDM-1, Chapter 5) Heat losses 0.05 Btuh · ft 2 · °F . through the basement floor is therefore determined by the following equation. $q = U * A * (t_B - t_G)$ Where: U is 0.05 Btuh · ft 2 · °F A is the net floor area in ft2 t_B is the basement temperature t_G is the ground temperature Walls 8-ft Below Grade Like the basement floor, the heat loss through a masonry wall of any thickness may be approximated in the same manner as that done for a basement floor. The U-factor for masonry walls from Table 35 should be 0.08 instead of 0.05 Btuh · ft 2 · °F . TABLE 35—TRANSMISSION COEFFICIENT U– MASONRY FLOORS AND WALLS IN GROUND (Use only in conjunction with Table 35) Floor or Wall Transmission Coefficient U (Btuh) (sq ft) (deg F) * Basement Floor 0.05 Portion of Wall Exceeding 8 feet ground level Below 0.08 *Some additional floor loss is included in perimeter factor, See Table 36. Equations: Heat loss through floor, Btuh = (area of floor, sq ft) ∗ (U value) ∗ (basement – ground temperature). Heat loss through wall below 8 foot line, Btuh = (area of wall below 8 ft line, sq ft) ∗ (U value) ∗ (basement – ground temp). NOTE: The factors in Tables 35 and 36 may be used for any thickness of uninsulated masonry wall or floor, but there must be a good contact (no air space which may connect to the outdoors) between the ground and the floor or wall. Where the ground is dry and sandy, or where there is cinder fill along wall or where the wall has a low heat transmission coefficient, the perimeter factor may be reduced slightly. Figure 41 Transmission Coefficients (from SDM-1, Chapter 5) Load Estimating 36 LOAD ESTIMATING, LEVEL 1: FUNDMENTALS Grade to 8-ft Below In order to account for the variable temperature gradient, SDM-1 Table 36, provides a perimeter factor based on the distance of the floor (wall height) below grade. Heat loss is determined by the following equation: $q = L_p * Q * \Delta t$ TABLE 36—PERIMETER FACTORS FOR ESTIMATING HEAT LOSS THROUGH BASEMENT WALLS AND OUTSIDE STRIP OF BASEMENT FLOOR (Use only in conjunction with Table 35) Distance of Floor From Ground Level Perimeter Factor (Q) 2 Feet above At ground level 2 Feet below 4 Feet below 6 Feet below 8 Feet below 0.90 0.60 0.75 0.90 1.05 1.20 Where: Q is the perimeter factor from Table 36 Equation: Heat loss about perimeter, Btuh = (perimeter of wall, ft) L_p is the lineal feet of basement ∗ (perimeter factor) ∗ (basement – outdoor temperature). wall (perimeter) Δt is the difference between out- Figure 42 side air and basement Perimeter Factors (from SDM-1, Chapter 5) temperatures. Infiltration Infiltration air quantity in the winter can be more than in the summer because of the increased wind velocities, from an average of 7.5 mph in summer to 15 mph in winter. In addition, a much larger temperature difference exists between the outside and inside air temperatures. Predicting infiltration rates before a building is constructed is not an easy task. Modern building construction techniques result in tightly constructed buildings with minimal infiltration. Infiltration can often be ignored for low-rise buildings with inoperable windows and those operated under a slight positive pressure. Most designers simply add a small safety factor to their heating load es- Heating infiltration rules of thumb: timate to account for infiltration. The exceptions are Older buildings leak at 1 air high-rise buildings and those expected to be subjected to change per hour in the summer high wind loads. Unoccupied heating should be checked and two air changes per hour in to see if including infiltration raises the total load be- the winter. cause most buildings go to intermittent fan operation at night, allowing infiltration to occur. Load Estimating 37 LOAD ESTIMATING, LEVEL 1: FUNDAMENTALS No Credits The heating load is estimated for the winter design temperatures, which usually occur at night. Consequently, no credit is taken for the heat given off by internal sources (people, lights, etc.). Some buildings, such as telephone exchanges, which have a continuous reliable source of heat, could use their heat source as a credit. Typically, however, a conservative approach to sizing heating equipment is taken, i.e., sizing for the worst-case condition. Due to the large difference between outside and inside air temperatures, space comfort could be adversely affected in worstcase conditions. Worse yet, frozen pipes, tanks, etc. could lead to very costly damage if the heating capacity was not available. Warm-Up Safety Factor If night setback temperature control is used to conserve energy, then some warm-up safety factor is needed as equipment reserve capacity to be available at the start of the occupied cycle to bring the space up to set point in a reasonable amount of time. A warm-up safety factor of 25 percent is often used in colder climates. Summary Load estimating is very important to HVAC system design because it not only calculates the many heat transfer load components that make up cooling and heating loads, it can model the dynamics of the building, along with the unique response of a specific HVAC system. Heat transfer theory is relatively straightforward, utilizing simple formulas and computer software that models the complex dynamics of building heat storage and time-dependant heat balance equations. Like many other aspects of HVAC design, simple check figures and rules of thumb allow the load estimating process to begin early in the design cycle when rough approximations are needed by the design team. Load estimate output data is useful to the designer in many ways. Load profiles give the designer a visual representation of the load estimate relationship to outside air temperature and permit analysis of key load component impacts on building performance. Plotting state points and the RSHF line on the psychrometric chart begin the process of representing the interaction between the building load estimate and HVAC system response to the load. Always make sure the building data is accurate, that the load estimate output is consistent with the building/HVAC system design, and do not forget to use the simplest method of estimating that fits the current need. Towards the middle of the design process, once most of the building component and system equipment details have been firmed up, use a software load estimating process that will be easy to update and keep current as the designs are finalized. Load Estimating 38 LOAD ESTIMATING, LEVEL 1: FUNDMENTALS Work Session 1 1. Why is it important to understand the sources of the various building load components and how to combine them? ____ ____ 2. What three categories can all load components be classified into? ____ ____ ____ 3. Explain what infiltration is. ____ ____ 4. Explain why it is difficult to accurately estimate this load component ____ ____ 5. Under what conditions would ventilation air be considered a room load? ____ ____ 6. Name the four supply air losses that exist between the coil of a central air handler and the room supply air terminal. ____ ____ ____ ____

7. Would a blow through fan arrangement in a central air handler cause you to calculate the supply air fan heat (SAFH) as a loss between the coil and supply air terminal? (Yes/No)? Why? ____ ____ ____ 8. Why must exhaust air be considered in a typical air conditioning system? ____ ____ 9. Define Grand Total Heat (GTH). ____

Load Estimating 39 LOAD ESTIMATING, LEVEL 1: FUNDAMENTALS 10. Define refrigeration load. ____ ____ 11. What is the meaning behind the ASHRAE 0.4%, 1%, and 2% cooling db/mwb temperature columns? ____ ____ 12. Of what use is the maximum design summer wet bulb temperature? ____ ____ 13. In what project locations might one expect to use the maximum wb/mdb temperature columns? ____ ____ 14. Why is the peak of the horizontal glass curve so much greater than that of the south glass? ____ ____ 15. Why is the solar gain through the west glass nearly zero before noon? Why isn't it zero? ____ ____ 16. Explain why the actual cooling load caused by the sun's rays penetrating a window is smaller than and occurs at a peak time later than the instantaneous solar heat. ____ ____ 17. Can the simple steady state equation ($q = U * A * \Delta t$) be used to determine the wall and roof transmission loads? ____ ____ 18. Explain what Equivalent Temperature Difference (ETD) represents. ____ ____ Load Estimating 40 LOAD ESTIMATING, LEVEL 1: FUNDMENTALS 19. Determine the sensible and latent load created by 100 people dancing (moderately) in a room whose temperature is maintained at 75º F. ____ ____ 20. Explain why stored energy from lights is generally neglected in calculating the light load component for a building. ____ ____ 21. Explain why an accurate estimate of supply duct losses is not possible at the load-estimating phase of an air conditioning system design. ____ 22. What is a typical percent of RSH used to estimate supply duct heat gain? ____ ____

23. Indicate where you would estimate the fan heat losses for the following: Supply Duct Return Duct A. Draw through fan ____ ____ B. Blow through fan ____ ____ 24. Explain what bypassed outdoor air load is. ____ ____ 25. When the ceiling plenum is located under a roof, ____ % of the roof load is absorbed by the return air, and ____ % is transmitted to the space. ____ % of the light heat is transmitted to the space, while ____ % is picked up by the return air. 26. Name the load components that make up a building heating load. ____ ____ 27. What load components could be used as a heating load credit? Explain why. ____ ____

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