Required Reading; Cooling Load: Part One

Walter Grondzik

Context

These notes have been prepared to supplement the relatively small amount of information in your textbook dealing with design cooling load. There are several methods that can be used to calculate building cooling load. The most basic of these methods is use of a rule-of-thumb value—for example, square feet of floor area per ton of cooling. Such rules-of-thumb are useful in schematic design as a means of getting an approximate handle on equipment size and cost. The main conceptual drawback to extensive use of rules-of-thumb is the presumption that design decisions will not make any difference. Such rules tend to predict the same outcomes for a bad design as for a good design. This is not the case—design matters.

The method of calculating cooling load presented in *Mechanical and Electrical Equipment for Buildings* (using Design Equivalent Temperature Differences and Design Cooling Load Factors) is a somewhat more sophisticated method developed primarily for single-family residences. The biggest drawback to this method is that it lumps most opaque envelope components together, such that a dark east wall is considered similar to a shaded south wall or a flat asphalt roof. In commercial/institutional buildings such simplifying assumptions are not appropriate. These assumptions also tend to suggest that good design—understanding how building components perform and using that knowledge to improve performance—has little effect.

The method of calculating design cooling load presented herein is a manual method developed by ASHRAE. It does not mask the effects of design decisions; in fact, can easily be used to test the impacts of design decisions on building performance. Computerized simulations using much more sophisticated ASHRAE methodologies are commonly used to predict design cooling load in practice. These methods, however, do not provide insight into how envelope design input drives cooling load output—cause and effect are not always clearly related.

Introduction

Heat loss calculations are made to determine a building heating load. Under the fairly static conditions experienced under the assumptions used to make such calculations, “heat loss” and “heating load” are functionally identical. Heat loss (the simultaneous summation of all heat flows out of a building) is synonymous with heating load (the capacity of equipment required to account for such a load). The same is not true of “heat gain” and “cooling load.”

Heat gain is a simultaneous summation of all heat flows into a building through the envelope along with those flows generated inside the building envelope. Cooling load is the capacity of equipment required to account for such a load. Due to the dynamic nature of heat gain, and the opportunities for heat storage (capacitance) that accompany dynamic loads, heat gain is often not equal to cooling load. Gains that enter a building but are stored in materials or furnishings do not have to be “handled” at the time of initial flow—and are not included in cooling load. In general, convective and latent heat flows are instantaneous; for these elements, flow equals load. Radiant loads tend to be partially stored in a building (what percentage depends upon several factors); for radiation, flow does not equal load.

As with heat loss, it is necessary to calculate a “design” load to characterize building performance during over-heated period (normally summer) conditions. For an individual room in a building, peak cooling load may occur in spring or fall—making the use of software to analyze complex buildings essentially mandatory. Design cooling load calculations are normally made to size HVAC (heating, ventilating, and air-conditioning) systems and their components. A building experiences a range of cooling loads in any given year, ranging in magnitude from zero (no cooling required) to whatever the maximum load happens to be that year. A “design” cooling load is a load near the maximum magnitude, but is not normally the maximum. This should become clear when the assumptions behind the calculations are understood. Design cooling load is intended to summarize all the cooling loads experienced by a building under a specific set of assumed conditions.

The assumptions behind design cooling load are as follows:

1. Weather conditions are selected from a long-term statistical database. The conditions will not necessary represent any actual year but are representative of the location of the building. ASHRAE has tabulated such data, as have other groups. The designer may select a “severity” of weather that seems appropriate for the building type in—although energy codes may specify what data shall be used (to minimize over-sized systems).

2. The solar loads on the building are assumed to be those that would occur on a clear day in the month chosen for the calculations.

3. The building occupancy is assumed to be at full design capacity.

4. All building equipment and appliances are considered to be operating at a reasonably representative capacity.

5. Lights are assumed to be operating as expected for a typical day of design occupancy.

6. Latent as well as sensible loads are considered.

7. Heat flow is analyzed assuming dynamic conditions, which means that heat storage in building envelope and interior materials is considered.

The above assumptions make calculation of design cooling load much more complicated and complex than calculations of design heat loss (with its many simplifying assumptions). Unfortunately, there is no way around this—especially in a cooling load dominant climate as occurs in much of the southern United States as well as in internal-load dominated building typologies.

The total building cooling load will involve heat transferred through the building envelope and heat generated by occupants, equipment, and lights. The envelope heat flows are termed external loads, in that they originate with the external environment. The other loads are termed internal loads, in that they are generated from within the building itself. The percentage of external versus internal load varies with building type, site climate, and building design decisions. The total building cooling load also consists of sensible load components and latent load components. The sensible loads will affect dry bulb air temperature; the latent loads will affect absolute (and thus relative) humidity.

Buildings are classified as envelope-load-dominated and interior-load-dominated. Envelope-dominated buildings (also called external-load-dominated) experience most of their cooling loads as a result of the interaction between the exterior environment and the interior environment. Interior- (or internal) load-dominated buildings experience most of their cooling loads as a result of activities occurring within the building. It is useful to be able to predict whether a building will be dominated by internal or external loads as this knowledge will substantially change the focus of design efforts related to energy efficiency.

External (Envelope) Loads

External cooling loads consist of the following:

- sensible loads through opaque envelope assemblies (roofs, walls, floors);
- sensible loads—both radiant and convective—through transparent or translucent envelope assemblies (skylights, windows, other glazed openings),
- sensible loads caused by the leakage of outdoor air through the building envelope (called infiltration);
- latent loads through opaque envelope assemblies; and
- latent loads from infiltration.

Because of the inherent differences in these types of heat flows, they are calculated (estimated) using six different equations:

(1) $q_S = (U)(A)(CLTD)$ is used for sensible loads from opaque elements located above ground;

(2) $q_S = (A)(SHGC)(SHGF)(CLF)$ is used for radiant sensible loads from transparent/translucent elements;

(3) $q_S = (U)(A)(CLTD)$ is used for convective sensible loads from transparent/translucent elements;

(4) $q_S = (CFM)(1.1)(\text{delta } t)$ is used for sensible loads due to infiltration;

(5) $W = (M)(A)(\text{delta } p)$ is used for latent loads through elements above ground;

(6) $q_L = (CFM)(4840)(\text{delta } W)$ is used for latent loads due to infiltration

These equations are commonly used by engineers to calculate cooling loads and size systems based upon decisions made entirely by architects. Although a building designer should have some awareness of the basic methods used to size key building systems, that is not the primary reason for introducing this information. The main reason an architect should be aware of these equations is because they define all the possible decisions that will influence the energy consumption, carbon emissions, and comfort potential of a completed facility that can be made during the design of the building envelope. Most of these decisions are made—either explicitly or by default—during the architectural design process. In effect, using an accounting analogy, engineers employ these equations to figure out how much taxes are owed after the fact; architects can use them to reduce the taxes before it is too late.

Internal Loads

Internal cooling loads consist of the following:

- sensible loads due to lighting;
- sensible loads due to occupants;
- latent loads due to occupants;
- sensible loads due to equipment and appliances; and
- latent loads due to equipment and appliances.

Because of the inherent differences in these types of heat flows, they are calculated (estimated) using five different equations:

(1) q_S **= (Installed Lamp Watts)(3.41)(Usage Factor)(Ballast Factor)(CLF)** is used for sensible loads from lighting systems;

(2) q_S **= (No. of People)(Btuh**$_S$**/person)(CLF)** is used for sensible loads from occupants;

(3) q_L **= (No. of People)(Btuh**$_L$**/person)** is used for latent loads from occupants;

(4) q_S **= (Installed Watts)(3.41)(Usage Factor)(CLF)** is used for sensible loads from equipment;

(5) q_L **= (Tabulated Latent Output)(Usage Factor)**

Information on each of the equations used in cooling load calculations—and the design decisions that lie behind the equations—is provided in Part Two of this reading.