Heating and cooling requirements

Stephenson, D. G.

Publisher's version / Version de l'éditeur:
https://doi.org/10.4224/40000789
Canadian Building Digest, 1968-09

Canadian Building Digest

Division of Building Research, National Research Council Canada

CBD 105

Heating and Cooling Requirements

Originally published September 1968

D.G. Stephenson

Please note

The heating and cooling load for a room is the rate at which heat must be supplied to or removed from it in order to keep the temperature within a specified range. This is the load that must be handled by the air-conditioning system. Its magnitude depends on outside climatic conditions, the type of occupancy, and, to a great extent, the design of the building.

The design of the building will, on the other hand, depend to some extent on the design of the air-conditioning system, inasmuch as space must be provided for the heating and cooling ducts or pipes and associated boilers, chillers and fans. The amount of space needed depends on the type of air-conditioning system and the magnitude of the load it must handle. The same factors also influence the capital and operating costs of the building.

Thus, all the design choices are inter-related and each has to be made with an awareness of its effect on the other parts of the system. This is the crux of systems engineering; and it can be applied to advantage in building design. This Digest is concerned primarily with the way the various components of the heating and cooling load vary during a day and during a year. An appreciation of the magnitudes of these loads and the way they vary can be helpful in making some of the initial architectural decisions, particularly with respect to windows.

Cooling Load

The cooling load for a room is made up of some or all of the following components:

1. heat from lights and equipment;
2. heat given off by people;
3. cooling and dehumidification of ventilation air;
4. heat transferred through the building envelope.

Their importance can be appreciated most easily in terms of an example. Consider an office space 15 ft by 20 ft, accommodating four people:

Lights.

An illumination of 100 ft-candles provided by recessed fluorescent fixtures requires about 1.5 kw of electric power. If it is assumed that the lights are on continuously for 10 hours every day, the cooling required to dissipate the power drawn by the lights would be as shown in Figure

1(a). This indicates that less than half the electrical power supplied to the lights appears immediately as a part of the cooling load. The difference between the energy supplied to the space and the heat removed by the cooling system is stored by the structure and furnishings and is released after the lights have been turned off. This is why the cooling load persists during the time when the lights are off. The cooling load increases continuously when the lights are on, but even after 10 hours it reaches only 80 per cent of the input power. Increasing the mass of the building, particularly the mass of the floor slab, increases the heat storage capacity of the structure and causes the cooling load from lights to be spread more evenly over the entire 24 hours.

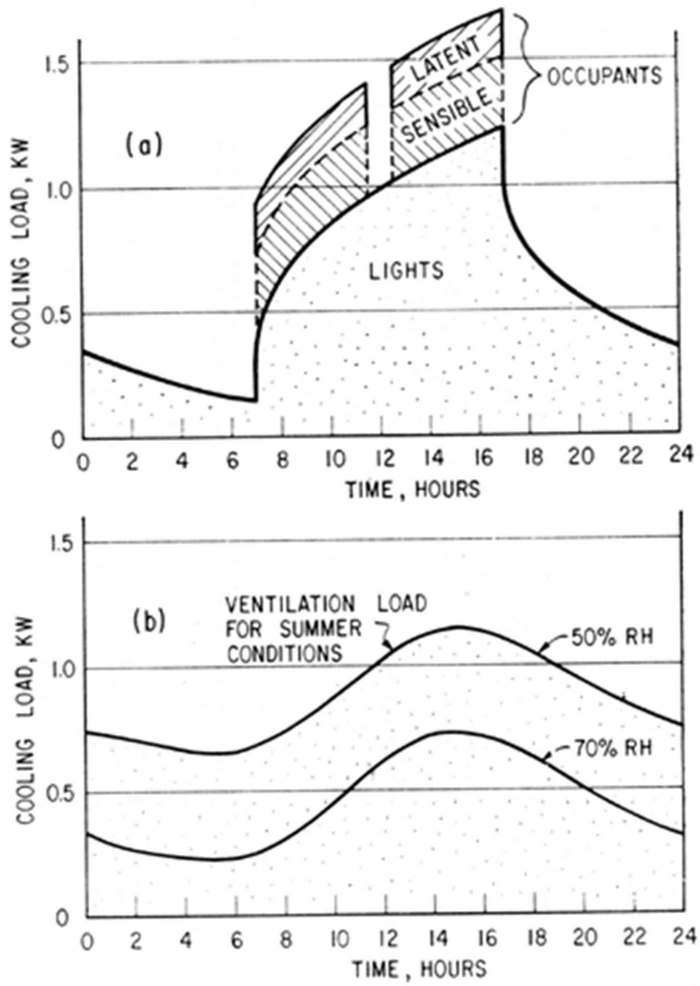

Figure 1. Cooling load for 300 ft² interior office space.

People.

The sensible and latent heat produced by four people doing normal office type work is shown by the hatched areas in Figure 1(a). The sensible heat production is about 75 watts per person: and it causes the temperature of the air in the room to rise. A small part of this heat is stored by the structure and given off after the occupants leave, but this effect is small and has been neglected in the example. People also give off water vapour, and the latent heat associated with this vapour imposes a load on the air-conditioning system when water is removed from the air. This latent component of the cooling load due to people is about 60 watts per person for those engaged in a sedentary occupation in a comfortable environment. If the room is a bit too warm or if the occupants are particularly active, the latent load increases substantially.

Ventilation.

An office with 300 sq ft of floor area requires 75 cu ft of fresh air per minute for adequate ventilation. Cooling and dehumidifying this air from the conditions that prevail outside to the conditions required in the room is a significant part of the total cooling load. Figure 1(b) gives values for this component for a daily range of outside wet bulb temperature from 71 to 77°F, the highest design value for Canada. The higher curve is for a room in which the relative humidity is kept at 50 per cent; the lower curve indicates the reduction that would occur with an inside relative humidity maintained at 70 per cent. Recent studies have indicated that, in summer, comfort (for people at rest or engaged only in light work) is independent of relative humidity for values up to 70 per cent if the air temperature is less than 78°F. The curves in Figure 1(b) show the advantage, from a cooling load point of view, of accepting the higher humidity, although 70 per cent is substantially above the recommended levels for general use.

If 75 cu ft per minute of fresh air has to be supplied to the room, an equal amount of room air has to be exhausted. It could be used to ventilate the space between the ceiling and the floor of the room above and thus remove some of the heat being given off by lights. This approach would reduce the peak cooling load from lights in this example by about 10 per cent. It would also reduce the total cooling that must be provided by the refrigeration machinery, because this exhaust air is discharged to the outside and does not constitute a load on the air-cooling plant. The benefit of this technique would have to be weighed against the cost of arranging the air return. It is one example of the interrelatedness of the various sub-systems, in this case lights and ventilation.

Figure 2 shows the sum of the loads from occupants, lights and ventilation (assuming 70 per cent humidity is maintained in the room). If the room is in the core of the building this sum is the total cooling load.

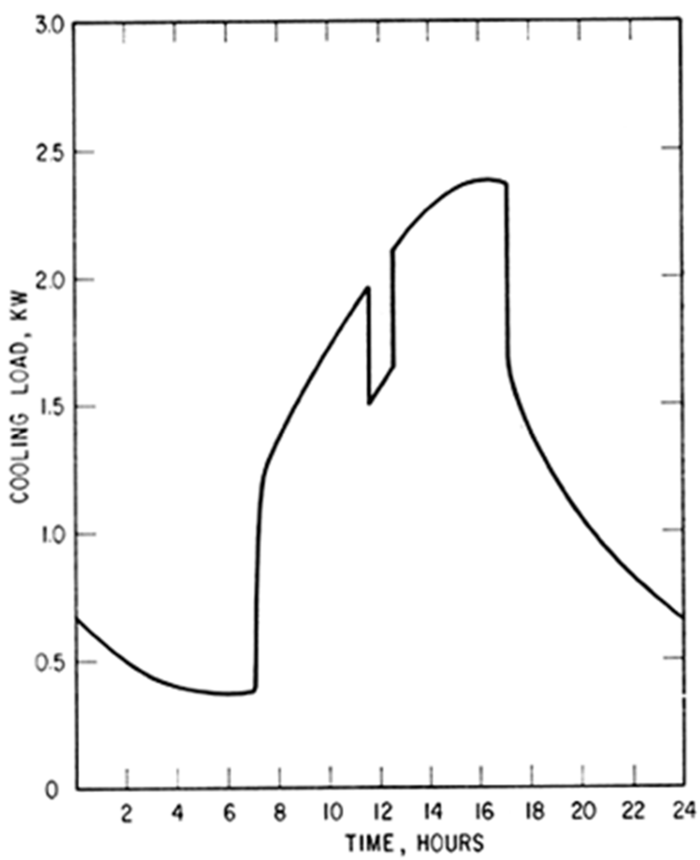

Figure 2. Total cooling load for 300 ft² interior office space.

Heat Transfer Through Walls and Windows.

In addition to loads from lights, people and ventilation, rooms with an outside wall gain and lose heat through the wall and window. There may also be some air infiltration through the outside wall owing to wind effects.

Figure 3 shows the additional cooling load imposed by 100 sq ft of double-glazed window that has a shading coefficient of 0.55. This shading coefficient is appropriate for sealed double glazing with an outer pane of heat absorbing glass or for an ordinary clear-glass double glazing unit with a venetian blind. The hatched area at the bottom is the part of the window load resulting from the difference between inside and outside air temperature, and is the same regardless of the direction the window faces.

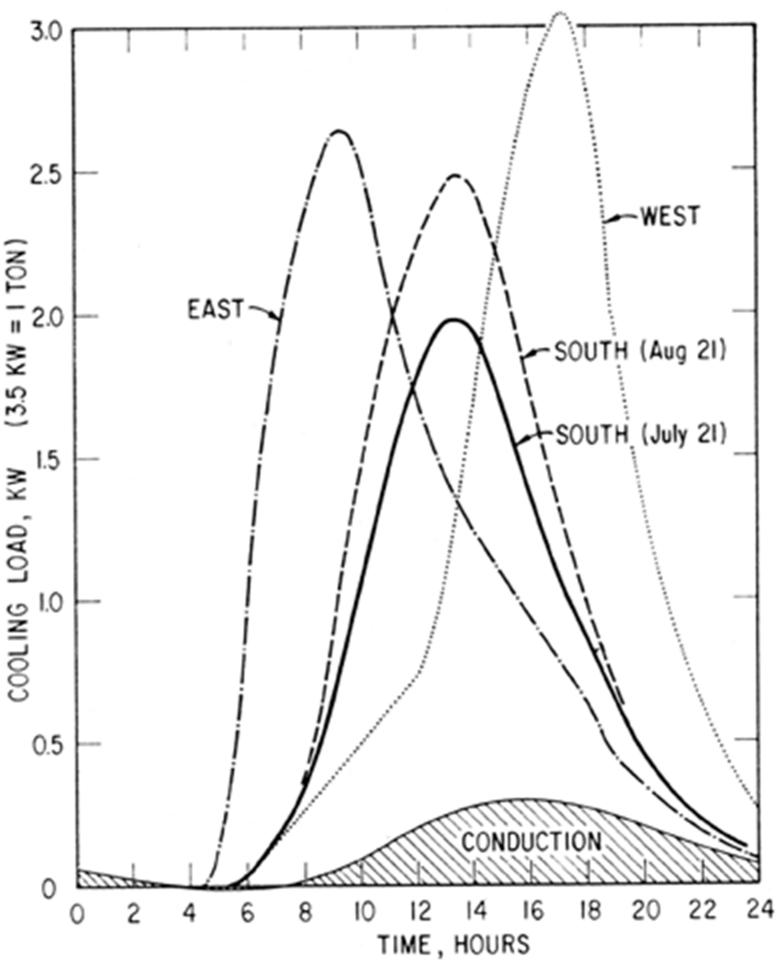

Figure 3. Cooling load for 100 ft² double glazing.

The solar component of the window load is dependent on orientation. The load from east and west windows is practically the same for any sunny day during the summer, regardless of latitude. Thus, the curves for east and west exposures shown in Figure 3 are representative of summer conditions anywhere in Canada. The curves for a south window are based on the solar intensities that would occur on an average cloudless day at Ottawa (45 degrees north latitude). The load for a south window increases continuously as the summer progresses. The change between 21st July and 21st August is shown by the two curves in Figure 3; the increase in the following month is even greater.

The heat gain through an insulated wall is very small compared with that through glass areas. If the office considered above had 150 sq ft of outside wall, with a light coloured outer surface and a U-value of 0.03 watt/ft² °F (0.10 Btu/ft² hr °F), the maximum cooling load associated with the heat gain through the wall would be only 100 watts.

The load due to the infiltration of outside air is difficult to estimate precisely because it depends on the air tightness of the building shell and the air flow patterns around the building. In any case, it is quite small compared with the solar load from the windows, and is only present when there is a wind blowing. A wind causes the solar load from the windows to decrease and this drop in the window load is probably about the same as the increase caused by the infiltration, assuming that the building is reasonably tight. Thus, the curves in Figure 3 can be taken as including the effect of infiltration, since they were calculated for calm conditions.

If the room considered in this example had an outside wall with 40 per cent of the wall area glazed, the total cooling load would be the sum of the base load given by Figure 2 plus the values given by one of the curves in Figure 3 appropriately adjusted for the glass area involved. If the room were at a corner of the building and had glass in both outside walls, the solar loads for both exposures would have to be added to the base load. A comparison of Figure 2 and Figure 3 brings out one favourable aspect of windows facing east compared with those facing west: the peak cooling load from the east glass occurs early in the day, well before the load from lights and ventilation reaches its maximum value. With west-facing glass, all the components of the room cooling load reach their daily maximum at about the same time, so that the total cooling load has a much higher maximum value.

Heating Load.

A heating load is just a negative cooling load; i.e. if the sum of all the cooling load components is negative, it means that an equal amount of heat must be supplied in order to keep the inside temperature at its specified value. During a large part of the year the temperature of the outside air is lower than that inside the building, so that the cooling load associated with ventilation air and the conduction part of the load due to windows are negative. The negative load associated with ventilation air can be increased by increasing the proportion of fresh air delivered to the room; and under some conditions the heat from lights, people and windows can be dissipated by ventilation alone (without any refrigeration). Unfortunately, the negative cooling load components are greatest during the hours when the positive components are lowest and vice-versa.

Thus it is common, especially during spring and fall, to need heating during the night and early part of the morning, and require cooling in the afternoon. This requirement for heating and cooling during different parts of the same day complicates the design of the air-conditioning system. There is no specific date when the cooling season can be said to end and the heating season to begin. In fact, rooms with large areas of glass facing south may need cooling late into the fall and again early in the spring. During the same period, night time heating loads can be very substantial.

The maximum heating requirement occurs during clear winter nights. For example, if the outside air temperature is -25°F and inside conditions are maintained at 75°F and 30 per cent RH it requires about 2.8 kw to heat and humidify 75 cu ft per minute of outside air. Under the same conditions the conduction heat loss through 100 sq ft of ordinary double glazing is about 1.8 kw, and the heat loss through 150 sq ft of insulated wall is less than 0.5 kw. Thus, as in summer, heat flow is much greater through the window than through the opaque sections of wall, but the wall heat losses are not negligible.

The major component of the heating load is associated with ventilation air. Ventilation should be kept to a minimum, therefore, when the building is not occupied; but it cannot be eliminated completely. There is bound to be some air leakage resulting from wind action and stack effect. For a room with 150 sq ft of opaque wall and 100 sq ft of window the air leakage might be about 50 cu ft per minute under severe winter conditions. It would require about 1.9 kw to heat and humidify this amount of outside air. In other words, the heating load due to air leakage may be of the same order of magnitude as the heat loss through the glass area.

Conclusion

A building is made up of many interdependent sub-systems. The designer should take full account of their interaction in order to produce an optimum design for the building rather than an optimum air-conditioning system, an optimum lighting system, or an optimum wall, etc. One of the links that joins the various sub-systems is the heating and cooling requirements. An appreciation of the nature of these requirements, as they are affected by and as they affect occupancy, location, fenestration, lighting and other factors, is of primary importance in the initial phase of design. Such an understanding enables the architect to make the best use of his specialist consultants, from the initial design phase through the final optimum design.

The heat gain through windows is a relatively large part of the total heat gain of a space at the perimeter of any building. Thus, the choice of window type and the extent of fenestration in each facade requires careful analysis from the point of view of air-conditioning requirements. South-facing glass has lower cooling loads at mid-summer than either east or west windows, but this advantage dwindles as the summer progresses. In winter, the solar heat gain through south-facing glass helps to offset the high rate of heat loss due to the low outside air temperature.

Heat from lifts is the largest component of cooling load for spaces in the core of a building. It is desirable, therefore, to avoid excessively high levels of illumination. Any reduction in the power drawn by lights results in a double saving; it reduces the cost of operating the lights and the cost of the air-conditioning.

The other major component of cooling load is associated with ventilation air. The magnitude of this component depends on the relative humidity specified for the space. The higher the allowable humidity the lower will be the cooling load. A relative humidity of 70 per cent may be acceptable from a comfort point of view for people involved in sedentary activities.

The heating load in winter is caused by ventilation, air leakage and heat loss through the building envelope. As the two latter terms are, to some extent, at the discretion of the designer, the cost of any measures to reduce them should be compared with the resultant savings in the cost of heating.