Comfort Cooling

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Preface:

The use of comfort cooling is growing rapidly in Sweden. Most landlords of commercial premises are very aware of the importance of being able to provide good indoor climate conditions for existing and new tenants. At the same time, occupants are becoming increasingly aware of the requirements that can be posed in respect of the indoor environment.

The indoor environment consists of many parameters. However, the one that an occupant of an office building notices immediately is the thermal climate. It has long been accepted that the indoor temperature must not be too low: increasingly, there is pressure that it should not be too high, either.

Various types of comfort cooling system are being installed, both in new building projects and in connection with conversion or renovation. This publication provides a general review of the systems used today in order to distribute cooling throughout a building. Note, however, that the methods of ‘producing’ the cooling are dealt with only in brief.

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Contents:

The need for heating and cooling in buildings 4

Comfort cooling 6

Free cooling 8

Production of low temperatures for comfort cooling equipment 12

Discussion 14

References 15
The need for heating and cooling in buildings

The prime requirement in respect of the indoor climate in a building is that room temperature should be at a comfortable level, regardless of the weather conditions outside. In addition, the indoor air must be acceptably clean, lighting and acoustic conditions must be good etc. Nevertheless, the first and foremost condition for a building to be usable at all is that the indoor temperature is acceptable.

As soon as the ambient temperature is lower than the indoor temperature, heat flows out from the building through its boundary surfaces (the building envelope). At the same time, the building also loses heat through air infiltration, i.e. the inward leakage of outdoor air into the building through gaps and cavities in walls, roofs, doors and windows. Bearing in mind the fact that the indoor temperature in most buildings is maintained at a little over 20 °C, this means, throughout most of the year, the building is losing heat to its surroundings.

When buildings are used, there is almost always internal generation of heat, through the use of various appliances and equipment, from lighting and from the occupants themselves. There is also a heat input from insolation, which contributes to the internal heat generation.

Internal heat generation in residential buildings is normally relatively modest. For most of the year there is a heat deficit, which means that additional heat has to be supplied. During those periods of the year when there is a surplus of heat, this is usually dealt with by opening windows. There is also a greater tolerance of higher indoor temperatures in residential buildings. Systems for removing heat from residential buildings are extremely rare in Sweden.
The internal heat generation in commercial premises and some industrial buildings, on the other hand, is often relatively great. In combination with the fact that construction standards have been developed and improved, so that buildings are nowadays well insulated and airtight, this means that the heat losses through the building envelope are small. If we consider new office buildings, department stores, hospitals and similar buildings within the commercial premises and industrial sector, we find that heat deficits usually occur only during the night and at weekends, while there is nearly always a heat surplus during working hours. Such buildings require only simple heating systems to meet the modest heat deficits, as opposed to the considerably more extensive systems needed in order to deal with the substantial heat surpluses, and to prevent the indoor temperature becoming unacceptably high during working hours.

As the requirements in respect of room temperatures are given, the capacity of the cooling system is determined largely by the amount of heat that it must be capable of dealing with. In general terms, the greater the heat surplus, and therefore the greater the capacity of the cooling system, the more difficult it is to produce an indoor climate that is good in all respects. It is therefore always important to attempt to design the building in general so that there will be only a low heat surplus. To do this requires, in turn, an overall approach to the building, to its services systems and to the activities carried on in it.
Comfort cooling

In everyday language, the surplus heat that has to be removed from buildings in order to maintain the indoor temperature below some previously determined maximum permissible temperature is referred to as the cooling requirement. In other words, the cooling requirement of the building is exactly the same as its heat surplus. Again, in order to maintain the link with ordinary terms, we shall refer to ‘cooling requirement’ in the rest of this brochure.

The climate control system in a building has to maintain both the thermal climate and the air quality. Maintaining the thermal climate consists primarily of keeping the temperature of the indoor air within given limits. Maintaining the air quality consists of controlling the ‘cleanliness’ of the indoor air by supplying a sufficient quantity of outdoor air to ventilate the interior of the building. Maintenance of air quality sometimes also includes ensuring that given concentrations of particles and/or gases are not exceeded.

All-air cooling systems

The design air flow rate in these systems, and thus the necessary sizes of ventilation ducts, is determined by the design cooling requirement. In other words, it is the thermal requirements, and not the air quality requirements, that determine the necessary air flow rate. Figure 1 is a schematic diagram of an all-air cooling system.

In existing buildings, it is normally both difficult and expensive to replace the ventilation duct system. If the existing ducts cannot transport sufficiently large air quantities to meet the cooling requirements, all-water cooling systems will usually be installed in connection with conversion or modernisation.

The cooling system must be able to deal with variations in the cooling requirement, whether over the day or over the year. The two basic types of all-air cooling systems are the constant air flow system and the variable air flow system, although there are also combinations of the two methods.
Constant air volume systems (CAV systems)

In such systems, the temperature of the air supplied to the building can vary, but the air flow rate is kept constant. Such systems are referred to as Constant Air Volume (CAV) systems.

It is the rooms having the greatest cooling requirement that normally determine the supply air temperature delivered by the central air conditioning unit: the air may, if necessary, be heated before supplied to other rooms.

Although a CAV system supplies air at a constant flow rate, the fans are sometimes powered by two-speed motors, running at the lower speed when the building cooling requirement falls. The air flow rate is then reduced in proportion to the fan speed. The use of two-speed motors in CAV systems must not be confused with VAV systems (see below), in which the air flow can be varied in order to control the cooling power delivered.

As mentioned above, the supply air temperature in a CAV system may be either constant or varied. The temperature may be varied:

- independently of the ambient temperature, but dependently of changes in the heat surplus. This type of temperature control is carried out in heating coils etc. in the immediate vicinity of the zones concerned.
- dependently of the ambient temperature. This type of temperature control is provided in the central air conditioning unit.
- as a combination of the above two methods.

Variable air volume systems (VAV systems)

The air flow rate to each room is varied as necessary, but with maintenance of a constant supply temperature, i.e. the supply temperature does not change even if the load changes. However, the supply air temperature is normally changed in step with the time of year, as a function of the ambient temperature. Systems of this type are referred to as Variable Air Volume (VAV) systems.

The air flow to each individual room is controlled by dampers in some form of box (VAV-box) in the immediate vicinity of the supply point to the room, while the central supply and exhaust air fans are controlled by variable inlet vanes or by adjustable speed drive controlled motors, usually of the frequency-inverter type. The control system normally maintains a constant static pressure in the supply air duct. The flow rate varies from a maximum, during the hottest days, down to perhaps 20 % of maximum flow rate during the coldest days of the year, when the purpose of the air is only to maintain the air quality.
All-water cooling systems

Systems of this type supply all-water cooling to the individual rooms, with the ventilation system designed purely to maintain the air quality. Figure 3 shows a schematic diagram of such a system.

Systems of this type are often chosen in connection with conversion or renovation projects. There is usually space above the false ceilings to install the water pipes needed for distribution of cold water throughout the building.

Combined systems

All-air and all-water cooling systems can be combined in many ways. One such need for a combined system is if all-air cooling is used, but the cooling requirement is so great that an all-air cooling system alone is not capable of dealing with it satisfactorily, as such high air flow rates would be required that draughts would be unavoidable.

It is also possible to combine all-air cooling systems so that certain parts of the building, or certain rooms, are cooled by a VAV system, while other parts of the building are cooled by a CAV system.
Cooling supply devices:

Cooling can be supplied to a room in a number of different ways. The following are brief descriptions of how chilled beams, cooling panels, fan coil units and induction units operate. Fan coil units and induction units are normally positioned below windows in the outside walls.

**Chilled beams**

These are units which, by natural convection from a finned heat exchanger, cool the air in the room, as shown schematically in Figure 4. They may also be combined with the supply air terminal device in order to provide both functions and, in many cases, to increase the cooling capacity of the baffle. Some chilled beams can also incorporate a heating function.

**Cooling panels**

Cooling panels can be hung from the ceiling, as shown in Figure 5. Cold water flows through an aluminium plate, which transfers heat from the air to the cold water. The panel cools the warm room air and also cools the room surfaces by low-temperature radiation. These panels are produced in a number of versions, e.g. for mounting flat against the ceiling, hanging, or for integration in a false ceiling. Most of their cooling capacity is provided by radiation.

**Fan coil units**

These are units by which both heating and cooling can be supplied to a room (although not at the same time). Figure 6 shows a schematic arrangement of such a unit. A fan coil unit incorporates a fan which circulates the room air through the unit, in which the air is either heated or cooled as required. The two heat exchangers (heating and cooling) are supplied with hot or cold water from a central unit in the building. This type of room cooler unit can meet the highest cooling requirements, but it also has the highest noise level.

**Induction units**

These are units by which both heating and cooling can be supplied to a room (although not at the same time). Figure 7 shows a schematic arrangement of such a unit. When in use, the ventilation air for the room is supplied through the induction unit. It flows through a nozzle with high velocity, which therefore has the effect of inducing air from the room through the heating or cooling heat exchangers. This makes it possible to heat or cool the room in a single unit, without the use of a fan.
Free cooling

It is a common misconception that it is always necessary to run some form of mechanical chiller as soon as cooling is required. This is not actually the case: instead, it is often possible to use the outdoor air to provide what is known as free cooling.

There is no generally accepted definition of what free cooling is. However, a common interpretation is that it refers to the ability to supply cooling when it is required, without having to pay for the actual generation of the low temperature.

‘Free cooling’ is used particularly in connection with all-air cooling systems, and refers to the case when the cooling requirement can be met solely by outdoor air, without having to start a mechanical chiller. As all-air cooling normally operates with a supply air temperature of about 16-18 °C, the outdoor air can be used to meet the entire cooling requirement as long as its temperature does not exceed this temperature. It is only when the ambient air temperature exceeds about 16 °C that cooling is required from some mechanical source.

This means that, in an all-air cooling system, free cooling can be used as long as the ambient temperature is below about 16 °C. Figure 8 shows the number of hours during a typical year (one year = 8760 hours) during which the ambient temperature exceeds 16 °C.
In Gothenburg, for example, mechanical chillers would need to be operated for 895 hours per year, if the maximum temperature of the supply air is 16 °C. (This assumes that the ventilation system would be in constant operation, i.e. also during the nights. If the ventilation was turned off for some hours each day, the number of operating hours would be correspondingly reduced.)

Free cooling is also available for all-water cooling systems. This requires some form of heat exchanger between the water and the outdoor air, e.g. a cooling tower.

When using free cooling with an all-water cooling system, it is common to operate the system in such a way as to cool all the water with outdoor air when the air temperature is below a particular value. In other words, when the air temperature is below this level, no form of mechanical cooling is used. The temperature at which the two cooling systems change over is normally in the 7-10 °C range.

As already mentioned, there is no consistent definition of free cooling, which means that the term also covers cooling using water from lakes, rivers etc. as the heat sink.

Figure 8
The approximate number of hours during a climatically average year during which the ambient temperature exceeds 16 °C. [Taesler, R., Climate data for Sweden, SMHI, Stockholm, 1972].

Figure 9
Schematic diagram of a free cooling system with a cooling tower for all-water cooling.
Comfort cooling production equipment

The following pages provide a brief description of the various methods used today to produce cooling for comfort purposes.

The commonest way of producing cooling is to use conventional electrically-driven mechanical cooling equipment. However, alternative methods include evaporative and desiccant cooling. Larger installations may also have cooling produced by thermally-powered absorption chillers. District cooling systems have been built, or are being built, in a number of larger towns. In principle, they operate in the same way as district heating systems, except that it is cold water, rather than hot water, that is distributed.

An important difference of principle between evaporative and desiccant systems on the one hand, and other cooling systems on the other, is that the former group can be used only in all-air cooling systems. Producing cooling using absorption machines is practical only in very large systems. Comfort cooling using evaporative and desiccant processes are described in detail in a licentiate thesis from Chalmers University of Technology (Lindholm, T., Evaporative and Desiccant Cooling, D43, Department of Building Services Systems, CTH, 1998).

Conventional mechanical cooling equipment (electrically-driven compressor cooling)

Producing cooling with a compressor chiller is the ‘classic’ way of producing cooling. When mechanical cooling for comfort purposes is discussed, it is usually this that is implied. The machine operates in the same way as an ordinary heat pump, although in this case it is the cold side that is the ‘useful’ side. See Figure 10.

The heat absorbed by the evaporator is the quantity of cooling that can be supplied. Supplying this cooling requires an input of mechanical work to the compressor, normally in the form of electrical energy to drive a motor. The relationship between the cooling delivered by the machine and the input work to the compressor is referred to as the Refrigeration Coefficient of Performance (COP), and is defined as:

$$\text{COP} = \frac{\text{Annual cooling produced}}{\text{Annual input work}}$$

If we know the COP and the quantity of cooling to be produced, we can also work out the necessary energy input and so the resulting running cost. The annual COP is normally of the order of 3, depending on the temperature levels between which the machine works. The energy input to the compressor usually includes electricity to components directly needed for operation of the system, e.g. circulation pumps.

A compressor-driven chiller provides considerable flexibility in the choice of method of supplying cooling to the building. As previously mentioned, cooling can be supplied either to cooling coils in an air-conditioning unit, or to cooling equipment installed directly in the rooms of the building, e.g. cooling panels at ceiling level or fan coil coolers.
Evaporative cooling

Evaporative cooling of air involves the principle of reducing the air temperature by causing it to evaporate water from a surface over which the air passes. This can be done as long as the air is not saturated. Heat is required in order to evaporate the water, i.e. to change it from the liquid phase to the vapour phase. This heat (known as the latent heat of evaporation) is taken from the air. In so doing, the temperature of the air is reduced.

The lowest temperature to which the air can be reduced with this type of cooling is limited by the wet bulb temperature of the air at saturation.

Direct evaporative cooling is a process in which the supply air is humidified, thus increasing its moisture content and reducing its temperature. Indirect evaporative cooling humidifies the exhaust air instead, again reducing its temperature. The supply air is then cooled by heat exchange between the two air streams, so that the heat in the supply air is transferred to the exhaust air. This reduces the temperature of the supply air, while not increasing its moisture content. Direct and indirect evaporative cooling processes are shown schematically in Figures 11 and 12.

The amount of cooling that can be produced depends largely on the values of external parameters, with the temperature and humidity of the outdoor air being the most important.

Desiccant cooling

In order to be able to reduce the supply air temperature as much as possible, it is advantageous to start with as dry air as possible. In the desiccant cooling process, humidification from the evaporative process is complemented by drying the incoming supply air before it is humidified, as shown in Figure 13.

A desiccant cooling unit consists of a dehumidifier, which dries the air, and a following section (the evaporative section) that cools it. The dehumidifier is a moisture-absorbing rotor: the warmed exhaust air passing through one side of the rotor drives the absorbed water out of it. This requires heat, and so a desiccant cooling unit also requires an input of heat.

District cooling

Today, several energy utilities provide what is known as district cooling. The way in which the ‘cold’ is produced and distributed varies from one town to another, depending on the particular conditions of the energy utility, its production facilities and on the type and density of the load. Production units can consist of everything from free cooling systems (e.g. cold lake or river water that can be used directly for cooling), to heat-powered absorption chillers, via conventional compressor chillers. It is relatively common to use the cooling from existing heat pumps, which are already being used to supply heat to the district heating system.

Customers to district cooling systems are normally those with relatively substantial cooling requirements, such as a hospital campus or a shopping centre.

Customers receive cold water to sub-stations, in essentially the same way as hot water is supplied to district heating sub-stations. Cold secondary water is then distributed to the building or buildings to be cooled, as shown in Figure 14.
Discussion

It is not possible generally to say when some particular type of cooling system should be chosen or not. In most cases, it is possible to choose between several systems, all of which will work satisfactorily from a technical viewpoint. The decisive factor in the final choice is the cost of buying and running the system.

However, it can be said that when there is a very substantial requirement for cooling, problems can arise if cooling is to be provided by an all-air system alone. For considerations of comfort, for example, there might be problems in attempting to supply large quantities of supply air at low temperatures (draught problems), depending on the type of building and the activities therein.

There are a number of basic factors that have to be considered when deciding on the choice of system:

- A system for all-air cooling requires more space for the running of ventilation ducts than does an all-water system. With all-water cooling, the sizes of the ducts can be determined on the basis of the necessary hygiene ventilation, while an all-air cooling system requires them to be dimensioned on the basis of the maximum cooling power required, which calls for higher air flow rates.

- Due to lack of space, it can be almost impossible to install an all-air cooling system in buildings that have previously had no cooling system. In such cases, all-water cooling systems must be installed.

- It is simpler to utilise ‘free cooling’ with an all-air cooling system than with an all-water system. An all-water system requires a heat exchange with the outdoor air in a cooling tower or similar arrangement. An all-air system requires no extra equipment in order to be able to utilise ‘free cooling’. Exceptionally, it is possible for an all-water system to utilise free cooling from a water body, when such is available.

- Evaporative and desiccant cooling can be combined only with all-air cooling systems. There are no climate-imposed restrictions on the use of such methods in Sweden.

- When indirect evaporative cooling is being used, it is important to remember that the ventilation exhaust air will be cooled. The supply air is cooled by heat exchange with the exhaust air, which means that the supply air temperature is therefore dependent on the exhaust air temperature. If the temperature in the building rises, the temperature of the supply air will also rise. In practice, it is difficult to lower the supply air temperature by more than about 5 °C. With a conventional cooling system, using compressor cooling, it is possible to control the temperature at which the supply air is delivered to the building, regardless of what the temperature is in the building. Designing an indirect evaporative cooling system requires more work and greater knowledge on the part of the designer.

- A source of heat is also required when using desiccant cooling. A suitable source of such heat is often summer district heating, as temperature levels around 65-70 °C are sufficient.
References


Lindholm, T., Evaporative and desiccant cooling, D43, Department of Building Services Engineering, CTH, 1998.
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