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DESIGN OF HEATING SYSTEMS

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Abstract

Comfort criteria and the thermal properties of the building are basis for the design of a heating system. The heat demand and its distribution in time must also be studied carefully as it influences the operation of the system. These matters and the possibilities to simulate building and heating systems are discussed, and examples of simulations are given.

INTRODUCTION

In a cold climate, like in Sweden, heating systems are the most important type of installation for climatisation of buildings. In the old days, the buildings had to adjust to the heating; they were small with small windows and built around the furnace. The heat production efficiency was bad and the control was manual. As heating was associated with the labour of providing fire wood, mean indoor temperature seldom was too high during the heating season, although the temperature distribution in time and space was uneven. Now central heating systems have made the architect free from the furnace. The heating is automatically controlled and care has to be taken to overheating implying unnecessary airing (ventilation is however too small in most Swedish buildings today). Thus proper distribution of heat in the building is important.

In the last decades buildings in Sweden have been built tight and thermally well insulated, providing a more uniform thermal environment. Ventilation systems have often been provided with heat recovery. The heat losses from the new buildings are small, often resulting in only intermittent need for heating also during cold weather. This is a new situation, giving new problems and possibilities, and perhaps more freedom for the heating system designer and the architect.

Comfort

Fanger and coworkers have explored most aspects of the thermal comfort problem, as comfort temperatures, limits for radiation asymmetri, and draught for thermally neutral persons.

Comfort temperature depends on activity, clothing and other parameters. In practice a temperature about 22°C is often suitable.

Radiant asymmetri is important for the location of the heater. If 5% dissatisfied persons is accepted an asymmetri of 10°C can be accepted from a cold wall. The value from a cold ceiling is even bigger. In practice such big values are extremely rare.

For a well insulated building with small heat demand resulting in small or low temperature heaters radiant asymmetri from cold surfaces is no problem. For asymmetri caused by warm walls the sensibility is still smaller. The limiting radiation factor for location of a radiator in a room thus is not the asymmetri in itself but variations in operative temperature. For a well insulated building this normally is within 1°C. It can be eliminated by locating a radiator below the window, which is traditional.

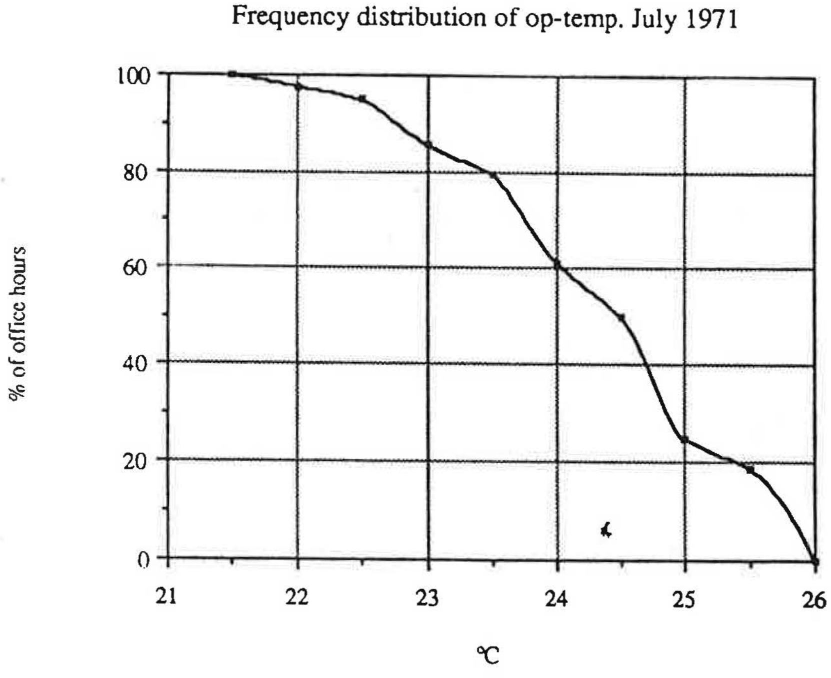

Fig 1. Cumulative distribution of operative temperature. Example for one month calculated with BRIS.

Man is most sensible for asymmetrical radiation on the head. A ceiling must not be warmer than 4°C above the temperature of other surfaces. This allows a heat output of 25 W/m² which normally covers the heat losses. Floor heating is also a possibility as 19°C-29°C is acceptable for 90% of a population (95% is not possible to reach for this case). Surface temperatures can be calculated with computer programs. A partial measure is the operative temperature, see fig. 1.

Air temperature gradients and velocities are more difficult to control. A warm ceiling supports stagnation and a vertical air temperature gradient. However, a temperature difference of 3°C between the 0,1 m level and 1,1 m level in a room is accepted.

A warm floor induces convection and mixing of air and no vertical air temperature gradient. Radiators below windows creates gradients (smaller than warm ceilings) but the mixing of air is big enough to force air exchange efficiency to values close to 0,5 (Sandberg 1987).

In Sweden it has been a recommended practice since many years to locate a radiator below the window in order to prevent draught from cold convection air flows from the window. If there is no leakage around the window and the window is not too big, the cold air stream from a triple glazed window will not cause discomfort. However, a combination of convection, leakage and low radiation temperature is a good reason for a panel radiator below the window.

Warm air heating has increased in use in Sweden the last ten years. One reason is that the lower heat demand makes it possible to use air flow rates of the same size as normal ventilation air flow rates. The combined problem of matching a ventilation demand (in proportion to air volume) with a heating demand (in proportion to outdoor wall area), creating a uniform thermal environment and an acceptable air change and ventilation efficiency is difficult and needs further studies.

Heat demand

The heat demand is the difference between heat losses from the building and the heat release from solar and internal gains.

The heat losses are proportional to the mean temperature difference between indoor and outdoor. They will be smaller if the mean temperature is decreased. In Stockholm the mean temperature difference between indoor and outdoor in the heating season is 20°C. A 1°C lower indoor temperature thus will save 5% of the heat losses, but comfort will decrease. In order to save energy different temperature control strategies including night set-back are used. The sucess of this depends on the dynamic thermal behaviour of the building. It is clear that a "light" building where indoor temperature can be rapidly changed is favourable from this point of view.

The amount of "free heat" that can be utilized for heating also depends on the dynamic thermal behaviour of the building. As the "free heat" output normally is only in the daytime more can be used for heating in the night if heat can be stored in the building structure without a big increase of indoor temperature. Thus a "heavy" type of building is favourable from this point of view. An alternative is of course to design installations capable of handling the heat accumulation.

Which is best evidently depends on the use of the building and the relative amounts of heat losses, free heat and accumulated heat. Well insulated buildings have small heat losses which increases the relative importance of heat stored in the building structure.

Thermal characteristics of buildings

A measure of the ratio of heat accumulated in the structure and heat losses is the fictitious time constant defined by:

$$\tau_b = C \cdot R$$

$$R^{-1} = \Sigma\ (h \cdot A + q \cdot \rho \cdot c_p)$$

where

C = the thermal capacitance of the building (J/K)

R = thermal resistance of the building $(W/K)^{-1}$

h = heat transfer coefficient $(W/K,m^2)$

A = Area (m^2)

q = air flow rate (m^3/s)

ρ = air density (kg/m^3)

C_p= massic heat for air (J/kg,K)

τ_b increases when R is increased. As the cooling of the building then is slower, Design Winter Temperatur can be increased.

Much of the heat capacity of the structure is not accessible for cyclic temperature variations with a period of 24 hours. This depends rather on the characteristics close to the surface, less than 10 cm. Those characteristics of a room can be studied with computer simulation, see fig. 2 and 3.

Both are examples of rooms with rather "heavy" characteristics, not extremely well insulated and with only little "free" heat. Two quite different heating strategies are used. In fig. 2 the room is used only in the daytime, when the temperature is set at 20°C. In the night the air temperature is set at 18°C, which is not reached until the morning. All heat is provided in the daytime. The heat entering the "structure" is partly accumulated, partly lost due to transmission. As can be seen it contributes significantly to the thermal course of events. Fig. 3 is taken from a dwelling, a room used only in the evening. Here quite another strategy is used with constant heat output all day and night. It is evident from the figure that the accumulation is big enough to keep the indoor temperature (operative temperature in this case) almost constant.

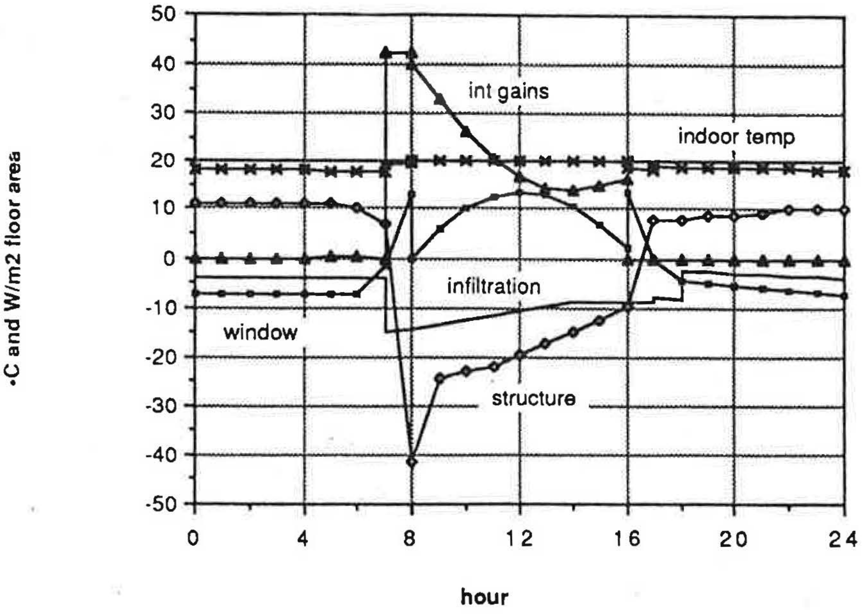

Fig 2. Heat balance for a room during a 24h-cycle.
Results from computor simulation with the BRIS-program.
Heating only in the day. Night set-back.

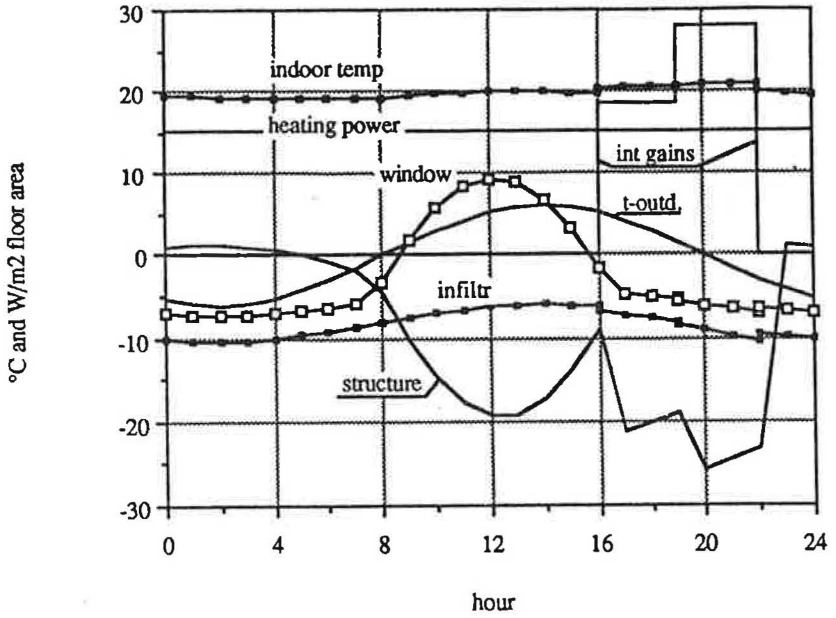

Fig 3. Heat balance for a room during a 24h-cycle.
Results from computor simulation with the BRIS-program.
Constant heat output.

The examples demonstrates also that there often are possibilities for simple control where advantage is taken of the improved thermal comfort characteristics of the building discussed earlier. The building has a big thermal capacitance and small heat demand which makes the temperature easy to control, at least to keep within an interval. There are often possibilities to supply the necessary heat at off peak hours. For modern offices it is also worth noticing that there almost never will be a heat demand in an occupied room. Comfort reasons will of course in such cases carry only little weight when designing the heating system.

The heat distribution system

Heat losses from a distribution system are big from a badly insulated pipe or duct system located in slots in a badly insulated outdoor wall, and in such cases interesting because of their absolute size. In a well insulated building the heat emitting surface of the distribution system often is big compared with the area of the heaters. This gives a new dimension, that of control of the heat output in the building, to the heat loss problem, which in this case will be interesting because of its relative size. Clearly, thermal insulation of the piping or ducting may be necessary.

When hot water is used for heating, the fact that the temperature efficiency of the heater is less than one moderates the consequences of bad adjustement of flow rates in the system. The possibilities to control the heater with a thermostatic valve depend however on the combined effect of the temperature efficiency and the valve authority in the distribution net but also on components and dynamic characteristics of the system. Also the behaviour of such systems can be simulated, however. Fig. 4 gives an example of results of a simulation with the computer program "Disnet", developped at KTH in cooperation with other participants of annex 10 of the IEA Building Energy Programme (Olsson 1988). The figure shows an example from a comparision of thermostatic valves in a hydraulic net with small flow rate, small pressure losses in the piping and high supply temperature or in a more conventional distribution net. Both graphs show unstable function of the valves. The simulation is made for a low insulated building.

It is most important that there are no possibilities for hidden leakage of water in the building. Care must be taken to make the piping tight and to arrange so that a leakage rapidly will be detected.

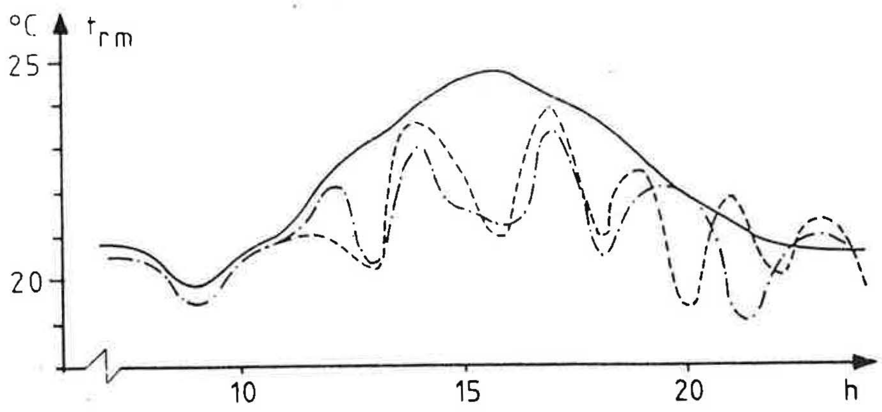

Fig 4. Selected results (room 4) showing the time dependence of the room air temperature (trm) given as hourly mean values.

Denotations
solid lines = fixed valve position
curves with dots = thermostatic valves, "high-flow" case
broken curves = ditto for the "low-flow" case
Control range 19-21°C (air)

Discussion

The better insulated and tighter buildings that are built today give the designer of the heating system more freedom. The thermal comfort can be increased or the location of heaters and time for heat output can be chosen more freely. Often the "free" heat during working hours in an office is so big that the heating system is used only intermittently in occupied rooms. This will anyhow give thermal variations in the room. A conscious consideration to the heat accumulation properties of the building may then give the designer opportunity to take advantage of the situation to simplify the system or the control strategy.

It is important that the heating system not contributes to indoor air pollution. This may happen through increased outgassing from building materials heated too much, from water leakages resulting in mould formation or from smoke. The method for heating rooms also influences air distribution in the room and ventilation efficiency.

Finally, it is also most important that the installations not are obstacles for the intended use of a room!

References

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