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Should Future HVAC-Systems be Demand Controlled?

W. Braun

Geilinger Ldt
Grüzefeldstr. 47
CH-8401 Winterthur, Switzerland

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CH-8401 Winterthur, Switzerland

Abstract

Demand controlled HVAC-systems have many advantages. The principle is to optimize comfort and to minimize energy consumption simultaneously.

In modern office buildings, indoor temperature is very often a useful control parameter. The question is, wheather it should govern the system for each room individually or for a zone. In the latter case: how shall the zones be defined? Above all, performance criteria have to be weighed against the investment cost.

This paper discusses different strategies, which have been or are going to be realized for office buildings. The results are from computer simulations and show the fields of application. The investigation concentrates on ceiling cooling by a water system (which is part of combined water/air HVAC-system).

1. Introduction

In this paper it is looked at up-to-date and future office buildings which offer a high standard of user comfort and minimized energy consumption [1]. Both principles may be fullfilled at the same time relaying on a building concept which incorporates excellent thermal insulation of the envelope and soft HVAC-technology [2]. If the internal heat loads exceed 30 W/m^2, it might be appropriate to use combined water-air systems [3].

In large office buildings, a variety of activities take place. Some of them result in high internal heat loads, but others doen't. For this reason, the control of the HVAC-system is an important part of an integral building concept. Many kinds of control strategies can be thought of or have already been realized. Two diverging philosophies are known: one is to use highly sophisticated demand control. On the other side, one can try to avoid control as far as possible.

Both principles have already been put to practise. But comparable results are not available up to now. In this paper, a theoretical investigation on the problem of control of water cooling systems is presented.

2. Type of Building and HVAC-System

This study concentrates to a specific type of building [4]. Nevertheless, the results may be generalized. We assume that the building has an airtight envelope with windows with an outstanding thermal insulation (U-value below 0.8 W/m^{2}K), and a soft climatisation, which meets the requirements of comfort and energy saving. Although there are no radiators below the windows, there is no sensible downdraft in the environment of the window and a nearly symmetrical infrared radiation field even in strong winters. The user experiences a very pleasant indoor climate throughout the year.

The large variety of performance purposes has brought up a number of different control types for the HVAC-system. Control parameters are time, temperature, humidity, CO_2, etc. Since control equipment raises the investment costs, rooms with similar load profiles are often bound together to control-zones. Unfortunately, the result of this procedure is in many cases unsatisfactory.

For this study, we assume to deal with mechanical climatisation of the combined type: the air system is a displacement ventilation with a rather limited, constant air change rate, so that time is the only control parameter - a simple on-off-function. (Clearly, auditora are excluded from this study). Its purpose is solely given by the requirements of air quality.

A water system acts as energy transport system, predominantly in the mode of cooling. The heat energy exchange between room and water takes place by the ceiling: water pipes are integrated in the concrete (this study). Other possibilities are to use ceiling mounted radiators or capillary networks attached to the concrete [5]. In any case, the infrared radiation exchange plays an important role.

Outstanding advantages of a system with splitted functions are the high energy transport capacity of water (this lowers the air duct sizes and also the investment costs drastically), and the possibilty to avoid the variable control of an air duct network.

Principally, there are three possibilities to control a water cooling system, namley:

- time (exclusively)
- temperature (exclusively)
- time and temperature

Further, the control function must be defined: it may simply be the on/off-function or it may be the water temperature (three way valves).

If temperature acts as control parameter, it's still the question: which temperature should be used? It may be:

- room temperatures (room individual control)
- mean temperature of a zone (control of zones)
- temperature of a reference room (control of zones)
- outdoor temperature (not very helpfull within this context)

Defining a control strategy, a variety of criterias must be observed. Among others, these are:

- comfort requirements (temperature range)
- variablilty of heat load profiles within the whole building (or zone)
- flexibility (modification of the ground-plan or purposes)
- investment costs
- energy consumption
- system behavior (time constants of the building mass, type of cooler)

A number of buildings based on the splitted concept have been planed by our company and have shortly been constructed or are still under construction. For this reason, practical experience is still missing. But with the help of numerical simulations, the fields of application of the different solutions have been checked. Some of the results are presented here.

3. Dynamic Simulation Models

Two different numerical models have been developped to specifically conduct investigations on the above described type of office building. Both are single room models with periodic boundry conditions. In order to simulate also thermal charge/discharge processes, the time step is 6 minutes only.

Although the physical concepts of the two models are different (e.g. in only one of the models the room air is incorporated), the same conclusions are obtained.

The model used in this study has the following features. The basic idea was to simulate in detail the two physical processes: infrared radiation between all surfaces of the room and heat energy conductance inside the thermal masses (floor, walls, ceiling).

The air is not simulated in this model. For the validity of this hypothesis, one can argue as follows:

- With the above defined concept (mechanical ventilation with a low air change rate and inlet air temperature at comfort level) only a small fraction of the heat energy produced by the sources is removed directly by the ventilation system. This fraction can be subtracted from the heat load prescribed in the model. The major part of the heat load is transferred from the sources to the surrounding surfaces by radiation and convection.

- Preliminary studies have shown that the heat removal process is not very sensitive to the distribution pattern of the sources (the reason is, that energy exchange by radiation is very efficient). Therefore, it can be assumed, that radiation is the only transfer mechanism from the sources to the surfaces.

- The time constant of the room air is in the range of 10 to 20 minutes. The mean room air temperature is strongly correlated to the wall surface temperatures.

The perceived temperature is a function of the radiative temperature and the air temperature. In this study, the area weighed average of all surface temperatures is taken instead.

The internal heat loads are held constant during 8 hours of each of the 5 work days. This simple assumption is dictated by the goals of the simulation: investigation of the fields of application of several control strategies means to look for the limitations.

The water cooling system is simulated by a parametrized model which has the vertical temperature gradient of the cooling ceiling as input. The on/off-function is controlled in four different modes:

- *permanent*:
  The cooling system is running permenantly (= no control).

- *temperature*:
  Cooling is swichted on if a wall surface temperature exceeds 21.0°C and is swichted off if it undergoes 20.7°C.

- *time*:
  Cooling is on during working time (8 hours, 5 days), or, alternatively at night (12 hours, 7 days).

4. Parametric Studies

The simulated room has a ground floor of 20m². Floor and ceiling are assumed to be built of concrete (each 15cm thick, periodic boundry conditions). Two types of wall constructions are assumed: light walls (very common in office buildings) and concrete walls (10cm). The stationary key values of the two room types are given in table 1.

Type	Capacity [MJ/K]	Temp.diff. [K]
light heavy	19.9 30.1	1.45 0.96

Table 1: Heat capacity of the thermal masses for the two types of room. The "temperature difference" is the result of a 1000 W source acting for 8 hours without cooling.

Heat loads of 200 or 1000 W, respectively, represent a low type and a high type case. The sources are switched on for 8 hours from the beginning of each work day.

At the start of each simulation, all temperatures are set to 20°C. The first day will therefore not represent a common performance. In the following, the third or fifth day is looked at. In some cases, one has to look for a steady state, which is reached after a few days up to two weeks, depending on heat load, wall mass, control strategy and water temperature.

Table 2 gives an overview of the three cases presented in this paper. Each case was done with the two wall types and the two heat loads as defined above. The water temperature is set to 18°C or 20°C, respectively. "Active part" means percentage of the ceiling surface, which acts as cooling ceiling. (For the case of suspended radiators, this is necessarily less than 100%, but here, 100% active part can be realized).

No.	Control strategy	Water temp.	Active part
1	temperature or time	18°C	100%
2	permanent	20°C	60 ... 100%
3	time (night)	20°C	100%

Table 2: List of cases discussed in this paper.

With figure 1, the effect of the temperature control shall be demonstrated. Its a simulation of case 1 with light walls and low type heat source. During the first 8 hours of the second day, temperatures increase as a consequence of the heat energy input. But since the wall surface temperature doesn't reach 21.0°C, the ceiling remains passiv. After the work time, the internal heat source is switched off. The surface temperatures begin to sink because of the equalizing effect of thermal conductance (thermal charge of the masses) and radiation. At the end of the second day, the heat energy is more or less equally distributed. The temperature is now 0.29 K higher than 24 hours before (Table 1, but 200 W only). - During the third day, the source is again active (hours 48 to 56). In the time span from hour 51 to hour 54, the temperature control puts the ceiling to the active cooling mode (water in circulation). After that, the active mode is turned off, but since the volume mean temperature of the concrete ceiling is well below the actual equilibrium temperature, the ceiling acts in a passive mode for the rest of the day. The next day begins with a room temperature slightly below 20°C.

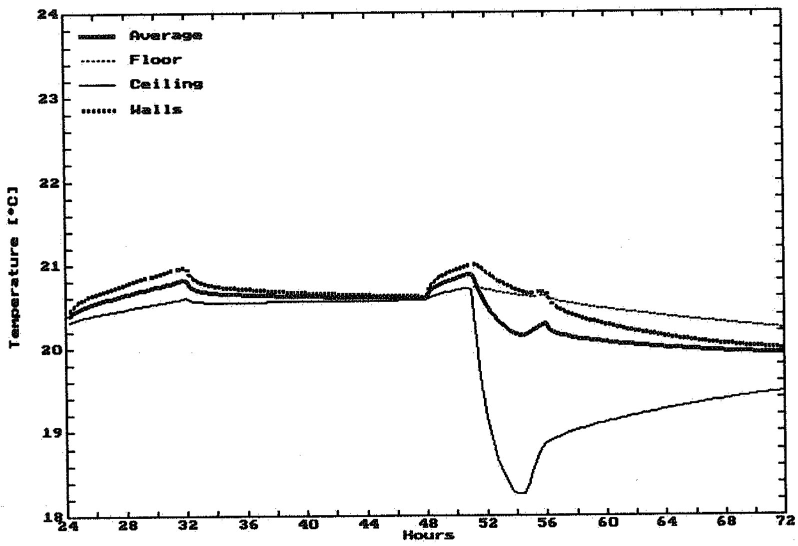

Figure 1: Surface temperatures for days 2 and 3 for case 1 with temperature control, light wall construction and 200 W heat load.

The type of wall construction has an important effect on the temperature behavior of the room. This is demonstrated with two simulations of case 1, both temperature controlled and with 1000 W internal heat sources: one room with light walls, the other with concrete. The differences can be seen in figure 2. Expressed with the mean values of the room temperature (work time, third day), the difference is 0.5 K. The maximum temperatures are 21.6°C (light type) and 20.8°C. Light walls react to heat sources with higher temperatures compared to concret walls. Since in our model the wall temperature is taken as control parameter, the resulting time schedules of active cooling is different for the two rooms: In the room with the light walls, the system is switched on 30 minutes after the sources have started to operate, in the other room after 2.5 hours. (In practical applications, one would certainly choose different threshold temperatures for the two wall types).

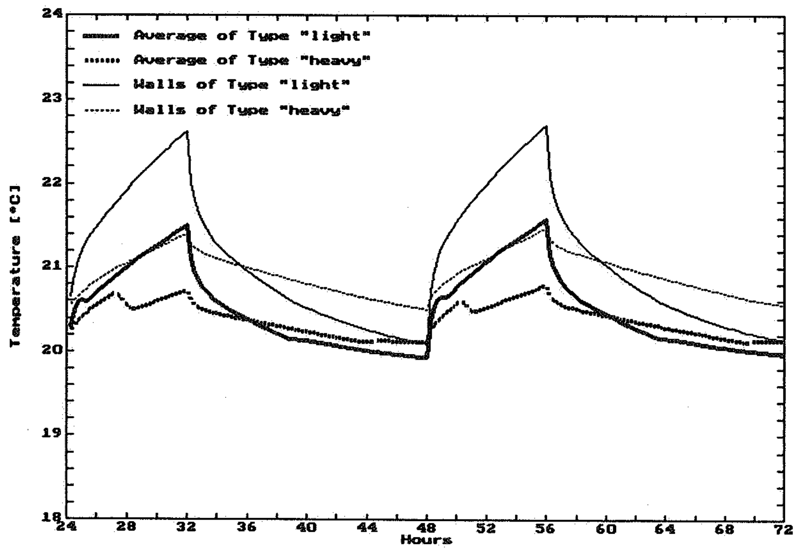

Figure 2: Room temperature and wall temperature for days 2 and 3 for two simulation of case 1, both with temperature control and 1000 W internal heat loads: light or heavy wall type, respectively.

In the examples given so far, the effect of thermal inertia of the masses could be seen. This is especially true for the next case. In practice, it might be an advantage to run the cooler during night time only. Therefore, the concrete ceiling acts as a buffer. Here, a simulation of case 3 is looked at: light wall construction, 1000 W internal heat load, cooling ceiling active during 12 hours each night. The process of thermal charge and discharge of the masses is shown in figure 3.

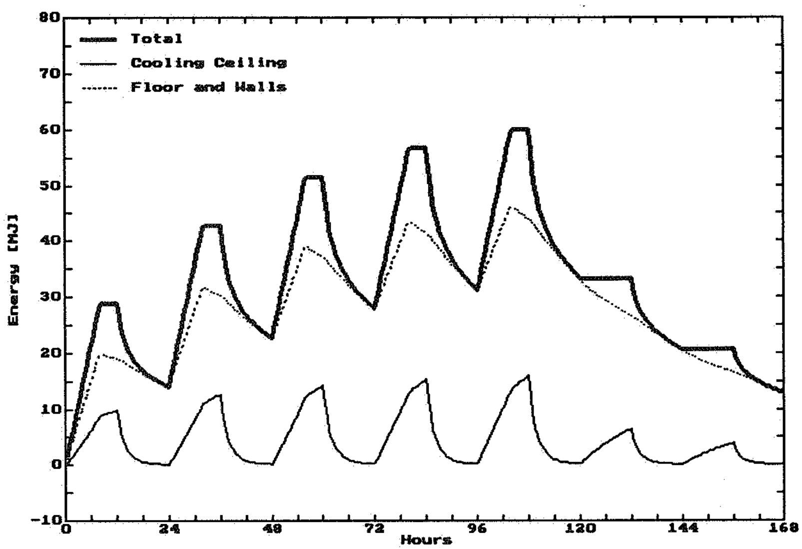

Figure 3: Energy contents of the thermal masses over one week. It's a case with light wall construction, 1000 W internal heat load, cooling ceiling active during 12 hours each night.

5. Results

The aim of this study is to come to an idea of the fields of operation for the different control strategies. Clearly, the power of the heat loads is a very important parameter. In many office buildings, the load profiles differ from room to room to a large extent. In any case, one must declare an upper limit of heat loads to which the comfort requirements have to be met. With some systems, it might also be necessary to define a minimum temperature.

Case 1

The two control strategies "temperature" and "time", as defined in chapter 3, are compared. Figure 4 shows the daily mean room temperatures (work time, third day) as a function of the heat load power. The four curves represent the combination of the two wall types with both control types. With temperature control and heavy walls, the mean temperature is practically independent of the heat load, with light walls, the dependance is minor. The situation becomes very different with the fixed time control. Either, the rooms with low heat loads are too cool, or, if the water temperature is shifted, rooms with substancial loads are critical to become unacceptably warm. Consequently, this type of control may be applied in buildings with minor variety.

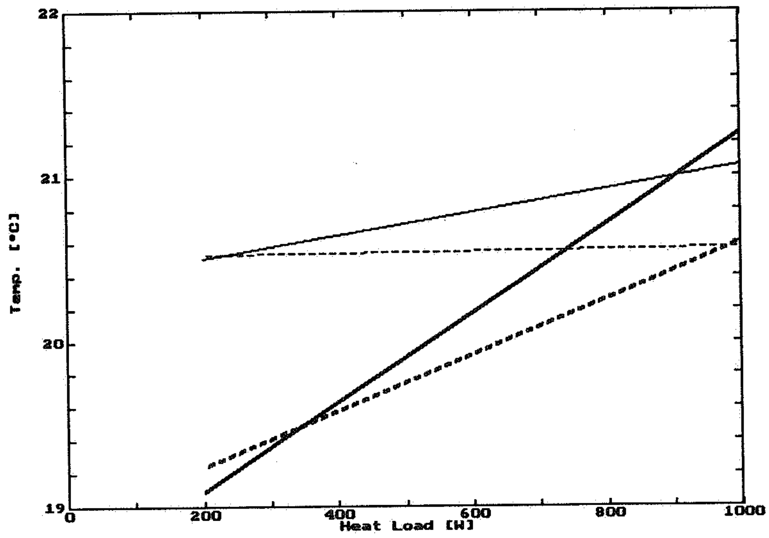

Figure 4: Daily mean room temperatures (work time, third day) as a function of the heat load power. The curves represent the four cases:

——— light walls, temperature control
▬▬▬ light walls, time control
------ concrete walls, temperature control
▪▪▪▪▪▪ concrete walls, time control

Case 2

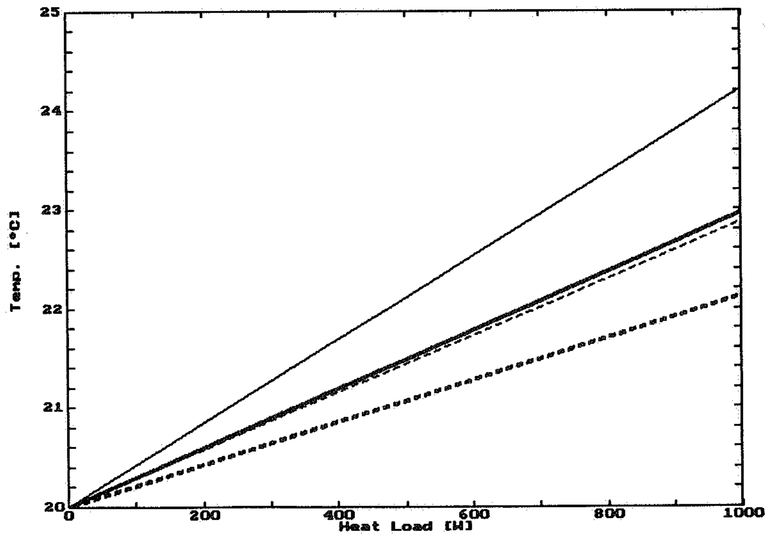

Figure 5: Daily mean room temperatures (work time, fifth day) as a function of the heat load power for permanently active cooling systems. The curves represent the four cases:

——— light walls, 60% active part
------ light walls, 100% active part
▬▬▬ concrete walls, 60% active part
▪▪▪▪▪▪ concrete walls, 100% active part

Case 2 demonstrates the ability of systems without any control of the cooling ceiling (strategy: permanent). The water temperature is held at

20°C in order to prevent undertemperature. Again, for four situations (light and concrete walls, 60 and 100% active part) the daily mean room temperatures are shown as a function of the heat load (figure 5). Day 5 is chosen for the following reasons: within the first week, the state of dynamic equilibrium is nearly reached in the cases "100% active part", but is not reached in the 60%-cases. So, the temperatures given in figure 5 are typical in the latter cases, but they represent an upper region for 100% active part. - The result is, that with 100% active part, the cooling ceiling can keep an acceptable indoor temperature throughout a large range of heat loads, whereas with a limited active part restrictions must be accepted.

Case 3

In this case, night cooling with fixed times (12 hours each night) is simulated. The results given in figure 6 are for the third and the fifth day of the first week (the argumentation of case 2 is again valid). Although the comfort conditions taken over the whole range are not as favorable as with permanent cooling, they are nevertheless acceptable.

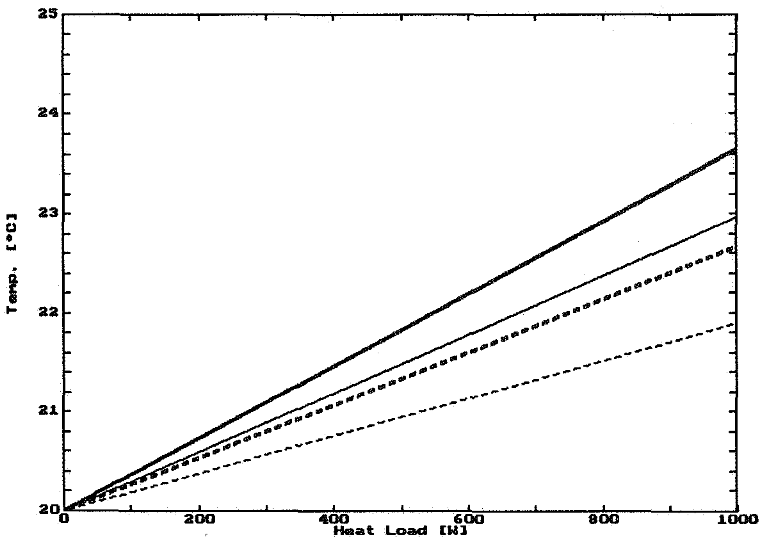

Figure 6: Daily mean room temperatures (work time, third and fifth day) as a function of the heat load power for night cooling systems. The curves represent the four cases:

- ——— light walls, third day
- ▬▬▬ light walls, fifth day
- ------ concrete walls, third day
- ▪▪▪▪▪▪ concrete walls, fifth day

The figures 4 to 6 show daily mean temperatures. Sometimes, limits for maximum temperatures have to be respected. Since the variation throughout a day depends on heat load, wall type, control strategy and water temperature, the same kind of investigation should be conducted for maximum temperatures.

6. Conclusions

Dynamic computer simulations demonstrate, that acceptable comfort conditions can be achieved with different or even opposing control strategies. In this paper it is looked to ceiling cooling systems with demand control by temperature, and, on the opposite side, to systems without any control.

Demand controled systems principally offer more flexibility than time controlled or permanently running systems. Nevertheless, there exist many situations in which the less sophisticated systems are attractive.

References:

[1] WIDMER F.
Raumlufthygiene und rationelle Energieverwendung sind kein Widerspruch
Heizung Klima Nr. 1/2, 1989

[2] BRAUN W.
Building Performance and Ventilation System
11th AIVC Conference, Italy, 1990

[3] ESDORN H., KÜLPMANN R.
Deckenkühlung in Verbindung mit Verdrängungslüftung: Hohe Einsparungen bei der Förderenergie
CCI 4, 1989

[4] BRAUN W.
Experiences with High Tech Buildings
CIB W67, Rotterdam, 1990

[5] ESDORN H., ITTNER M.
Betriebsverhalten von Deckenkühlsystemen