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COMFORT AND ENERGY CONSUMPTION ANALYSIS IN BUILDINGS WITH RADIANT PANELS

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ABSTRACT

The air flow program, PHOENICS-84, is used to study the three-dimensional air velocity and temperature distributions in an office room with a ceiling radiant heating system, a radiator heating system, or a warm air heating system. It has been found that the radiator heating system presents the smallest vertical air temperature gradient and air velocities in the occupied zone. The radiant heating system offers a rather comfortable indoor environment.

The energy consumption of the room with the three different heating systems is studied by using the computer program ACCURACY. It may be concluded that the radiant heating system uses 17% more energy than the other two systems. The main reason is that the ceiling heat capacity is very high and it stores a large amount of heat during office hours and releases the heat into the room during night hours and weekends. The heating loads of the radiator heating system and the warm air heating system are nearly the same regardless of the energy used for the ventilator in the warm air heating system.

INTRODUCTION

During last few years, many articles have been published for the investigation of radiant heating systems [1][2][3]. With radiant heating systems, the air temperature in a room can be set back below the usual comfort level because the temperature of the inside wall surfaces is higher than that in warm air heating systems. The higher temperatures in the inside wall surfaces and the radiant panels provide sufficient heat to achieve the same comfort environment. Does a radiant panel heating system save energy? This paper will present a comparison on the indoor air flow patterns and energy consumption among a radiant heating system, a radiator heating system and a warm air heating system (See Fig.1.).

INDOOR AND OUTDOOR THERMAL CONDITIONS

An office room which is 5.6 m long, 3.0 m wide and 3.2 m high as shown in Fig. 1 is used for the study. The room is regarded as a room in the middle of a building. Therefore, the spaces above, below and next to the room are considered to be of the same thermal conditions as those of the room. There is only one exterior wall with a double glass window in the room. For the radiant heating system, the ceiling is fully covered with radiant panels. The radiator under the window, which is of the same width as the room, is utilized for radiator heating. The main characteristics of the room is given in Table 1.

To generalize our results regardless of a person's location, orientation, or posture, we approximate the mean radiant temperature, T_{mrt}, as the area-weighted average of the room surface temperatures, T_i:

$$T_{mrt} = \sum_i (T_i A_i)/\sum_i A_i$$

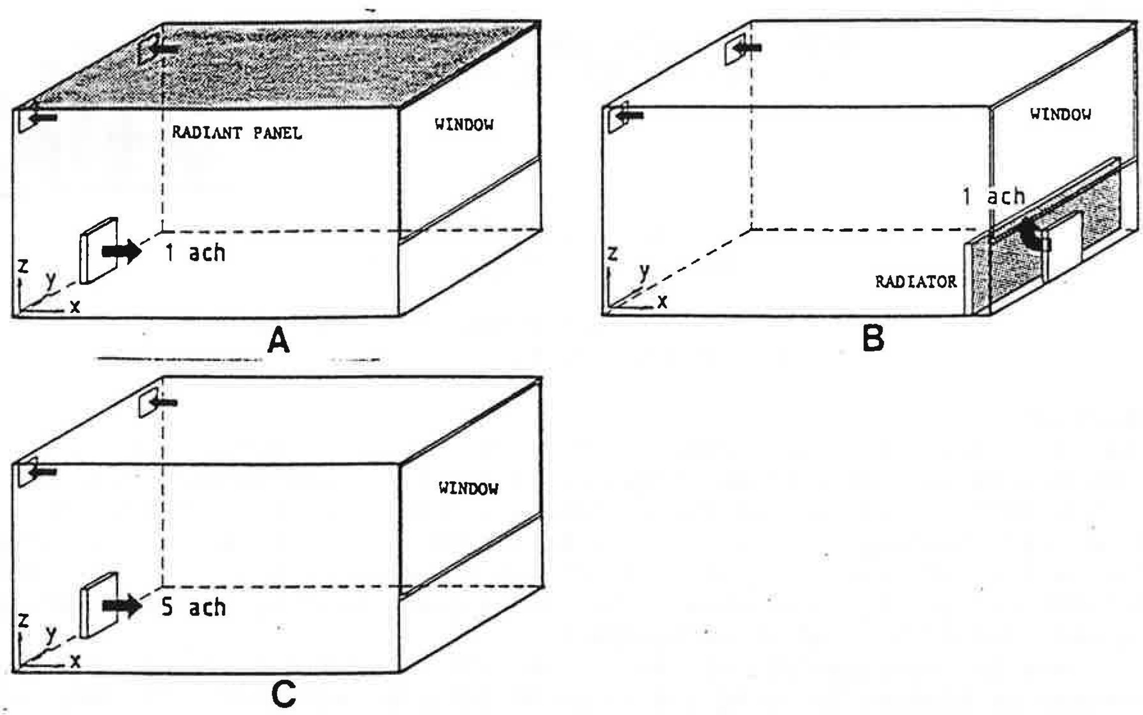

Figure 1. Three heating systems. (A) Radiant heating system, (B) radiator heating system and (C) warm air heating system.

where A_i is the area of inside surface i. The room environment is evaluated by the equivalent temperature in the centre of the occupied zone (x=2.8 m, y=1.5 m and z=0.9 m), T_{eu}. With the same equivalent temperature, a person will experience the same degree of thermal comfort. The equivalent temperature is defined as [2]:

$$T_{eu} = 0.45\ T_{mrt} + 0.55\ T_{air}$$

where T_{air} is the air temperature in the centre of the occupied zone.
The computations presented in this paper are performed by using the Dutch weather data of 1 September, 1971 to 31 May, 1972. It is assumed that there are 55 office hours each week, i.e. from 7:00 to 18:00 from Monday through Friday. During these office hours, the equivalent

Table 1. The main characteristics of the room

Enclosure	Layer	Thickness m	Density kg/m³	Specific heat J/kgK	Thermal conductivity W/mK
Ceiling and floor	1st 2nd	0.175 0.100	2300 35	840 840	1.9 0.041
Rear and side walls	1st	0.140	700	840	0.23
Parapet	1st	0.100	30	1470	0.035
Window	Double-glass: thickness 6 mm, absorption coefficient 0.018				
Internal conditions	Fresh air is one-time air exchange per hour (i.e. 1 ach). For the warm air system, 4 ach return air is used. Hence, the total air supply for the system is 5 ach.				

temperature in the centre of the occupied zone is maintained to be 20.0°C. However, one-time exchange rate per hour of fresh air is always required for comfort during office hours. It is supposed that there is always 200 W convective heat released into the room air during the office hours. This amount of heat is considered to be the convective heat from the occupants, appliances and lights, etc. in the room. For weekends and night hours, there is no internal heat gain in the room and the heating system is switched off. Therefore, there is no energy consumption during weekends and night hours. For the warm air heating system, the total air supply is equivalent to a five-time air exchange rate per hour where four-time of it is the return air from the outlets.

INDOOR AIR FLOW PATTERNS OF THE HEATING SYSTEMS

The indoor air flow patterns are calculated by the air flow program PHOENICS-84 [4]. The computations involve the solution of three-dimensional equations for the conservation of mass, momentum, energy, turbulence energy and the dissipation rate of turbulence energy with improved wall function expressions for solid boundary conditions [5]. The wall boundary conditions such as inside wall surface temperatures and heating loads are determined by the cooling load program ACCURACY [5][6]. Iteration between the two computer programs is necessary because they are interrelated.

Figs. 2-4 illustrate the numerical results in section y=1.5 m of the room under the three heating systems. They are the indoor air flow distributions on 18 January, 1972, Tuesday, at 9:00 am. In the computations, all the internal heat gain is distributed uniformly in each wall by the area-weighted average method. The air temperature in the centre of the occupied zone is about 19.5°C for radiant heating, 20.0°C for radiator heating and 21.0°C for warm air heating. However, the vertical air temperature gradient in the occupied zone for the radiator heating system is the smallest and for the radiant heating system is the largest. The air temperatures near the outlets in the upper part of the room are nearly the same.

Generally speaking, the air velocities in most space of the room are

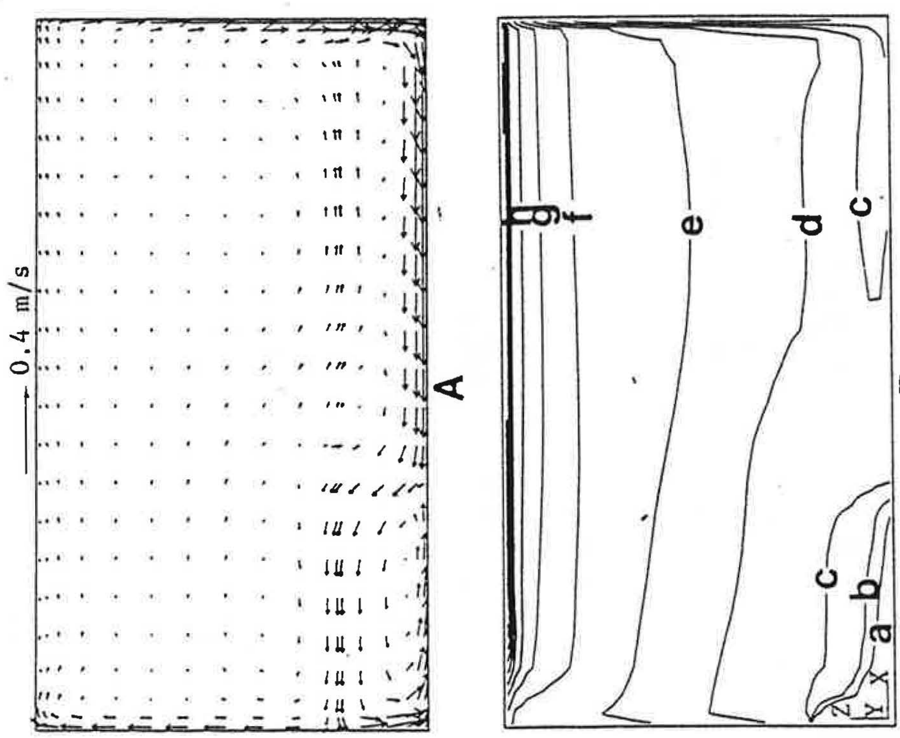

Figure 2. The computed airflow distribution of the radiant heating system in section y=1.5 m. (A) Velocity and (B) temperature (°C) a-18.0 b-18.5 c-19.0 d-19.5 e-20.0 f-20.5 g-21.0 h-21.5

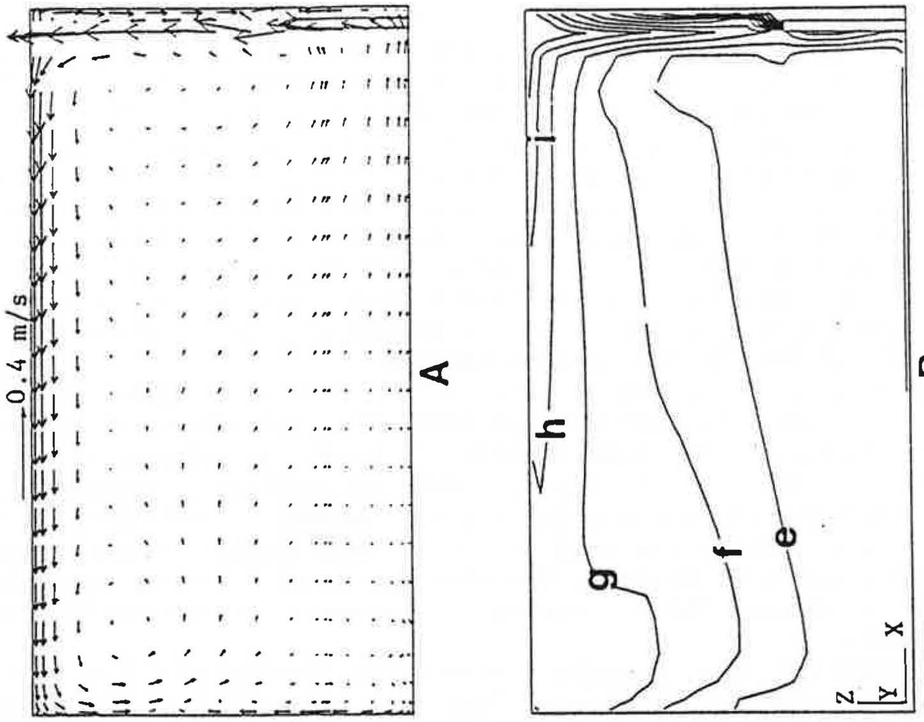

Figure 3. The computed airflow distribution of the radiator heating system in section y=1.5 m. (A) Velocity and (B) temperature (°C) e-20.0 f-20.5 g-21.0 h-21.5 i-22.0

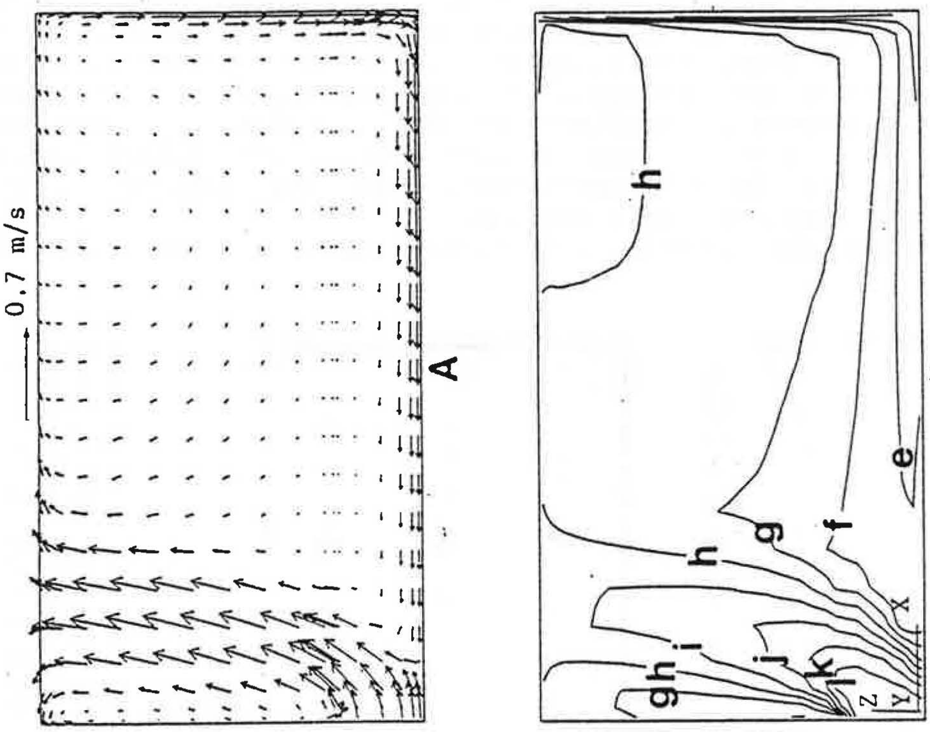

Figure 4. The computed airflow distribution of the warm air heating system in section y=1.5 m. (A) Velocity and (B) temperature (°C) e-20.0 f-20.5 g-21.0 h-21.5 i-22.0 j-22.5 k-23.0 l-23.5

small. However, due to the large buoyancy generated from the inlet and the window surface, the velocities in the floor area are rather high in the radiant and warm air heating systems.

From the velocity and temperature fields, we may conclude that the radiator heating system is the most comfortable one and the warm air heating system is the worst. Nevertheless, in the radiator system, the asymmetry of the radiator may result in discomfort. The radiant heating system offers a rather comfortable indoor environment. Further research on evaluation of comfort is necessary.

ENERGY CONSUMPTION OF THE HEATING SYSTEMS

The hourly heating load, which is regarded as energy consumption of the room, is calculated by the cooling load program ACCURACY. The program is a coupling of a cooling load program and an air flow program. It is based on the room energy balance method and uses Z-transfer functions and window energy balance equations for the heat transfer through enclosures. The influence of temperature distributions of the room air on space load can be studied in the program [5][6].

When the Dutch weather data from 1 September, 1971 to 31 May, 1972 is used, the computed heating load is 446 kWh for the radiant heating system, 383 kWh for the radiator heating system and 382 kWh for the warm air heating system. The heating load of the radiant heating system is 17% higher than that of the warm air heating system. The heating load of the radiator heating system is almost the same as that of the warm air heating system apart from the energy used for the ventilator in the warm air heating system. The main reasons can be summarized as the following:

(1) The ceiling is constructed with heavy concrete and its heat capacity is large. Hence, a large amount of heat is stored during office hours and the heat will be released into room air during night hours and weekends. It is very evident at the first office hour since a great amount of heat is required for heating-up the room. This also results in a higher air temperature during night hours and weekends in the room in the radiant heating system. This can be seen from Fig. 5 which illustrates the air temperature in the centre of the occupied zone of the three heating systems on 18 January, 1972, Tuesday.

(2) Although the room air temperature in the radiant heating system is lower than that in the warm air heating system, the temperatures of the inside window surface and the parapet surface are almost the same. This is because the view factors between the radiant panels and the window and the parapet surfaces is large and there is a big amount of radiative heat exchange. With the same inside surface temperature, the total heat loss through the window and parapet is nearly the same between these two heating systems.

(3) The outlet air temperatures are the same between the radiant heating

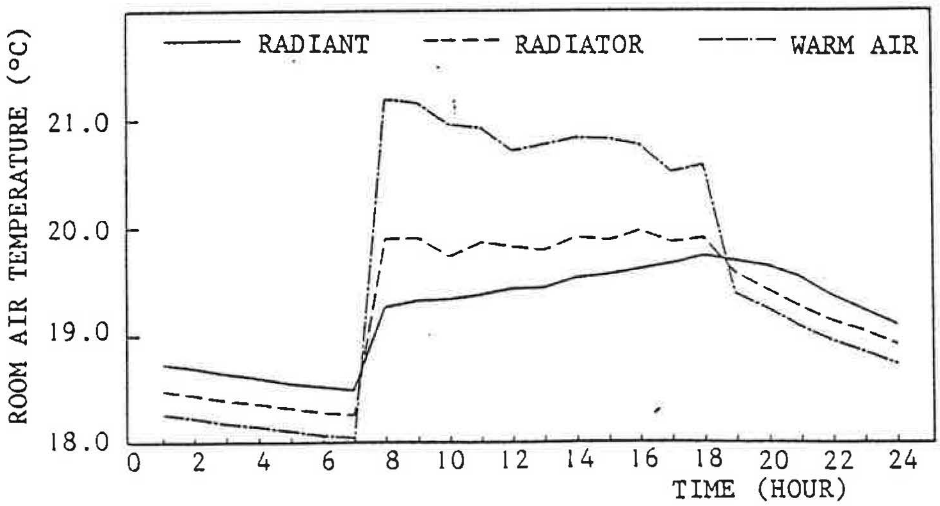

Figure 5. The air temperatures in the centre point of the occupied zone of the three heating systems on 18 January, 1972, Tuesday.

system and the warm air heating system because the presence of the vertical air temperature gradients. This indicates that the heat losses due to the one-time exchange rate per hour of fresh air are the same.

(4) In principle, the radiator heating system is similar to the radiant heating system. Since the heat capacity of the parapet is small, a relatively small amount of heat is required for the first office hour to heat up the room. Besides, the view factor between the radiator and the window surface is zero. Therefore, the heat loss via window is smaller because its surface temperature is lower. However, a certain amount of heat is still stored in the walls of the room by the radiative heat exchange. As a consequence, the heating load of the radiator heating system is the same as that of the warm air heating system.

CONCLUSIONS

From the numerical solutions of the air velocity and temperature distributions in the room with a radiant, radiator or warm air heating system, we may conclude that the radiator heating system is most comfortable one but with asymmetry heating. The warm air system will cause draught because the air velocities near the floor are large. The radiant heating system offers a rather good environment since there are no asymmetry problems and the air velocities in the occupied zone are acceptable from the view point of comfort.

The heating load of the radiant heating system is 17% higher than that of the other two heating systems. The main reason is that the ceiling is constructed with heavy concrete and its heat capacity is large. Therefore, the ceiling stores a large amount of heat during office hours. The heating load of the radiator heating system is almost the same as that of the warm air heating system.

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