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Two-Pipe Chilled Beam System for Both Cooling and Heating of Office Buildings

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Abstract

Simulations were performed to compare a conventional 4-pipe chilled beam system and a 2-pipe chilled beam system. The objective was to establish requirements, possibilities and limitations for a well-functioning 2-pipe chilled beam system for both cooling and heating of office buildings. The building model had a net volume of 3669 m^3, (L*B: 25.5m*11.5 m) and net ceiling height of 2.55 m. The building model was assumed to consist of 78 office rooms, 6 meeting rooms and 5 corridors with a 50% occupancy. Simulations were executed using Bsim, an energy simulation program, to calculate the energy consumption and hence energy savings in the 2-pipe chilled beam system in comparison with the 4-pipe system. The 2-pipe chilled beam system used high temperature cooling and low temperature heating with a water temperature of 20°C to 23°C, available for free most of the year. The system can thus take advantage of renewable energy. The results showed that the energy consumption was 3% less in the 2-pipe chilled beam system in comparison with the conventional 4-pipe system when moving cooled and heated water through the building, transferring the energy to where it is needed. Using free cooling (taking advantage of low external air temperature for cooling), together with transfer of energy, the energy consumption in the 2-pipe system was 5 % to 18% less in comparison with the 4-pipe chilled beam system. The energy savings from cooling alone ranged from 5 % to 60 %.

Keywords – Chilled beam, energy saving, cooling, heating, free cooling

1. Introduction

In buildings, the energy used for cooling and heating systems accounts for a substantial part of the total energy consumption. One of the technical solutions for buildings that contribute to a reduction of the energy

consumption is an active chilled beam system [4, 2]. This system reduces energy consumption in buildings and provides a comfortable indoor climate [3, 5].

A chilled beam system can be used for ventilation, cooling and heating of office buildings for thermal comfort. The system uses water as an alternative to air to cool a room. It means that the system can remove excess heat and at the same time the demand of supply air can be reduced. The system is partially an alternative system to air conditioning and heating systems [1]. In addition, the system ensures that cool air can be distributed uniformly and in higher quantities everywhere in the office buildings.

The hypothesis that formed the basis for this project was that a system variant of the active chilled beam system could use high temperature cooling and low temperature heating. The water temperature in the system was 20°C to 23°C, which was available most of the year. The system reduced energy consumption by moving cooled and heated water through the building, transferring the energy to where it was needed.

In this project, the possibility of using the same pipes for both heating and cooling was investigated, depending on the requirements pertaining to the heating and cooling seasons.

The main objective of this project was to study requirements, possibilities and limitations for a well-functioning 2-pipe system for both cooling and heating of office buildings.

2. Methods

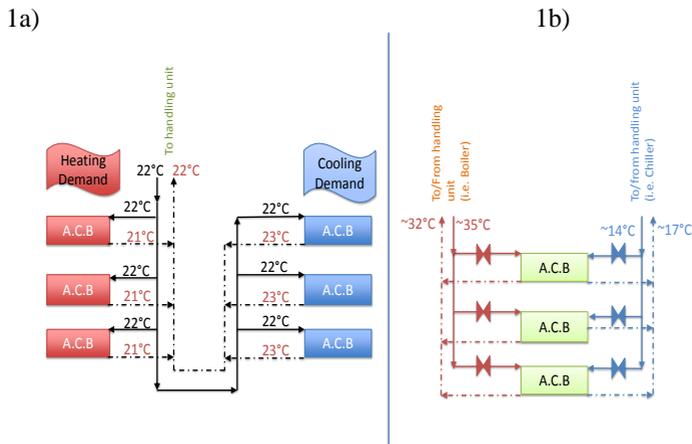### The active chilled beam systems

Fig. 1 Schematic pictures of the active chilled beam system for both cooling and heating. *1a)* 2-pipe chilled system and *1b)* 4-pipe chilled system.

Figures 1a and 1b illustrate the active chilled beam systems for both cooling and heating. The system includes the pipes for transport of cold and warm water and also thermal zones showing water temperatures.

Simulation

Simulations were executed using Bsim, an energy simulation program, to calculate the energy consumption and hence energy savings in the 2-pipe chilled beam system in comparison with the 4-pipe system.

The energy study was made on an imaginary multi-storey non-residential building consisting of five floors with a net volume of 3669 m^3, net ceiling height of 2.55 m and with 50% occupancy. Each floor consisted of 78 office rooms, 6 meeting rooms and 5 corridors. The building was assumed to be located in a cold climate in the northern part of Europe.

The analysed office rooms were assumed to be a normal office environment with a corridor on each floor. It was assumed that the doors between the office rooms and the corridors were closed at all times and had the same U-value as internal walls. It means that the airflow between all thermal zones was not allowed. The physical size and constructions of the rooms and corridors in the building model were constant throughout the entire analysis.

Table. 1 Input data of tempertures.

	Winter			Spring & Autumn			Summer		
Time	0-7	7-17	17-0	0-7	7-17	17-0	0-7	7-17	17-0
Air supply (°C)	18	22	18	14*	21	18	14	20	-
Heating (°C)	18	22	18	18	21	18	18	20	-
Cooling (°C)	22	23	-	21	22	-	20	21	-
Water mean (°C)	18.5	22	18.5	18.5	21.5	18.5	18.5	21	-
@Max cooling power (°C)	19	32.5	29	29	32	29	29	31.5	-

* If $T_{out} \leq 14°C$ then $T_{supply\ air}=14°C$ and If $T_{out} >14°C$ then $T_{supply\ air}=T_{out}$

Table 1 shows the input data of temperatures for calculating yearly energy demand of the building model and also for determining cooling, heating and ventilation loads for the four seasons of the year.

The HVAC system consisted of a ventilation system, a heating system and a cooling system. The ventilation system was a constant air volume (CAV-system). The average specific ventilation rate was 2.3 l/s m^2. This equalled an average ventilation rate of 23 l/s in an average area of office rooms, corridors and meeting rooms of approximately 10 m^2.

The supply air had a set point temperature according to Table 1. The temperature was different during working hours and non-working hours. The working hours and non-working hours mentioned in Table 1 were the hours that the HVAC system operated at different times of the day. Weekends were

assumed to be non-working hours i.e. with the same input parameters as for 17-24.

Table 2 shows the U-values and thickness of roof, floor, ground floor, outer wall, inner wall and window. These values corresponded to the values of modern Danish buildings with well-insulated walls and windows with triple-glazing.

Table. 2 Input data of U-values and thickness.

Part of building	Roof	Floor	Ground floor	Outer wall	Inner wall	Window
U-value (W/K m^2)	0.161	0.417	0.169	0.251	0.418	1.273
Thickness (m)	0.37	0.347	0.347	0.345	0.116	-

The internal heat generation included heat from people, office equipment, lighting and solar radiation through windows. Working hours were from 8:00 – 17:00, Monday to Friday, all year round. Holidays were excluded in the simulations. It was also assumed that the meeting rooms were occupied all weekdays between 10:00-11:00 and 14:00-15:00 and that the office rooms and corridors were occupied 100% all weekdays from 8:00-17:00. Moreover, equipment loads were present in the corridors. The equipment in the corridors operated at 40% of capacity during non-working hours 00:00-08:00 and 17:00-24:00 and weekends.

The internal heat was assumed to be 31.6 W/m^2 in occupied office rooms, zero in unoccupied office rooms, 16.5 W/m^2 in corridors and 38 W/m^2 in meeting rooms.

Calculation of energy savings using energy transfer:
The aim was to calculate the energy consumption and hence the energy savings in the 2-pipe system in comparison with the 4-pipe system by means of moving cooled and heated water through the building, transferring energy to where it was needed. The water temperature to the 2-pipe system was 20 - 23°C and 14-16 °C to the 4-pipe system.

Calculation of energy savings using energy transfer together with free cooling:
Using energy transfer together with free cooling, the aim was to calculate the energy consumption and hence energy savings in the 2-pipe chilled beam system in comparison with the 4-pipe system.

The calculation consisted of three steps i.e. simultaneous heating and cooling demand, cooling demand (summer case) and heating demand (winter case). Furthermore, the temperature range of the supplied water to the 2-pipe system was 20 °C -23°C, while the water temperature to the 4-pipe system

was 14-16 °C. The cooling capacity was 1590 W for the average area of the office rooms, the corridors and the meeting rooms is 10 m^2, equal to 159 W/m^2. The room temperature is listed in Table 1.

Table. 3 Scenarios for free cooling application.

	Free cooling (%)	Scenario			
		1	2	3	4
		Outdoor temperature[°C]		Outdoor temperature[°C]	
4-pipe system	100	<10	<10	<8	<8
	75	-	10-11	-	8-9
	50	-	11-12	-	9-10
	25	-	12-13	-	10-11
2-pipe system	100	<16	<16	<14	<14
	75	-	16-17	-	14-15
	50	-	17-18	-	15-16
	25	-	18-19	-	16-17

Table. 4 External air temperatures for cooling (free cooling).

	Scenario No.		5
	Free cooling [%]		Outdoor temperature [°C]
4-pipe system	100	In all seasons	<8
2-pipe system	100	Working hours in winter	<20
		Working hours in spring & autumn	<19.5
		Working hours in summer	<19
		Non-working hours	<16.5

Tables 3 and 4 show the free cooling temperatures in five different scenarios, numbered 1 to 5.

Scenario 1: Free cooling is applied as ON/OFF switching mode when the outdoor temperature exceeds certain temperatures (10°C for the 4-pipe system and 16°C for the 2-pipe system)

Scenario2: Free cooling is applied step by step. Free cooling (100% - 25%) decreases and outdoor temperatures increases, see Table 3.

Scenario 3: Free cooling is applied like in Scenario 1, but certain temperatures are different i.e. 8 °C for the 4-pipe system and 14 °C for the 2-pipe system.

Scenario 4: Free cooling is applied like Scenario 2, but temperature ranges are different (for the 4-pipe system 8 °C -11 °C and for the 2-pipe system 14 °C-17 °C)

Scenario 5: Free cooling is applied as ON/OFF mode for the 4-pipe system in 8 °C, but for the 2-pipe system it is applied when the outdoor temperature is 2 °C less than mean water temperature at certain time, see Table 4.

In order to calculate the energy savings by means of transfer of energy between different thermal zones a scenario with no free cooling was defined. The scenario is designated *Scenario 0*.

3. Results

Figure 2 illustrates the total energy demand of the building model of the full-year simulation. The result indicated that the total energy demand of the building was 58.5 kWh/m^2. Figure 3 illustrates the total energy demand when simulating the 2-pipe system and the 4-pipe system separately. The results from the calculation showed that the simultaneous cooling and heating was 1.6 kWh/m^2, 1.4 kWh/m^2, 1.3 kWh/m^2, 1.2 kWh/m^2 and 1.2 kWh/m^2, respectively, for Scenario 1 to Scenario 5. For Scenario 0 the result was 2.9 kWh/m^2.

Simultaneous heating and cooling (SHC) was calculated for the 2-pipe system:

$$(SHC) = \sum_{i=0}^{n} |H_i - C_i| \tag{1}$$

Where H_i is the heating demand and C_i is the cooling demand for every single hour.

Figure 4 illustrates the total energy demand of the cooling system when simulating the 2-pipe system and 4-pipe system separately. The results showed that the simultaneous cooling demand was 0.5 kWh/m^2, 0.3 kWh/m^2, 0.2 kWh/m^2, 0.1 kWh/m^2 and 0.05 kWh/m^2 for Scenario 1 to Scenario 5 respectively. For Scenario 0 the result was 1.8 kWh/m^2. The results of the simulation showed that the use of external air temperature as a free cooling source in conjunction with the 2-pipe system increased the cooling energy saving potential in comparison with a 4-pipe system.

Simultaneous cooling (SC) was calculated for a 2-pipe system:

$$(SC)_n = \sum_{i=0}^{n} (H_i - C_i) < zero \qquad (2)$$

Where H is the heating demand, C is the cooling demand and SC is less than zero.
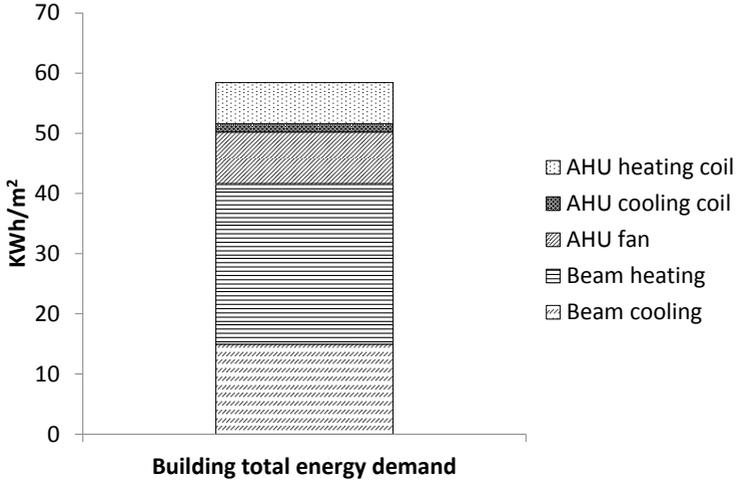

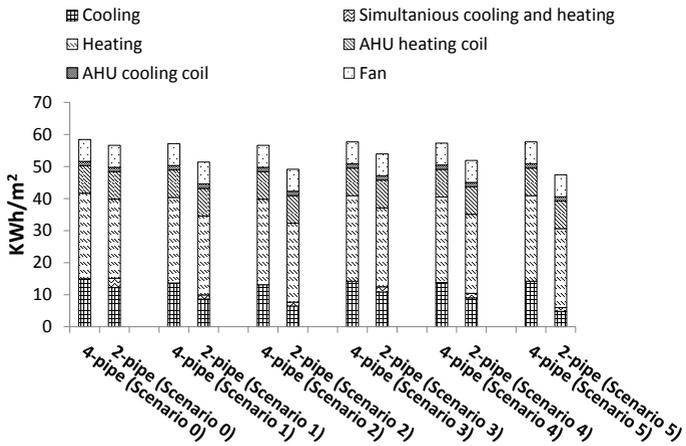Fig. 2 The total delivered energy use of the building model.

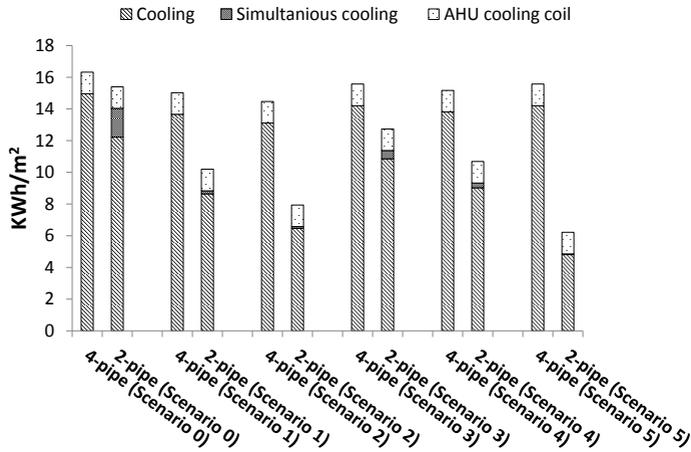Fig. 3 The total energy demand of the building model. A comparision between the chilled beam systems.

Fig. 4 The total energy demand of the cooling systems. A comparision between the chilled beam systems.

4. Discussion

Simulations have been performed comparing a conventional 4-pipe chilled beam system and a 2-pipe chilled beam system. The objective of this project was to establish requirements, possibilities and limitations for a well-functioning 2-pipe system for both cooling and heating of office buildings and to develop methods to design such systems. In order to achieve the aim, an energy study was made on a building model. A system variant of the active chilled beam system (2-pipe system) was compared with a standard system (4-pipe system). The water temperature in the 2-pipe system was 20 °C - 23 °C, which was available most of the year. In addition, the present paper presents results of simulation and calculation of energy savings when the external air temperature was used as a free cooling source in conjunction with the systems.

Energy savings due to energy transfer between zones

Scenario 0 in Figure 5 illustrates the total energy saving by transferring heat between different rooms. The results showed that the amount of saved energy, which was the energy demand difference between the 2-pipe system and 4-pipe system, was 1.8 kWh/m^2. This is indicated in Figure 6 by approximately 3 % energy savings. Furthermore, the amount of cooling energy was also calculated. Figure 7 shows the amount of cooling energy saved by the mean of heat transferring in Scenario 0. The 2-pipe system needed 5.6% less cooling energy than the 4-pipe system.
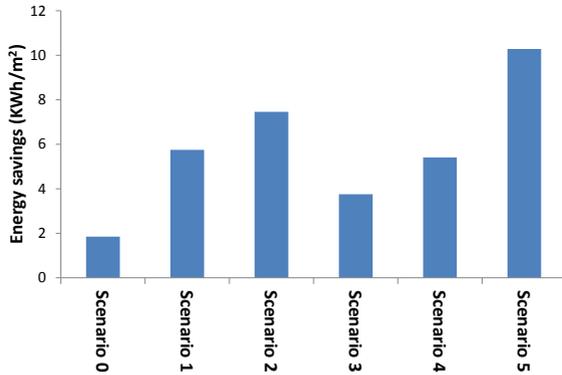
Fig. 5 Energy savings (kWh/m^2) by tranferring energy between rooms (Senario 0) and energy savings by energy transfer together with free cooling (Scenarios 1-5).
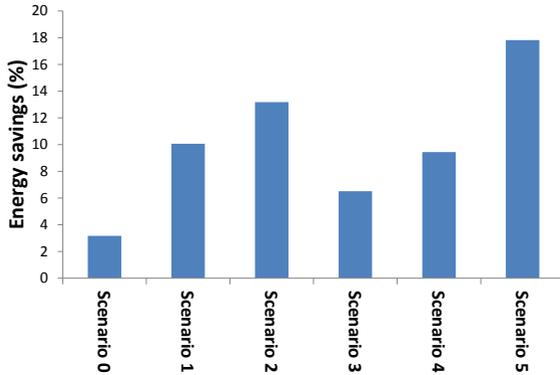

Fig. 6 Energy savings (%) by tranferring energy between rooms (senario 0) and energy savings by energy transfer together with free cooling (Scenarios 1-5)

Energy savings due to energy transfer and free cooling

In addition, the present paper introduces the calculation of energy savings when the external air temperature was used as a free cooling source in conjunction with the systems. Scenarios 1-5 in Figure 5 illustrate the energy savings as a result of energy transfer, and the energy advantage of free cooling in the 2-pipe system was compared with the 4-pipe system.

The results showed that the amount of energy saved in the 2-pipe system, compared with the 4-pipe system, varied between 3.7 kWh/m^2 and 10.2 kWh/m^2. The variation depended on the different scenarios of the free cooling application, which corresponded to 6.5-17.8% energy savings, as can be seen in Figure 6. Furthermore, the amount of energy needed to cool the

building model during a year was compared in Figure 7 with Scenarios 1-5. The results showed that by applying free cooling, the 2-pipe system needed 18-60% less cooling energy than the 4-pipe system.
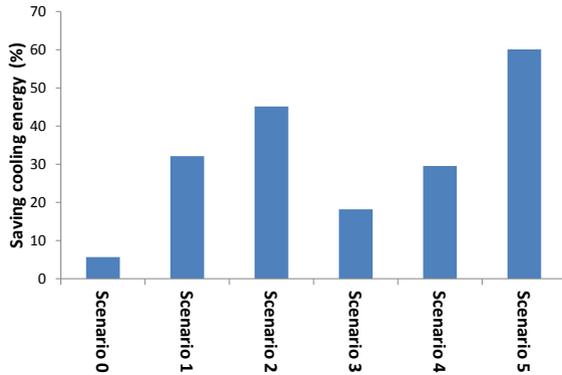

Fig. 7 Total amount of energy saved on cooling (%) by tranferring energy between rooms (Senario 0) and cooling energy saving using energy transfer together with free cooling (Scenarios 1-5)

5. Conclusion

The simulation and calculation showed that a 2-pipe system application of active chilled beams can save energy in different ways. The 2-pipe system can transfer energy between zones where the cooling and heating is simultaneously needed.

Since the 2-pipe system uses higher water temperature for cooling, a wider range of outdoor air temperatures can be used as a free cooling source.

Comparing the 2-pipe and the 4-pipe chilled beam system with regard to energy consumption in a building model, calculations shows that:

-Energy transfer between spaces is expected to save 1.81 kWh/m^2, which is almost 3% less than 4-pipe systems. This saves 5.6% energy for cooling energy.

-Using free cooling together with energy transfer, energy consumption can be reduced between 3.7 kWh/m^2 and 10.2 kWh/m^2 equalling almost 6.5% - 17.8%. Consequently, the consumption of energy for cooling decreases by 18-60%.

6. References

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