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Full-scale operation of a novel two-pipe active beam system for simultaneous heating and cooling of office buildings

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Abstract. This paper presents an investigation on the operation of a novel active beam system installed in an office building located in Jönköping, Sweden. The system consists of two parts: a dedicated outdoor air system (DOAS) to satisfy latent loads and ventilation requirements, and a water circuit to meet sensible heating and cooling loads. The novelty of the system is in relation to the water circuit, which is able to provide simultaneous heating and cooling through a single water loop that is near the room temperature. The energy performance of the system is currently being monitored through a number of sensors placed along the water circuit. Relevant physical parameters are being measured and data are available through a monitoring system. A preliminary analysis shows that the system is performing as designed. Results are shown for a typical week in winter, spring and summer. In particular, the supply water temperature in the circuit was between 20°C (in summer) and 23.2°C (in winter). The maximum supply/return temperature difference was found in summer and it assumed a value of 1.5 K. It is noticed that in spring supply and return water temperatures almost overlap.

1 Introduction

Active beam systems have gained increased recognition over the last decades as a sustainable technology able to provide good thermal comfort and advantages in terms of energy savings [1-2]. Although they are often referred to as "chilled" beams, in many cases active beams can be used for both heating and cooling [3].

Figure 1 shows the sectional view of a typical active beam unit. The water is circulated in a heat exchanger placed inside the active beam. The primary air enters the room via a pressure plenum. The high air velocity generated by nozzles reduces the static pressure and induces room air that passes the heat exchanger before it mixes with the primary air. The mixed air is discharged into the room through slots along both sides of the beam [4-5].

Conventional active beam systems consist of two main parts: a dedicated outdoor air system (DOAS) to satisfy latent loads and ventilation requirements, and a water circuit to meet sensible heating and cooling loads, as shown in Fig. 2. The water circuit is typically available in a four-pipe configuration, which allows simultaneous delivery of heating and cooling using two separated loops [6].

Recent studies conducted by the authors have investigated the possibility to design a novel active beam system able to provide simultaneous heating and cooling using only a single water loop (Fig. 2) [7-8]. The main characteristic of this novel system is related to the supply water temperature, which is around 22°C all year round.

Therefore, a room with an indoor air temperature of 20°C would be heated, while a room at 24°C would be cooled. Return water flows from single zones are mixed and the common return water flow is delivered to the central plant, which will operate in either heating or cooling mode, depending on the average resulting thermal loads in the building.
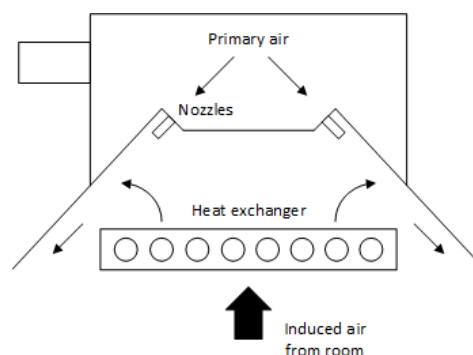
Fig. 1. Sectional view of a typical active beam unit

Beside the advantages in terms of exploitation of sustainable energy sources (due to water temperatures near ambient temperature), this piping configuration opens opportunities for transferring heat among building zones when simultaneous heating and cooling occurs in a building. By mixing the return pipes from individual zones, excess heat can be transferred from warm to cold zones through the water circuit.

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Fig. 2. Conventional four-pipe active beam system (left) vs. Novel two-pipe active beam system (right)
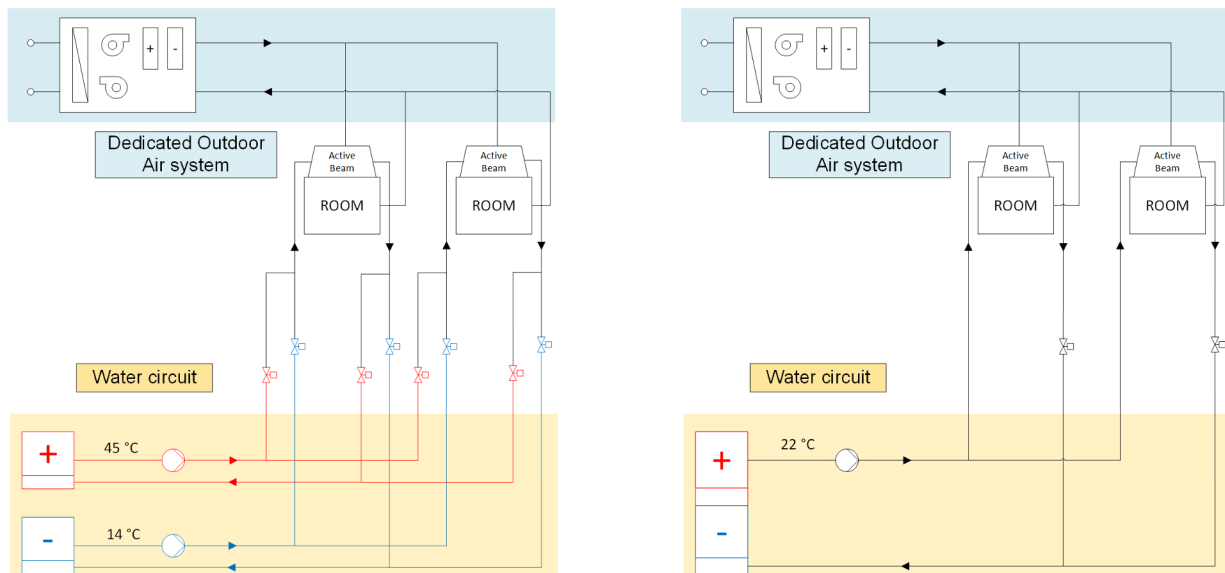
As shown by previous simulation-based works, this behaviour leads to a reduction of the annual energy use by approximately 18% when comparing the innovative two-pipe system with a traditional four-pipe system [9]. The design of the two-pipe systems also allows to save installation cost due to the need of only one water circulation pump, fewer pipes and no control valves. On the other hand, due to lower temperature differences between room air and water in the active beam, the two-pipe system requires approximately four times more heat transfer area than conventional four-pipe active beam systems. In addition, the design of the two-pipe system does not allow individual control of the air temperature in rooms.

So far, the energy performance of the novel two-pipe system have been evaluated through modelling and simulations studies. In this paper, preliminary data regarding the operation of the first full-scale two-pipe active beam system are presented. Measurements of indoor air temperature in one floor of the building are also shown in this paper in order to provide an indication of the thermal conditions provided by the system.

2 Methodology

The "Runda Huset" is a sixteen-storey office building constructed in 2015 and located in Jonkoping, Sweden (Fig.3). In author's knowledge, this is the first building equipped with the novel two-pipe active beam system described. Fourteen floors of the building are dedicated to offices, the ground floor hosts a restaurant and the top floor accommodates conference rooms.

2.1 Design and sizing of the system

The two-pipe system was designed in order to maintain an indoor air temperature of 21°C in winter and 23°C in summer. As previously mentioned, the system consists of two parts: a DOAS and a water circuit.

The DOAS serves the fourteen floors dedicated to offices and it consists of supply and return fans, heating and cooling coils, and a heat recovery unit. It mostly operates as a CAV system, delivering a constant air mass flow rate of 0.03 kg/s to each beam with a constant supply temperature of 21°C. Only few spaces are equipped with local VAV units in order to boost the cooling capacity when required (e.g. meeting rooms). Ground and top floor are equipped with decentralized air units due to different ventilation requirements.

The water circuit was designed to operate with a constant water mass flow rate (0.04 kg/s per beam), and a variable supply water temperature according to outdoor air temperature. In particular, at extreme low outdoor air temperatures, a maximum supply water temperature of 23°C was set. At extreme high outdoor air temperatures, a minimum supply water temperature of 20°C was set. A linear correlation was used between the two extreme points, as illustrated in Fig. 4.

Fig. 3. Runda Huset building in Jönköping (Sweden)

It is worth highlighting that no feedback controllers are installed in the building. Therefore, the system is solely regulated according to outdoor air temperature. Comfortable thermal conditions in the building are achieved thanks to the so-called self-regulating effect. Since the water circuit operates at temperatures close to room temperature the rate of heat transfer is very sensitive to changes in room temperature [9].
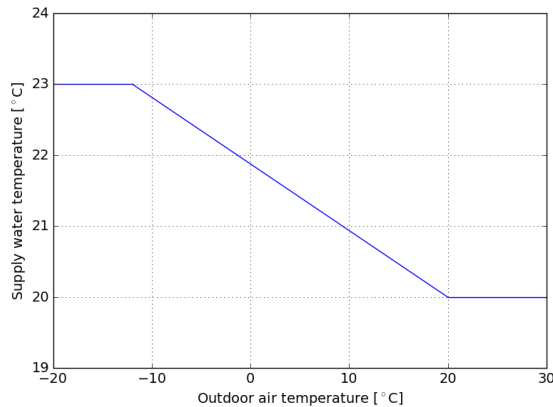

Fig. 4. Regulation of supply water temperature

In terms of sizing, 550 active beam units named SOLUS [10] were installed in the building. Each unit has a capacity of approximately 400 W and 700 W respectively in heating and cooling mode, according to the design values of temperatures and mass flow rates previously mentioned.

2.2 Monitoring system

The monitoring system was installed in order to collect relevant parameters of the operation of the two-pipe system. In particular, this paper focuses on presenting preliminary data regarding the water circuit, whose configuration represents the novelty of the system. The water circuit is illustrated in details in Fig. 5. Heating is provided by the local district heating system, while cooling by a nearby lake.
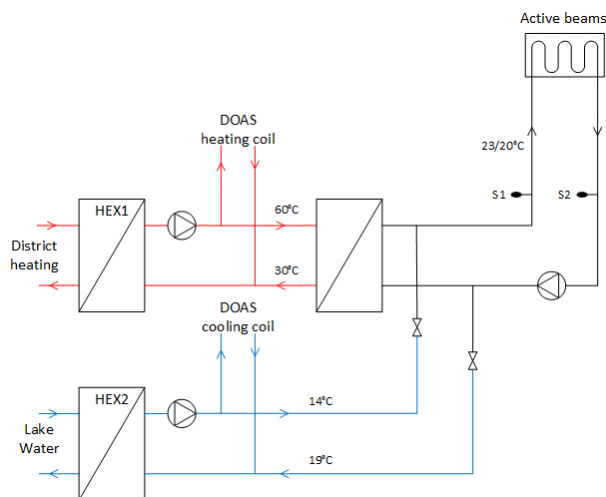

Fig. 5. Scheme of the water circuit including sensors

The heat exchanger HEX1 connects the district heating network to an intermediate hot water circuit with temperatures of 60-30°C.

This circuit serves both the DOAS unit (heating coils) and the active beams water circuit. HEX2 connects the lake water network to an intermediate chilled water circuit with temperature of 14-19°C. This circuit serves both the DOAS unit (cooling coils) and the active beams water circuit. Two temperature sensors (accuracy ±0.2°C) were placed in the circuit in order to monitor the supply (S1) and return (S2) water temperature.

2.3 Indoor air temperature measurements

In order to provide an indication of the thermal conditions provided by the two-pipe system, measurements of indoor air temperature were carried out by the authors in one floor of the building, which was chosen according to access permissions given by the building owner.

The floor accommodates a large open office space (approximately 200 m^2), few single office rooms, and a meeting room. Two air temperature sensors (accuracy ±0.3°C) were placed in two different locations of the open office space, as illustrated in Fig. 6. The sensors were placed at 1.1 m height. Measurements were collected for a continuous period of 24 hours using 5 min time-averaged values for a typical winter day (3rd of March 2017), and a typical summer day (24th of August 2017).
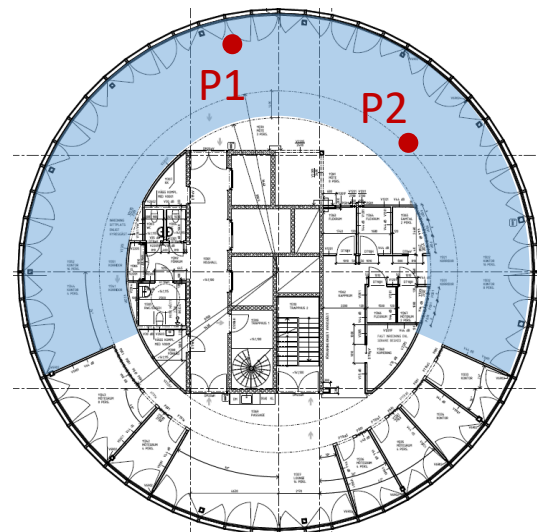

Fig. 6. Floor plan of the 13th floor of the building. P1 and P2 are the two locations where measurements were performed. The blue area represents the large open office space

3 Results and discussion

Results in terms of supply and return water temperatures, thermal power and energy use of the active beam circuit are shown for three typical weeks: winter, spring and summer. In addition, indoor air temperatures in one floor of the building are shown for a typical winter day and a typical summer day.

3.1 Supply and return water temperatures

Fig. 7 shows the hourly values of supply and return water temperatures in the active beam circuit for a typical winter week (from the 29th of January to the 4th of February 2018). The graph also shows the outdoor air temperature.
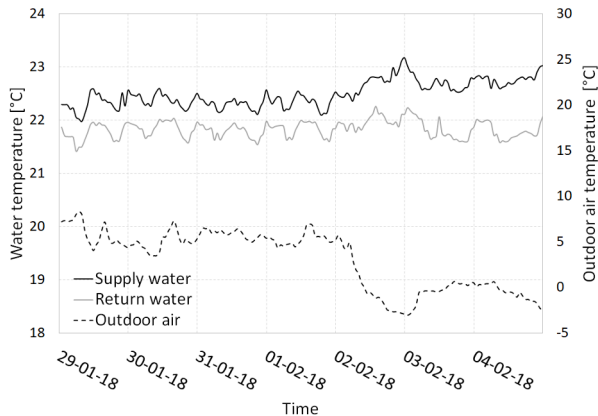

Fig. 7. Winter : supply and return water temperatures

The maximum supply water temperature is 23.2°C and, as expected, it occurs in correspondence of the minimum outdoor air temperature. The minimum supply water temperature occurs in correspondence of the maximum outdoor air temperature and it assumes a value of 22°C. The maximum temperature difference between supply and return water is approximately 1.2 K and it is found in correspondence of the minimum outdoor air temperature. This is because, in case of low outdoor air temperatures, the building requires larger heating demand. Since the system operates with constant water mass flow rate, this results in larger supply/return temperature differences. It is also noticed that the supply water temperature is always higher than the return water temperature, meaning that the building is always in heating demand mode.

Fig. 8 shows the hourly values of supply and return water temperatures for a typical spring week (from the 9th of April to the 15th of April 2018). The maximum supply water temperature is approximately 22.5°C while the minimum supply water temperature is approximately 21.5°C. It is noticed that supply and return water temperatures overlap for most of the time (during daytime), leading to small supply/return temperature differences. This means that heating and cooling loads in the building are balancing each other, and the system is providing simultaneous heating and cooling. At nights, higher supply/return water temperature differences are obtained, meaning that the building is in heating demand mode. The graph also shows how the supply water temperature oscillates according to the outdoor air temperature. During the day, when outdoor air temperatures are higher, the supply water temperature is lower. The opposite behaviour occurs during nights.

Fig. 9 shows the hourly values of supply and return water temperatures for a typical summer week (from the 30th of July to the 5th of August 2018).
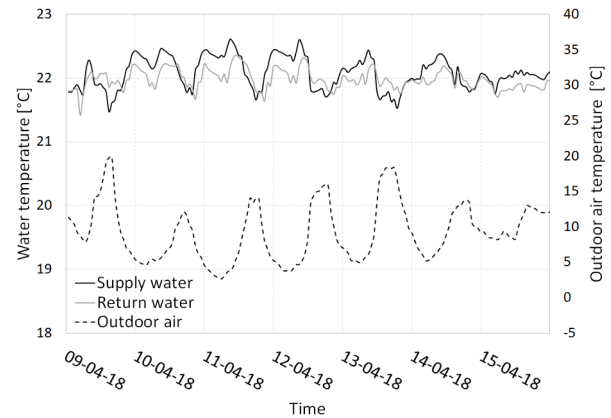

Fig. 8. Spring : supply and return water temperatures

The maximum and minimum supply water temperatures are 21.5°C and 20°C, respectively. In this case, the overlapping between supply and return water temperature occurs during nights, when the building is unoccupied. During daytime, the supply water temperature is always lower than the return water temperature, meaning that the system is providing cooling energy to the zones. The maximum temperature difference between supply and return water is 1.5 K.
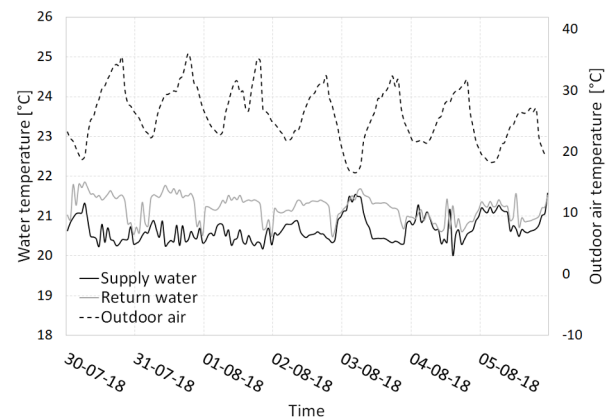

Fig. 9. Summer : suppy and return water temperatures

3.2 Thermal power and energy use

Figs. 10-11-12 show the thermal power delivered by the water system for the three typical weeks. The thermal power delivered is calculated as:

$$\dot{Q} = \dot{m}c_p\left(T_{sup} - T_{ret}\right) \tag{1}$$

Where $\dot{m}$ is the constant water mass flow rate (equal to approximately 22 kg/s), c_p is the water heat capacity, T_{sup} is the actual supply water temperature and T_{ret} is the actual return water temperature.

The peak heating power occurs during the winter week and it assumes a value of approximately 110 kW, while the cooling peak load occurs in summer and it assumes a value of approximately -145. In spring, the system oscillates between heating mode at night (positive thermal power) and cooling mode at day (negative thermal power).

Fig. 13 shows the energy use for the three typical weeks provided by the water system. This was calculated by integrating the thermal power profiles depicted in Fig. 10-11-12. The maximum energy use is found for the winter week and it assumes a value of 1.2 kWh/m². The minimum energy use is obtained for the spring week and it assumes a value of approximately 0.4 kWh/m².
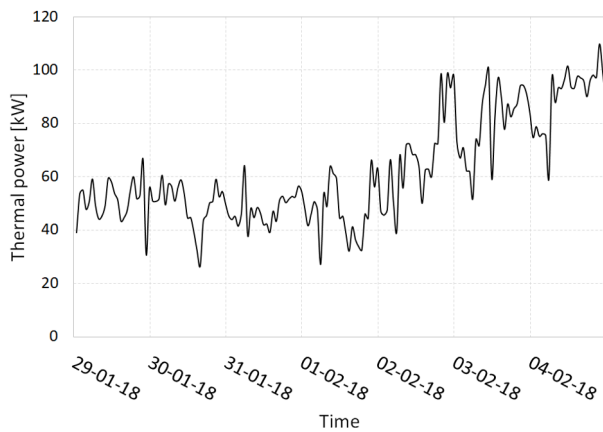

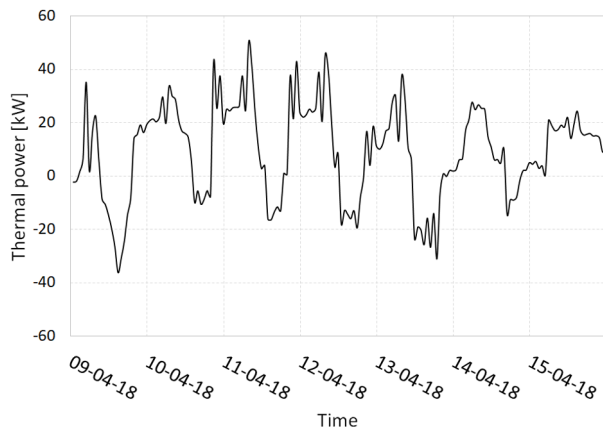**Fig. 10.** Thermal power profile during winter week

Fig. 11. Thermal power profile during spring week
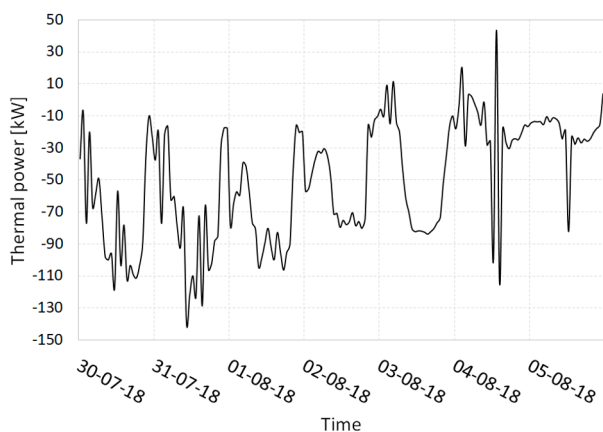

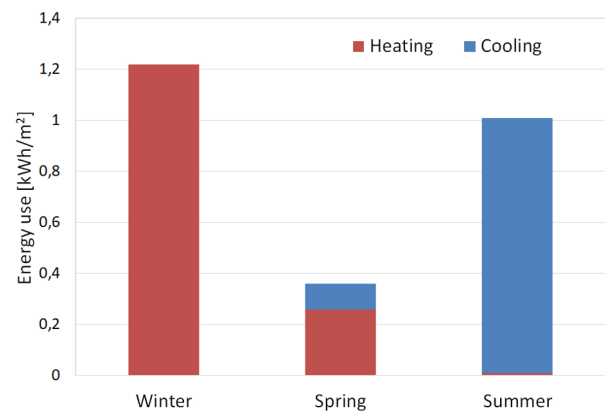**Fig. 12.** Thermal power profile during summer week

Fig. 13. Energy use of the three typical weeks

3.3 Indoor air temperatures

In order to provide an indication of the thermal conditions provided by the two-pipe system, Fig. 14 and 15 shows the daily indoor air temperatures obtained in correspondence of the two locations highlighted in Fig. 6. In winter, the indoor air temperature is between 21.2°C and 23°C, while in summer the indoor air temperature is between 21°C and 23.2°C.
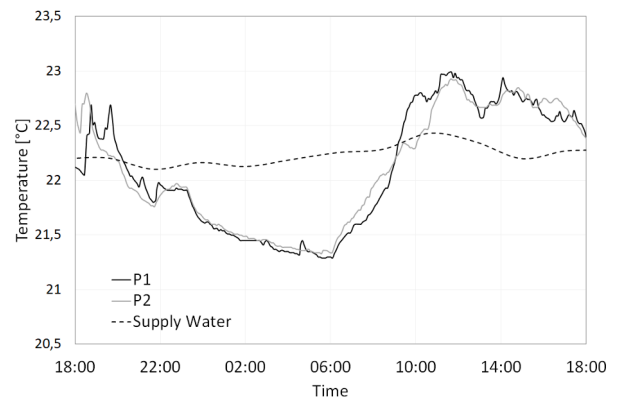

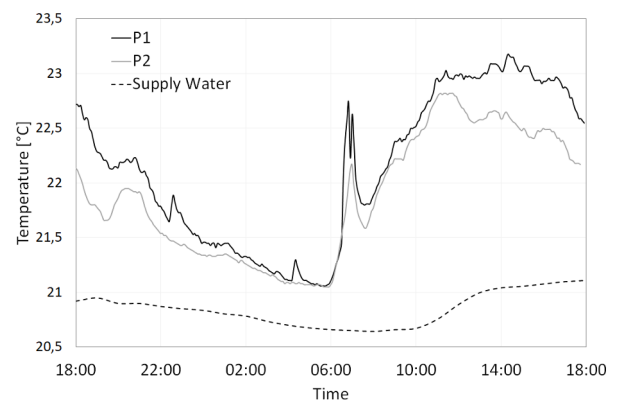**Fig. 13.** Air temperature profiles for the winter day

Fig. 14. Air temperature profiles for the summer day

In winter, there is little difference when comparing the air temperatures in the two locations. In summer, the air temperature closer to the window (P1) is higher than at the inner location. This might be attributed to the influence of solar gains.

Note that the low air temperatures observed in summer during non-working hours are due to the continuous operation of the system. At night, water at about 20.5°C circulates in the system, providing cooling energy to the building.

4 Conclusions

This paper presents preliminary results regarding an on-going monitoring campaign conducted to analyse the performance of a novel two-pipe active beam system. The novelty of the system is related to the water circuit, which operates supply temperature of approximately 22°C all year round. The analysis focused on three typical weeks: winter, spring and summer. Results are provided in terms of supply and return water temperatures, thermal power and energy use. Results from measurements of indoor air temperatures in the building are also shown in order to give an indication of the thermal conditions provided by the novel two-pipe system.

Generally, it can be concluded that the water system operates as designed. The supply water temperature was in the range of 23.2°C (winter) to 20°C (summer). The highest values of supply/return water temperature differences were observed in winter and summer, and they assumed a value of, respectively, 1.2 K and 1.5 K. Measurements of indoor air temperature in the building showed that the system is able to provide good thermal conditions in the building. Indoor air temperatures were between 21°C and 23.2°C. Therefore, it can be concluded that the actual operation of the system well matches the predicted operation, as calculated in the design and sizing phase.

The monitoring campaign is still ongoing and it will include analysis of yearly data, DOAS operation and electricity use of pumps and fans. In addition, further studies will investigate the overall perceived thermal comfort in the building by means of questionnaires.

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