Instant District Cooling System: Project Study Case Presentation

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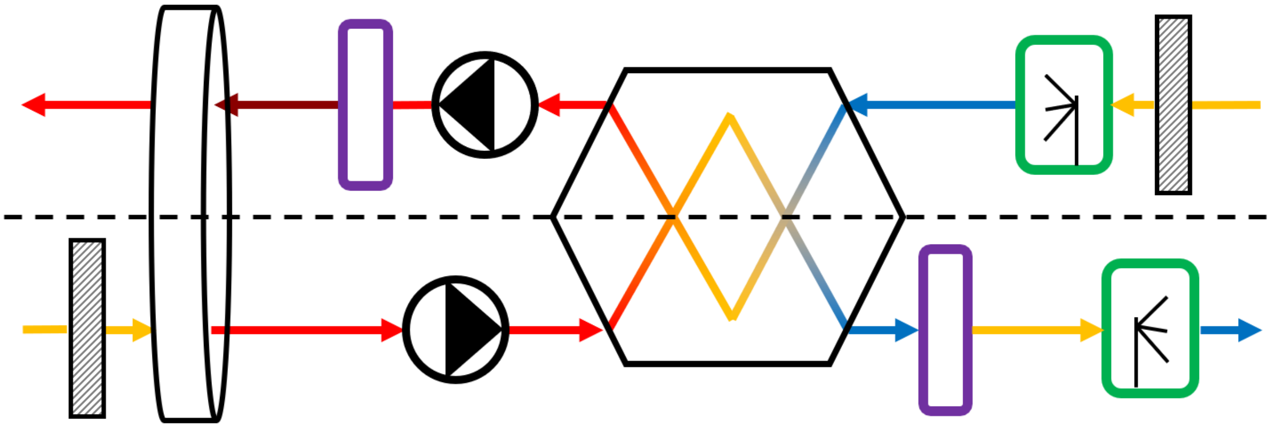
Hicham Johra



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Instant District Cooling System: Project Study Case Presentation

by

Hicham Johra

December 2021

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1. Foreword

The aim of this technical report is to present the study case of the Instant District Cooling System (IDCS) project which was carried out by Aalborg University, Department of the Built Environment (https://www.en.build.aau.dk/) in collaboration with SolarCooling ApS (https://solarcooling.dk/) from 1st of September 2020 to 15th of December 2021. This study case is also used for further investigations in the period following the winter 2021.

2. Summary of the IDCS project

The Instant District Cooling System (IDCS) project aims to study the performance of an air-handling unit performing cooling and indoor humidity regulation for large buildings (office buildings, commercial buildings, industrial buildings) by means of direct and indirect evaporative cooling method. This innovative Heating, Cooling & Air Conditioning (HVAC) system uses a heat source (typically a solar collector: Solar cooling configuration) as a primary energy input for the regeneration process of the dehumidification in the evaporative cooling cycle. Therefore, the IDCS has a low electricity usage compared to conventional vapour-compression cooling systems. In this project, the heat source of the IDCS is a direct connection to a district heating network. In cold winter-dominated countries like Denmark, the cooling demand is high and the heating demand is at its minimum (restricted to mostly sanitary hot water production) during the summer season. Heat is thus considered a less valuable source of energy compared to electricity that can be employed in a number of strategic applications such as transportations or appliances. Therefore, the IDCS presents a key advantage by diverting the cooling load from the electrical grid onto the district heating that is cheaper and largely under-used during the cooling season.

In this study, the IDCS is installed in a large office building suffering from chronic overheating in the summer and intermediate seasons. This test building is a university building comprising student rooms, teaching rooms, office rooms, meeting rooms and a dining hall. The building is compartmented in 6 zones with dedicated HVAC systems. The 2 southern zones are used for a side-by-side comparison: 1 zone remains the same with a conventional ventilation system without active cooling, the second zone is equipment with the IDCS. The indoor environment is monitored in these 2 zones (90 rooms in total) together with the energy performance of the conventional ventilation system in the reference zone and a very detail monitoring of the performance and operation conditions of the IDCS during the summer of 2021. A satisfaction online survey was also distributed among the building’s occupants.

The results of the study show that the IDCS performs according to the requirements specified for the supply of fresh air and cooling power. The IDCS can provide a sufficient amount of fresh air to the building with an adequate temperature and relative humidity to cool down the building and ensure a good thermal comfort and no overheating. Although the IDCS performs well, some indoor thermal discomfort remains in certain parts of the test building supplied by the former. After a thorough investigation, it was found that the local ventilation distribution and control system inside certain rooms (outside the scope of the IDCS project’s responsibilities) was defective. Despite the latter, the IDCS has proven to be effective at improving the indoor thermal comfort in the test building and reducing the overheating problems. The detailed monitoring data of this project are used to generate regression models for the design and sizing of the IDCS in other buildings in Denmark.

Suggestions for future work on the IDCS include a detailed study of its relative humidity regulation capacities during the winter season, and its impact on the satisfaction, productivity, well-being and health of office occupants.

3. Introduction and motivations

The market demand for cooling solutions and good indoor thermal comfort is considerable and will necessarily increase substantially, both nationally and internationally, as the climate is getting globally warmer. According to the International Energy Agency, the energy for cooling is growing faster than that of the other energy usages in the building sector. It has more than tripled between 1990 and 2016, which is reflected by three times more CO2 emissions since 1990 [1]. If in the past, cooling represented only a small portion of the energy needs for buildings, its share (of the total heating and cooling needs) is estimated to increase by up to 35% in 2050 and 61% in 2100 [2]. The key reasons for increased cooling demand in buildings are: the local and global climate change; the world's population increase in warm countries; the potential of economic growth [3]. This induces enormous stress on electricity grids in many countries because a majority of the air conditioning devices are electrically-driven vapour-compression systems [1].

Although cooling demand is highest in hot climate regions, the same problems are appearing in northern Europe. In countries with a dominant heating season like Denmark, the continuous tightening of the building regulations (high insulation level for the building envelope, restrictions on the infiltration rates) induces a significant reduction of the heating needs for the indoor environment conditioning. However, better-insulated buildings with low infiltration tend to have higher risks of overheating during summer, intermediate seasons and winter as well sometimes. In addition, office buildings and other facilities with high internal gains (people loads and equipment loads) and high window-to-wall ratios tend to increase the global cooling needs of continental and Nordic countries [4]. In addition, it is not uncommon for buildings to present higher internal gains during the occupation phase compared to the assumptions of the design stage. Consequently, the market for cooling units is also increasing in Scandinavia.

The IDCS project aims to study the performance of an air-handling unit (AHU) performing cooling and dehumidification for large buildings (office buildings, commercial buildings, industrial buildings) by means of evaporative cooling method (both direct and indirect evaporative cooling are possible in the IDCS AHU). The IDCS AHU can also provide heat and humidification (humidity control in general) during the heating season.

The IDCS uses a heat source as a primary energy input for the regeneration process of the dehumidification in the evaporative cooling cycle. Evaporative cooling systems have low electricity usage compared to conventional cooling systems. Solar collectors are typically used as a heat source for this type of evaporative cooling unit (thus commonly denominated "solar cooling" system). In this project, the solar collector of the IDCS is replaced by a direct connection to the local district heating network. Denmark has a very important district heating network covering all urban areas of the country. District heating presents a large investment cost, but it has been found to be the most energy-efficient and economically viable solution to supply thermal energy for space heating and sanitary hot water to buildings. However, this infrastructure is largely over-dimensioned for the heating needs of the summer periods when only sanitary hot water production requires thermal energy. In cold winter-dominated countries like Denmark, the cooling demand is high and the heating demand is at its minimum (restricted to mostly sanitary hot water production) during the summer season. Heat is thus considered a less valuable source of energy compared to electricity that can be employed in a number of strategic applications such as transportations or appliances. Therefore, the IDCS system presents a key advantage by diverting the cooling load from the electrical grid onto heat sources such as district heating and solar collectors that are cheaper and largely under-used during the summer season. The

IDCS solution increases the value of the existing district heating network while reducing the load on the electricity grid.

The overall cost-effectiveness of the IDCS solution is also very attractive when compared to traditional HVAC systems. Because of the price difference between district heating energy supply and electricity (electricity is significantly more expensive than district heating in summertime), the IDCS has a clear competitive advantage in terms of operation costs, when compared to conventional electrical vapour-compression units. It has thus been estimated that the operating costs of the IDCS connected to a district heating network could be more than 20% lower than that of conventional solutions.

Conventional vapour-compression AHUs typically require roof-mounted condenser, which can be problematic in terms of urban aesthetics or outdoor noise level. On the contrary, the IDCS does not need any roof-mounted or external elements and the whole unit can fit within a normal indoor ventilation technical room.

Furthermore, the increased heating demand induced to the district heating network by the IDCS can enhance the opportunities for the local industries and the thermal solar plants to inject a larger share of heat surplus into the district heating grid during the cooling season. This is particularly interesting since the allowed intake of waste heat from industries and input from solar collectors is typically calculated as the heat loss of the distribution network plus a marginal heating usage. Because this marginal heating usage is very limited during the summer season, the allowed supply from solar plants and local industries is modest.

This technical solution thus helps optimize the use of the existing district heating network during the cooling period without additional expensive infrastructure investments, which is a great socio-economic asset. In addition to using the available surplus heating capacity of the district heating network, the IDCS can efficiently regulate both the temperature and the relative humidity of the indoor environment, which are crucial factors for the thermal comfort, well-being, health and productivity of the buildings' occupants [5].

The IDCS is particularly well fitted for the market segment of central HVAC solutions for industries, large commercial buildings, hospitals, offices and other large building infrastructures with a significant cooling need and that are typically connected to a thermal grid in Denmark. This market share is considerable since 64% of the heat consumers in Denmark are connected to a district heating network. A preliminary study conducted by Aalborg University, Department of the Built Environment (former SBi) indicates that 14 443 office buildings in Denmark are supplied by a thermal network. Within those 14 443 buildings, it is estimated that 3100 are already equipped with a cooling system, and more than 3000 buildings might be equipped in the near future to tackle the ever-increasing over-heating problems that lead to poor indoor comfort with dramatic negative productivity effects on the employees [5]. An internal estimation from MOE A/S shows that 99% of all new office building projects are equipped with cooling systems in order to meet the indoor thermal comfort requirement of the Danish building regulation.

To study the performance of the IDCS in realistic operation conditions, an IDCS unit is installed in a pilot office building that has a significant unmet cooling need. This pilot building case is located in Aalborg (Denmark) and is monitored in detail to assess the capacity of the IDCS to maintain a comfortable indoor environment in terms of fresh air, temperature and humidity during the cooling period. The performance of this IDCS unit can be compared to the original conventional ventilation unit of the test building that does not have any cooling or humidity regulation capacities. These monitoring data can help calibrate data-driven models for the accurate design, sizing and simulation of this innovative IDCS.

The focus of this project also approaches several areas of growing interest: the Increasing share of cooling demand for buildings; the resilience of cooling system performance with respect to climate change and district heating network evolution; the efficient conversion of thermal grid resources to produce cooling service; the evaluation of water consumption for evaporative system solution (direct and indirect); the proper evaluation and optimization of evaporative cooling systems.

4. Description of the IDCS unit and its operation principle

The IDCS is a central heating, cooling and ventilation system that can perform humidity regulation as well. It has a low electricity consumption in comparison with conventional vapour-compression cooling systems. In addition, the IDCS does not use any dangerous, flammable or greenhouse effect gas, contrary to traditional vapor-compression systems.

The IDCS unit provides fresh air, cooling (and heating if necessary) and moisture regulation (dehumidification) to a conditioned indoor environment by lowering the temperature and adjusting the moisture content of outdoor air intake. The cooling and humidity regulation is performed by coupling heating, regenerative dehumidification, regenerative sensible heat exchange, and evaporative cooling processes (see *Figure 1*). The dehumidification of the outdoor air inlet is achieved by the dehumidification rotor (rotary desiccant wheel). A sensible heat recovery (sensible cooling) is then operated by a high-efficiency counter-flow plate-fin heat exchanger or a rotary heat exchanger. The evaporative cooling on both the supply air and the return (regenerative) air streams is performed by two humidifier modules. Finally, the heating power is supplied by two hydronic units that can be powered by district heating network or low-grade thermal energy sources such as roof-mounted solar collectors or solar walls. The IDCS unit is also equipped with fans, bypass dampers and filters. The entire operation of this HVAC unit is monitored and regulated by a state-of-the-art electronic control system.

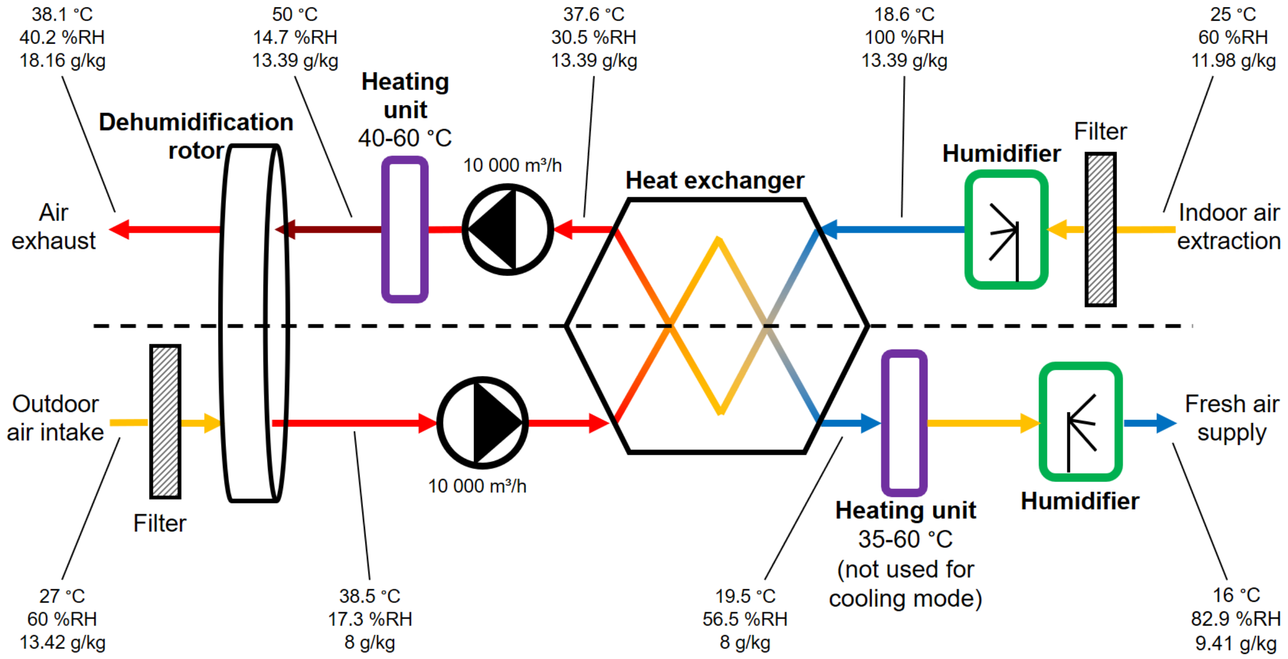

Figure 1: *The operating principle of the IDCS unit in cooling mode. The operational variables shown at the different stages of the IDCS unit process (temperature [°C], relative humidity [%RH] and moisture content [g_{water}/kg_{air}]) are for guidance and illustration only, the real operational variables may differ.*

In addition to the normal functionalities of supplying heating, cooling and fresh air to the indoor environment that are performed by conventional HVAC systems (AHU with vapour-compression system), the IDCS can also regulate the relative humidity of the supplied fresh air. This capability is inherent to the evaporative cooling process of the IDCS and consequently, the relative humidity regulation in the indoor environment is possible without extra energy or equipment cost. One can see in *Figure 2* the operation cycle of the IDCS in cooling mode for the supply and exhaust lines represented on an Enthalpy/Moisture content diagram (Ix-diagram).

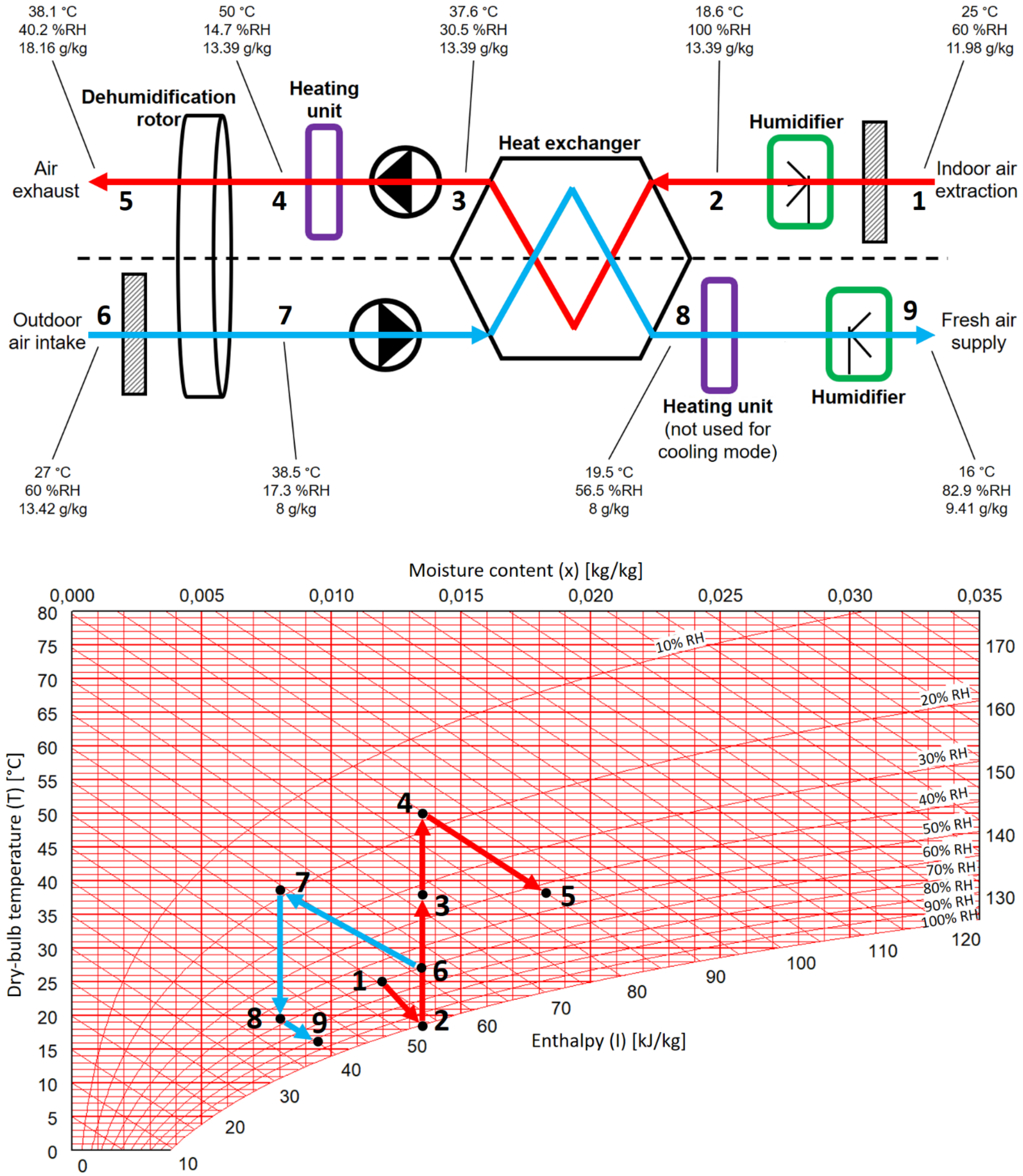

Figure 2: *The IDCS operation cycle in cooling mode (summer season in Denmark) for the supply and exhaust lines represented on an Enthalpy/Moisture content diagram (Ix-diagram). The operational variables shown at the different stages of the IDCS unit process (temperature [°C], relative humidity [%RH] and moisture content [g_{water}/kg_{air}]) are for guidance and illustration only, the real operational variables may differ.*

5. Study case building

This project consists in a full-scale monitoring study of the IDCS AHU implemented in an office building in Denmark that needs cooling. This study case is a university building (Aalborg University, Denmark) located in Aalborg and named CREATE (see *Figure 3*).

Figure 3: *View of the building study case: CREATE - Rendsburggade 14, 9000 Aalborg, Denmark.*

The CREATE building is located in Aalborg city center, nearby the Aalborg's fjord "Limfjorden". One can see the location of the CREATE building in its surrounding environment in *Figure 4*.

Figure 4: *Aerial view of the CREATE building in its surrounding environment in Aalborg city center.*

The CREATE building was designed according to the Danish building regulation BR class 2010 which specifies minimum levels of energy and indoor environment performances to be met. The main characteristics of the building are as follows:

- Building regulation energy class: Danish BR class 2010:
  - Maximum air changes through leakage in the building envelope at pressure difference of 50 Pa: 1.5 L/s.m^2.
  - Maximum design transmission loss: 7 W/m^2 of the building envelope.
  - Maximum total primary energy demand for heating, ventilation, cooling, domestic hot water production and artificial lighting: 71.4 kWh/year.m^2 of heated floor area.
- Year of construction: 2014.
- Number of floors: 5: ground floor, 1st floor, 2nd floor, 3rd floor, 4th floor.
- Ground surface area of the building: 5036 m^2.
- Total building area (including all floors of the building): 20 694 m^2.
- Maximum occupancy: 4450 persons.
- Building structure: Concrete elements.
- Roof: Flat and slightly inclined roof.
- Exterior wall material: Concrete elements.

The CREATE building is used for several activities:

- Offices and meeting rooms for research staff.
- Classrooms, group rooms and socialization areas for students.
- Workshops for students and teaching/research staff (on the ground floor only).
- A dining hall and a restaurant's kitchen for students and teaching/research staff (ground floor).

- An auditorium (ground floor).

The building comprises a large central atrium that is covered and part of the indoor environment (see *Figure 5*) and an open-air courtyard (see *Figure 6*).

Figure 5: *Central covered atrium of the CREATE building.*

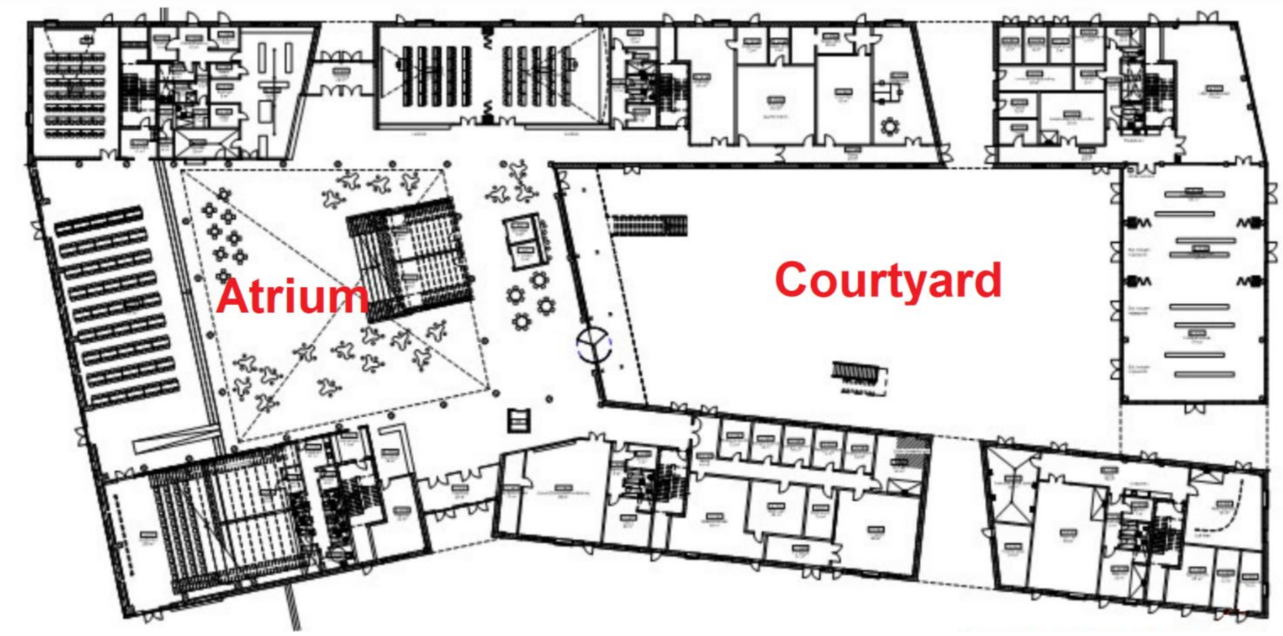

Figure 6: *Floor plan of the CREATE building.*

Although built according to the appropriate building standards of that time, the real occupancy of the CREATE building is significantly higher than what was estimated during the design phase (more students and staff members per square meters in the entire building). This larger occupancy density generates an unanticipated additional internal gain (both people load and equipment load such as computers) which leads to uncomfortable overheating in all parts of the building. Because the original ventilation system of the CREATE building is not equipped with an active cooling system, the extra internal load cannot be removed efficiently and thus overheating is a regular cause of indoor discomfort and complaints from the occupants.

In that context, the CREATE building is an ideal study case to perform a full test monitoring of the IDCS AHU. The CREATE test building is composed of 6 main zones, each of them being supplied in fresh air by their respective and independent AHU. For this study, the 2 southern zones of the building (Zone 1 and Zone 6) are selected for a side-by-side monitoring comparison: The both zones have a similar surface area, occupancy type (workshops on the ground floor; offices and meeting rooms on the first and second floor), number of floors, building envelope properties and exposure. The Zone 1 serves as reference case with a conventional ventilation system without active mechanical cooling system. On the other hand, the Zone 6 is the test zone in which the new IDCA AHU is installed to replace the original conventional ventilation system and provide mechanical cooling. One can see in *Figure 7*, *Figure 8* and *Figure 9* the blue print of the ventilation system in the Zone 1 and Zone 6 on the different floors of the CREATE building case.

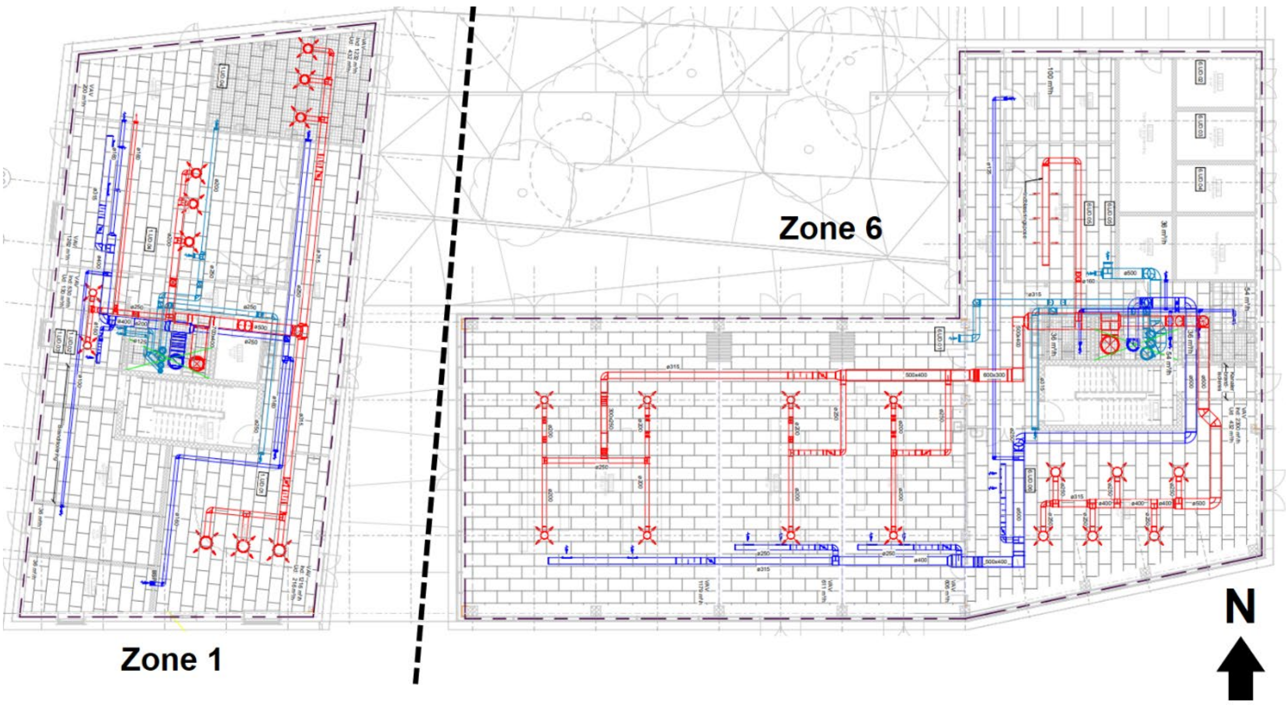

Figure 7: *Blue print of the ventilation system in the Zone 1 and Zone 6 on the ground floor of the CREATE building case.*

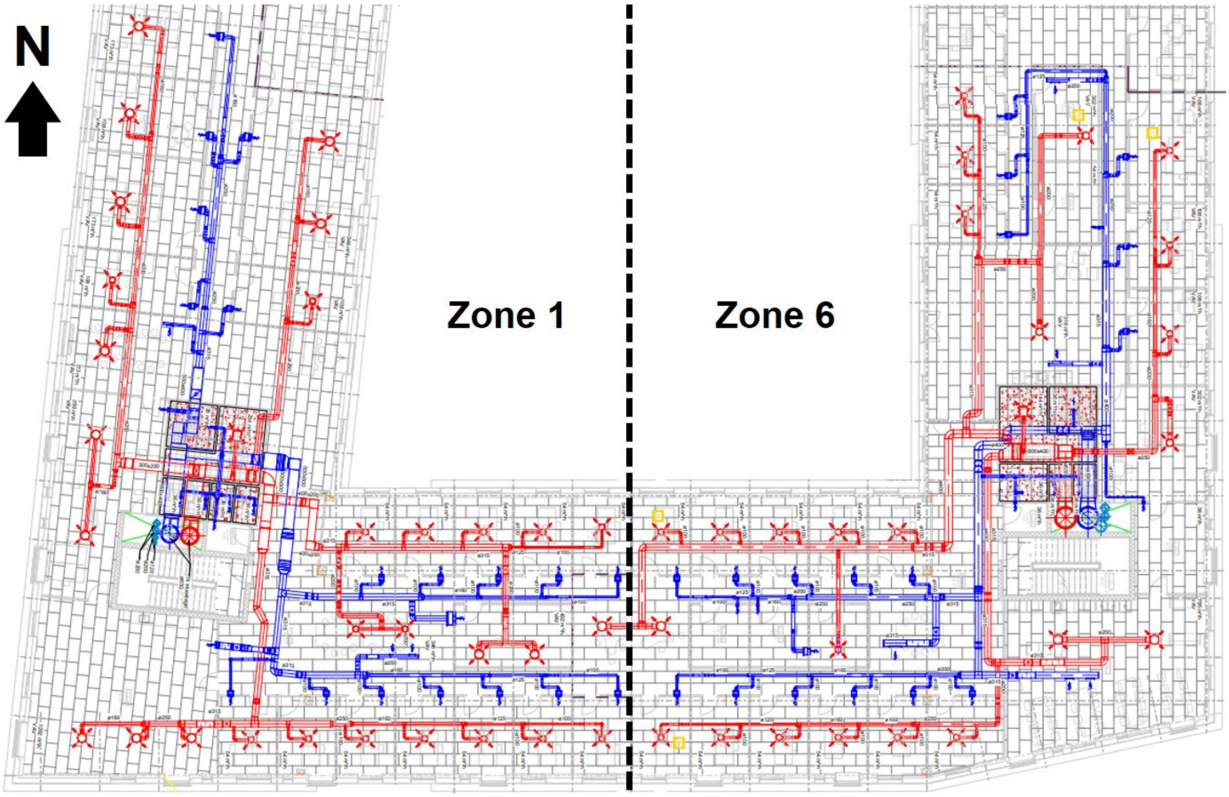

Figure 8: *Blue print of the ventilation system in the Zone 1 and Zone 6 on the 1st floor of the CREATE building case.*

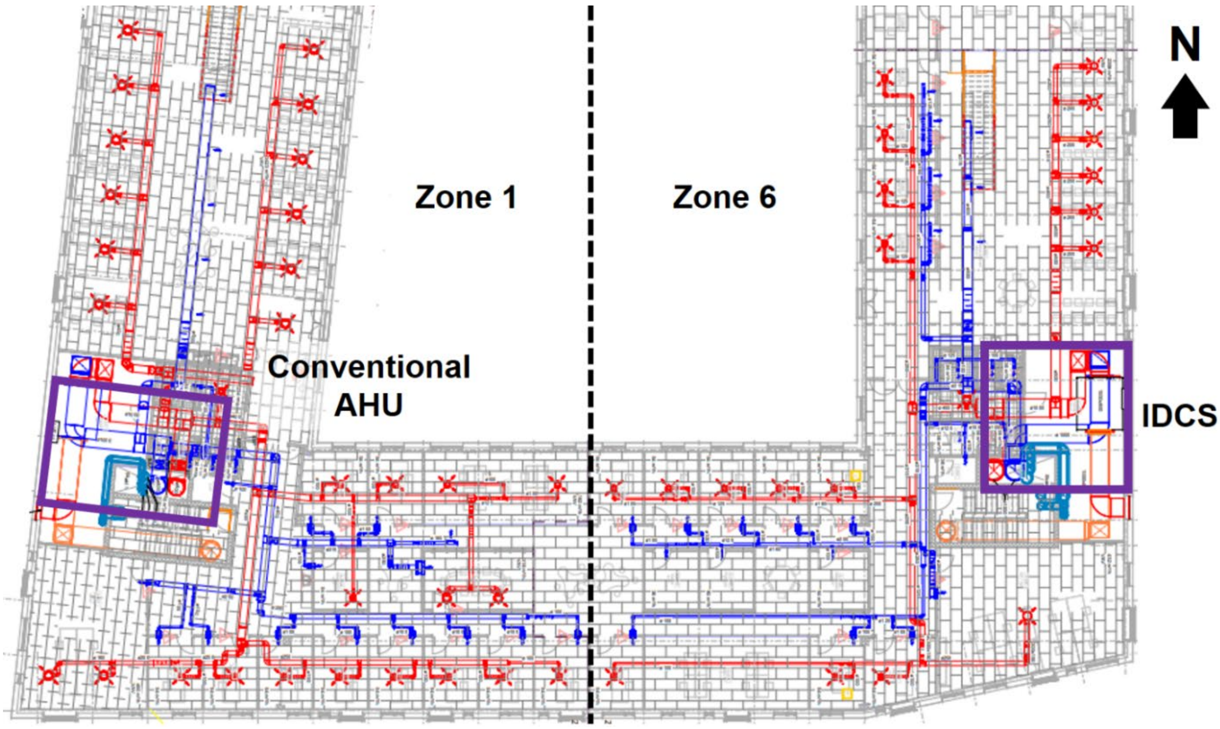

Figure 9: *Blue print of the ventilation system in the Zone 1 and Zone 6 on the 2nd floor of the CREATE building case.*

6. Study case IDCS

The IDCS installed in the Zone 6 of the CREATE test building is a modified SCK-15 unit from SolarCooling ApS. This SCK-15 unit has been modified to fit the needs and requirements of the CREATE test building. The stated characteristics of the SCK-15 are as follows:

- Nominal airflow rate: 15 000 m^3/h.
- Rotor (rotary heat exchanger) diameter: 2.19 m.
- Maximum sensible cooling power delivered to the building: 41 kW.
- Maximum total cooling power delivered to the building: 78 kW.
- Minimum supply air temperature delivered to the building: 17°C.
- Electrical use for fans, water treatment and humidifiers: 3.34 kW.
- Heat use for cooling process at full load (heat source temperature at 55°C and return at 30°C): 62 kW.
- Water use for cooling process at full load: 81 Liter/h.

The IDCS unit can be delivered on site as one-piece unit to the newly built building (see *Figure 10*) or assembled piece-by-piece inside an existing building with restricted access to the ventilation technical rooms.

Figure 10: *An IDCS unit being installed on the roof-top technical room of a new building (not the current test building project).*

7. Methodology

This study consist mainly in the monitoring and analysis of the performance of the IDCS in the test building. It is therefore important to measure multiple physical variables at different location inside the building (assessment of the indoor environmental quality) and inside the ventilation system (inside the IDCS and the ventilation distribution network). The building management system (BMS) of the CREATE test building is used to acquire the measurements of most of the indoor environmental variables in the different rooms of the Zone 1 and Zone 6 of the building. In each room, the indoor operative temperature, the indoor temperature setpoint, the opening position of the Variable Air Volume (VAV) valve and the window opening (ON/OFF) are recorded. In some of the rooms (usually large rooms and meeting rooms), the CO2 concentration is also recorded (only rooms equipped with CO2 sensors). One can see in *Figure 11* an example of the indoor environment variable that are recorded at the room level by the BMS inside the CREATE test building.

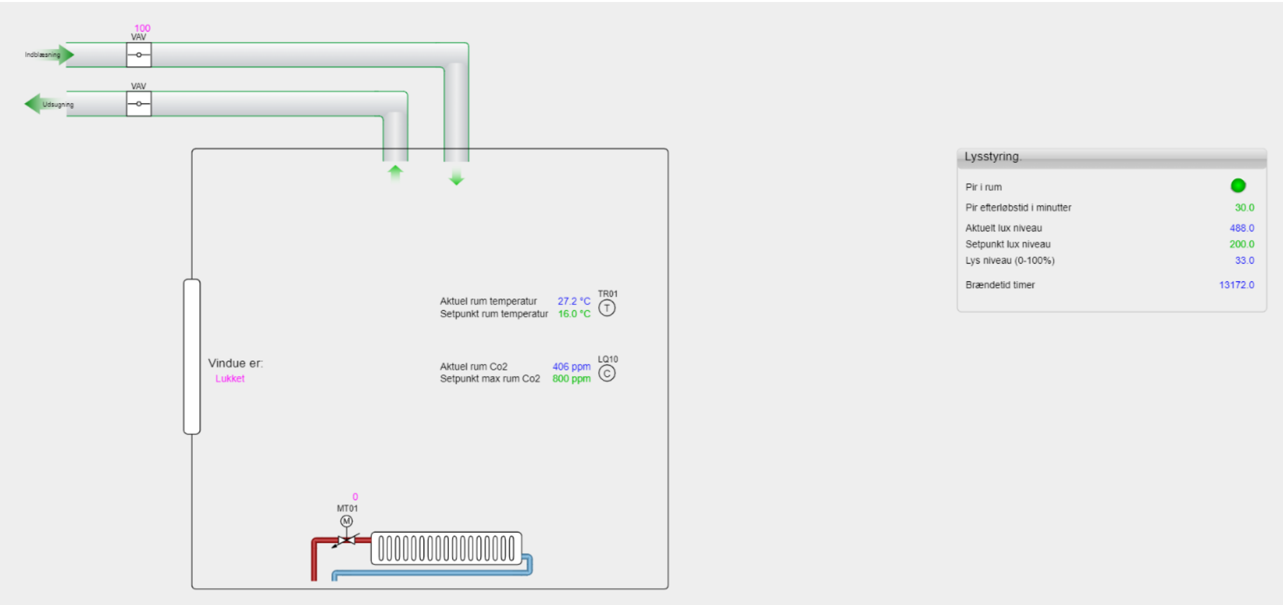

Figure 11: *Room level monitoring interface from the BMS of the CREATE test building.*

The BMS also records the operation variables of the conventional ventilation AHU without mechanical cooling in the reference Zone 1 (see *Figure 12*): air flow, inlet temperature, supply temperature, return temperature, heat recovery rate, fans' energy usage, heating use from the district heating network.

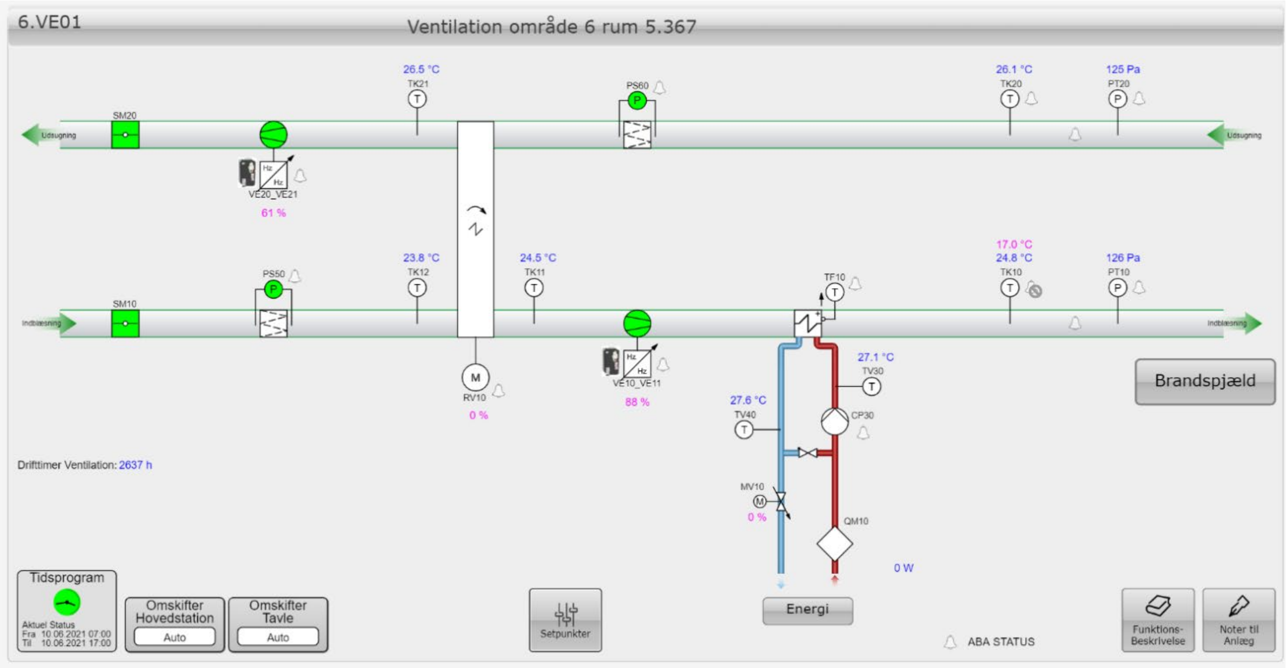

Figure 12: *Conventional AHU monitoring interface from the BMS of the CREATE test building in the reference Zone 1.*

The local outdoor weather conditions at the test building site are also recorded from sensors placed on the outside of the building: outdoor air temperature, solar radiation, relative humidity.

The IDCS is monitored in great detail with multiple sensors placed at the different stages of the evaporative cooling process. One can see in *Figure 13* the detail of all temperature, humidity, pressure sensors and energy meters, heat meters and water meters placed in the IDCS to monitor its performance.

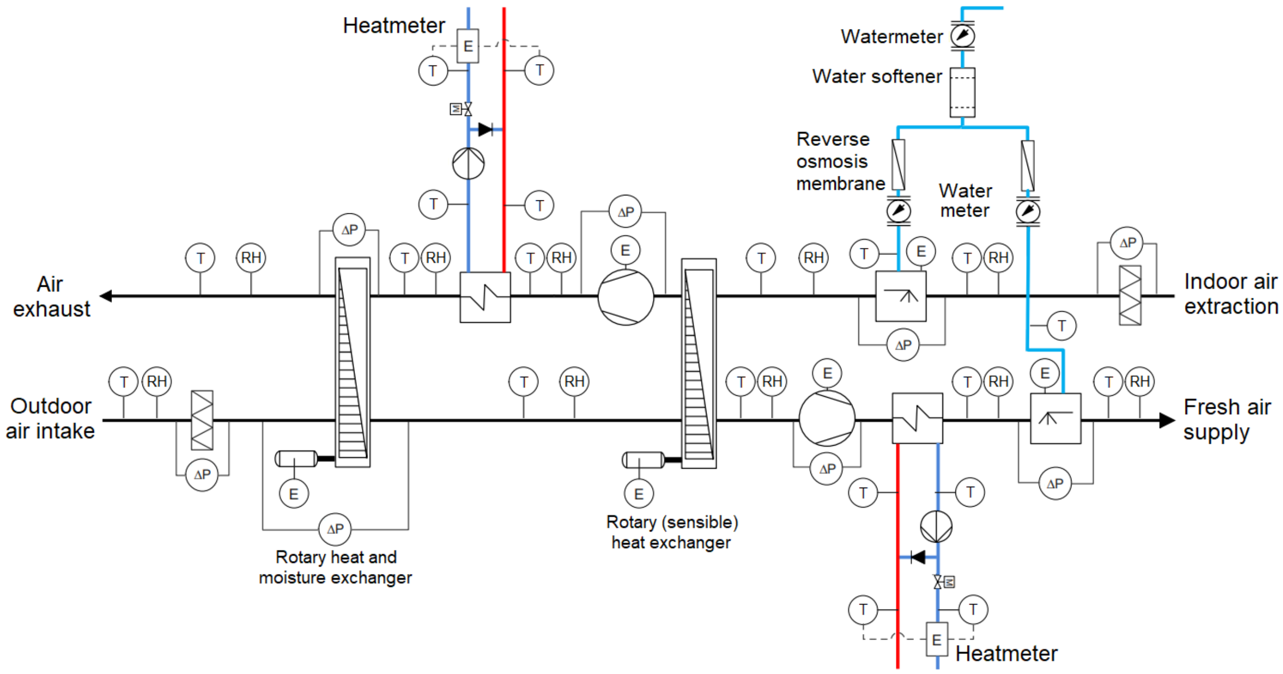

Figure 13: *Sensor placement for the performance monitoring of the IDCS in the CREATE test building.*

Additional monitoring equipment is installed in 6 rooms of interest to get more accurate insight on the indoor environmental quality. These additional sensors are calibrated in laboratory and placed in 6 specific rooms to measure the indoor operative temperature, relative humidity, CO2, inlet air temperature from the ventilation diffuser, fresh air inlet flow rate, and whether or not the shading device is activated (pulled down) in the room. The 6 rooms of interest are selected as follows (see *Figure 14* and *Figure 15*):

- 4 rooms on the 1st floor:
  - 1 single-office room on the South, as far as possible from the AHU.
  - 1 single-office room on the North, as far as possible from the AHU.
  - 1 larger single-office room on the East, as far as possible from the AHU.
  - 1 meeting room with no direct access to the façade, as far as possible from the AHU.
- 2 rooms on the 2nd floor:
  - 1 single-office room on the North, as close as possible from the AHU.
  - 1 single-office room on the South, as close as possible from the AHU.

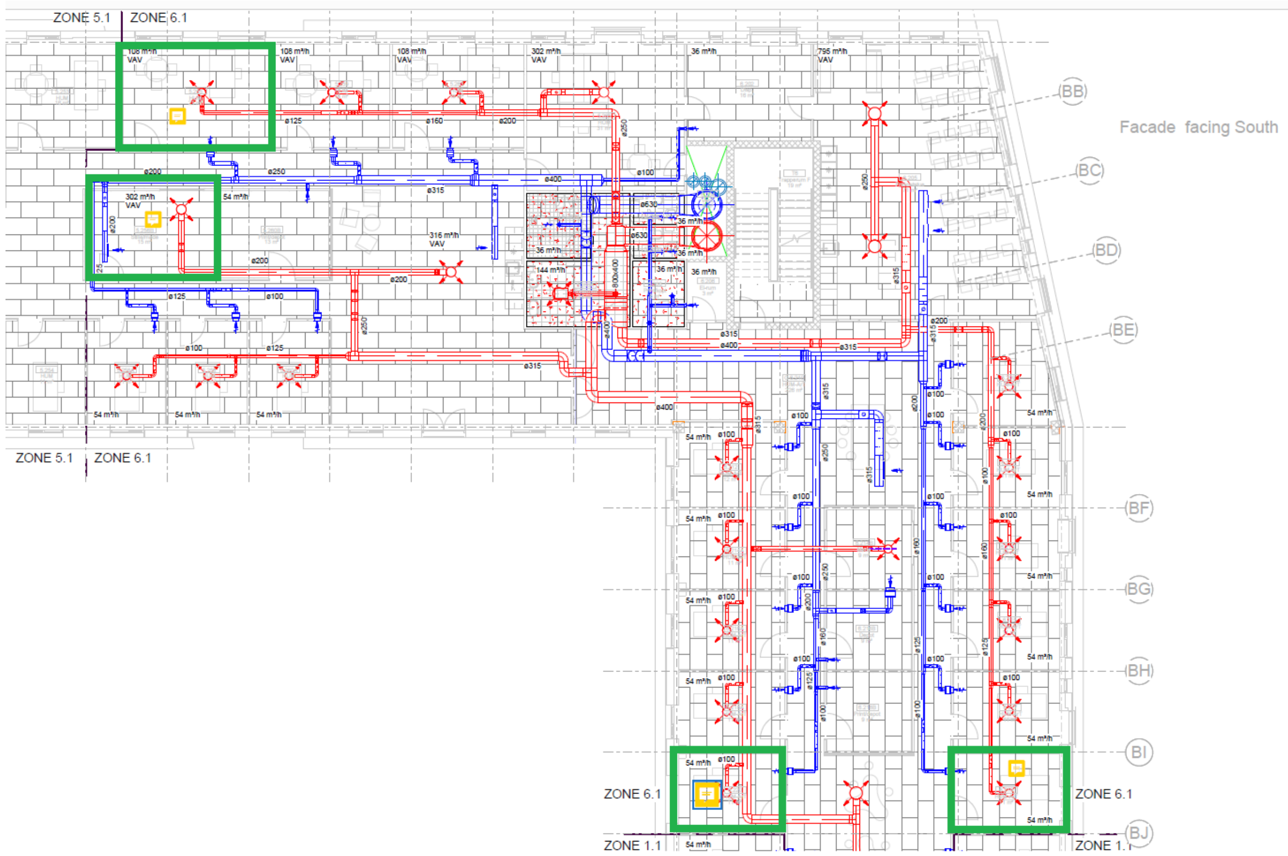

Figure 14: *Location of the rooms of interest with additional monitoring equipment on the 1st floor of the Zone 6 in the CREATE test building.*

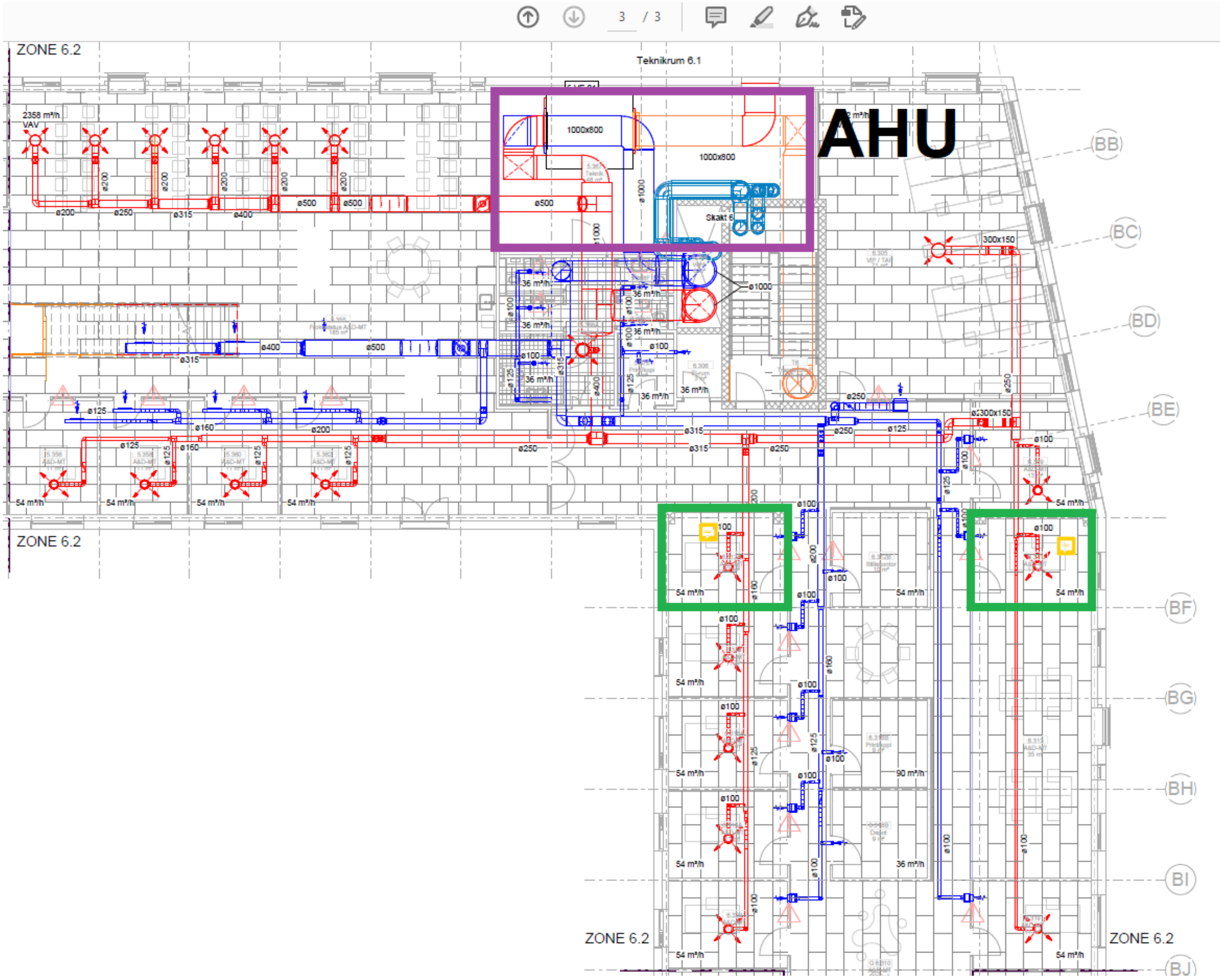

Figure 15: *Location of the rooms of interest with additional monitoring equipment on the 2nd floor of the Zone 6 in the CREATE test building.*

Finally, an online survey was created and sent to all the occupants of the Zone 1 and Zone 6 of the CREATE test building to collect their opinion on the perceived indoor comfort in general, and the indoor thermal comfort, indoor air quality, indoor daylight quality and acoustics quality in their office and in the building in general.

8. Preliminary results

During the first months of the summer 2021, some time was dedicated to the installation and commissioning of the IDCS in the CREATE test building. In addition, several problems had to be solved in the room-level ventilation distribution systems of certain rooms of the CREATE test building (these problems are not related to the IDCS itself). In this section, the analysis focuses mostly on the last warm week of summer 2021 in Aalborg (Denmark), spanning from the 6th of September to the 13th of September 2021.

8.1. Summer period reference situation with and without ventilation

One can see in *Figure 16*, *Figure 17* and *Figure 18* below the daily indoor operative temperature in Zone 1 and Zone 6 of the CREATE test building during a warm summer period in Denmark: from 20th of July to 3rd of August 2021. This period was fairly warm in terms of outdoor temperature and solar radiation. One can clearly see that the reference Zone 1 a with conventional ventilation system but without mechanical cooling (in blue in the figures) presents some overheating episodes in the afternoon. One can also clearly see that, on that period, the Zone 6 (in red in the figures) that does not have any mechanical ventilation or cooling is significantly warmer than Zone 1 with very large overheating and temperatures up to 39°C. These figures inform about the overheating in a well-insulated south-exposed office building with without any mechanical ventilation and only limited natural ventilation in Denmark during a warm summer period. Without mechanical ventilation and natural ventilation only, the building is more than 2°C warmer than with mechanical ventilation.

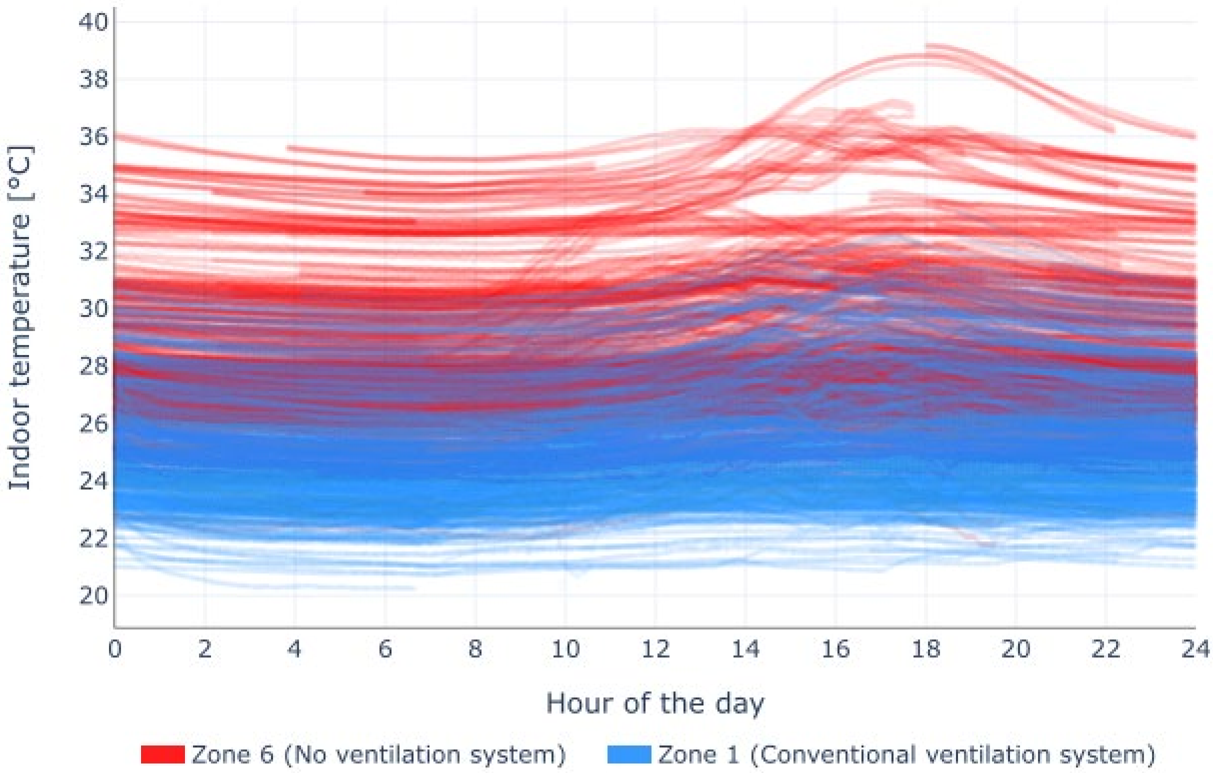

Figure 16: *Daily indoor operative temperature in Zone 1 and Zone 6 of the CREATE test building during a warm summer period in Denmark: from 20th of July to 3rd of August 2021.*

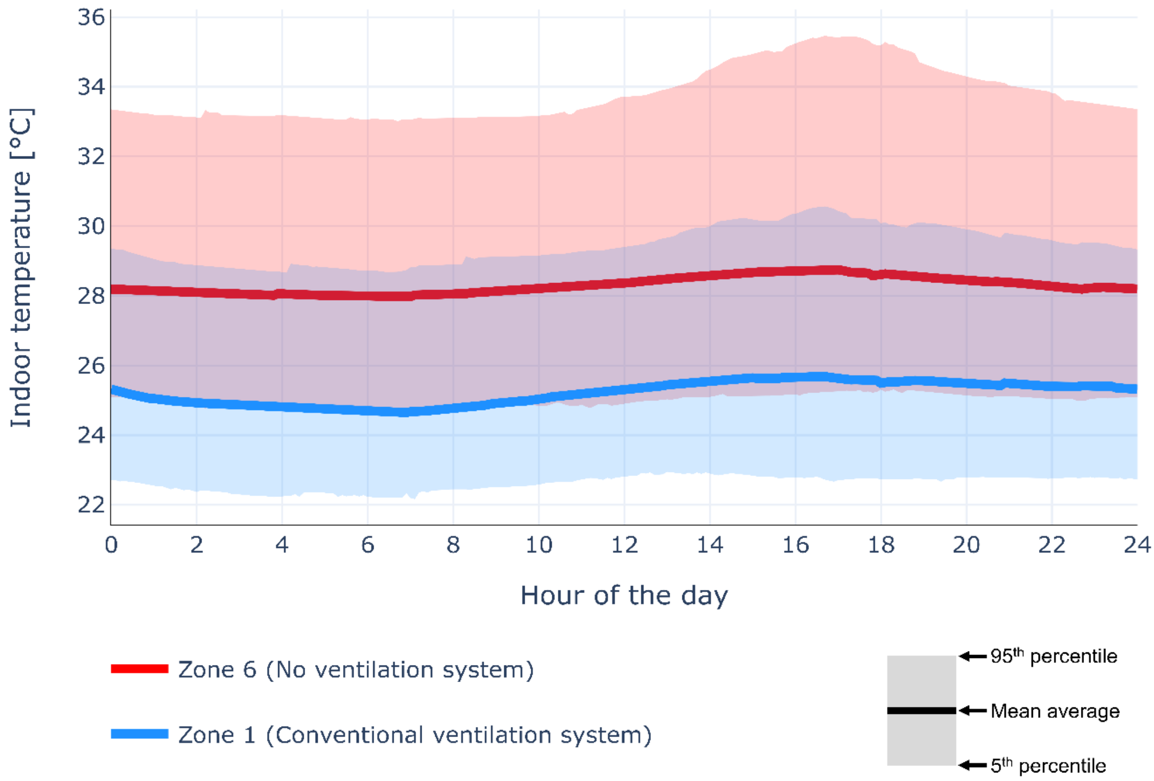

Figure 17: *Daily indoor operative temperature in Zone 1 and Zone 6 of the CREATE test building during a warm summer period in Denmark: from 20th of July to 3rd of August 2021.*

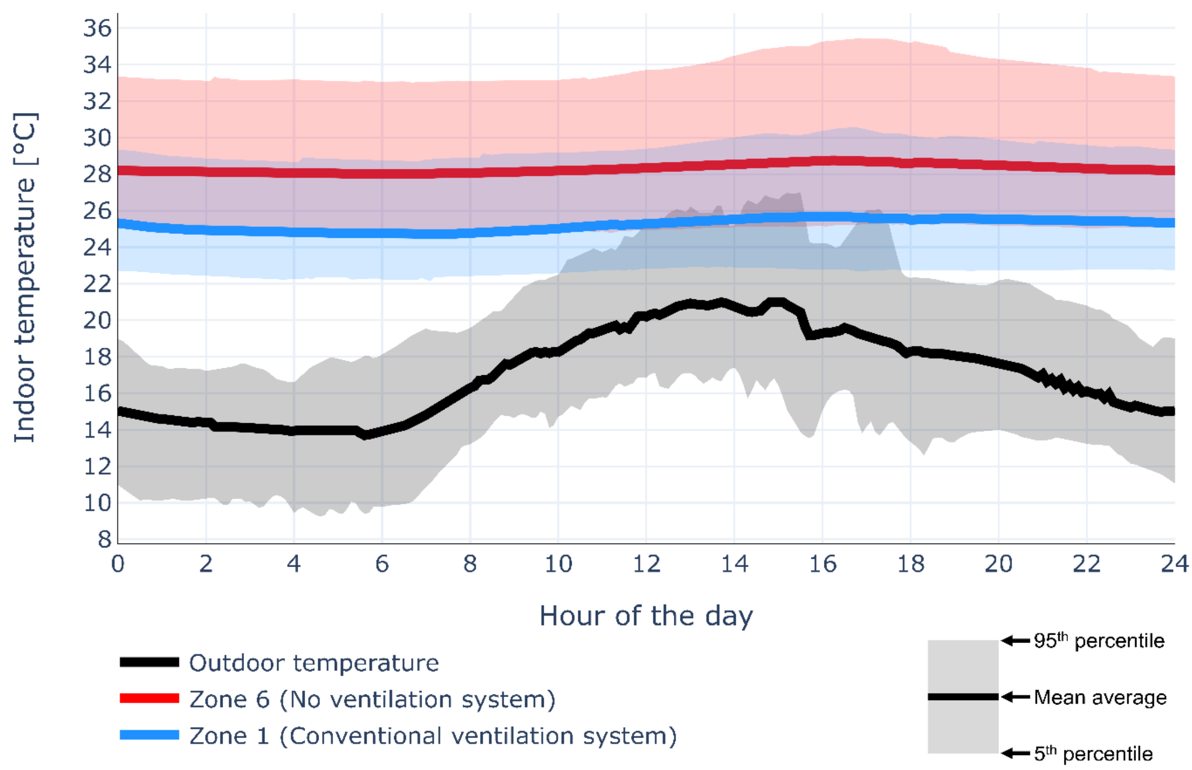

Figure 18: *Daily indoor operative temperature in Zone 1 and Zone 6 of the CREATE test building during a warm summer period in Denmark: from 20th of July to 3rd of August 2021.*

One can clearly see that, even with mechanical ventilation, this building is way too warm during the summer period and large overheating occurs, inducing very unpleasant indoor thermal discomfort for the occupants. These results clearly emphasize the overheating issues of the CREATE test building and justify the installation of an active cooling system in the building such as the IDCS.

8.2. Occupants indoor comfort survey

After the installation and of the IDCS in the Zone 6 of the CREATE test building, an online survey (both in Danish and English) has been sent to all occupants of the reference Zone 1 and Zone 6 to probe their perception of several aspects of the indoor comfort in their office rooms. Only 15 person have responded to the online survey, which does not make the results statistically strong. However, the following trends can be seen among the respondents' answers:

- The occupants are very dissatisfied with the summer thermal comfort in the reference Zone 1 that does not have mechanical cooling system.
- The occupants are much more satisfied with the summer thermal comfort in the test Zone 6 that is equipped with the IDCS AHU.
- Some occupants emphasize the discomfort due to dry skin (low relative humidity) in the winter time.

8.3. IDCS performance in cooling mode during a warm summer week

One can see in *Figure 19*, *Figure 20*, *Figure 21*, *Figure 22* and *Figure 23* the operation performances of the IDCS AHU supplying fresh air to the test Zone 6 of the CREATE building during a warm summer week.

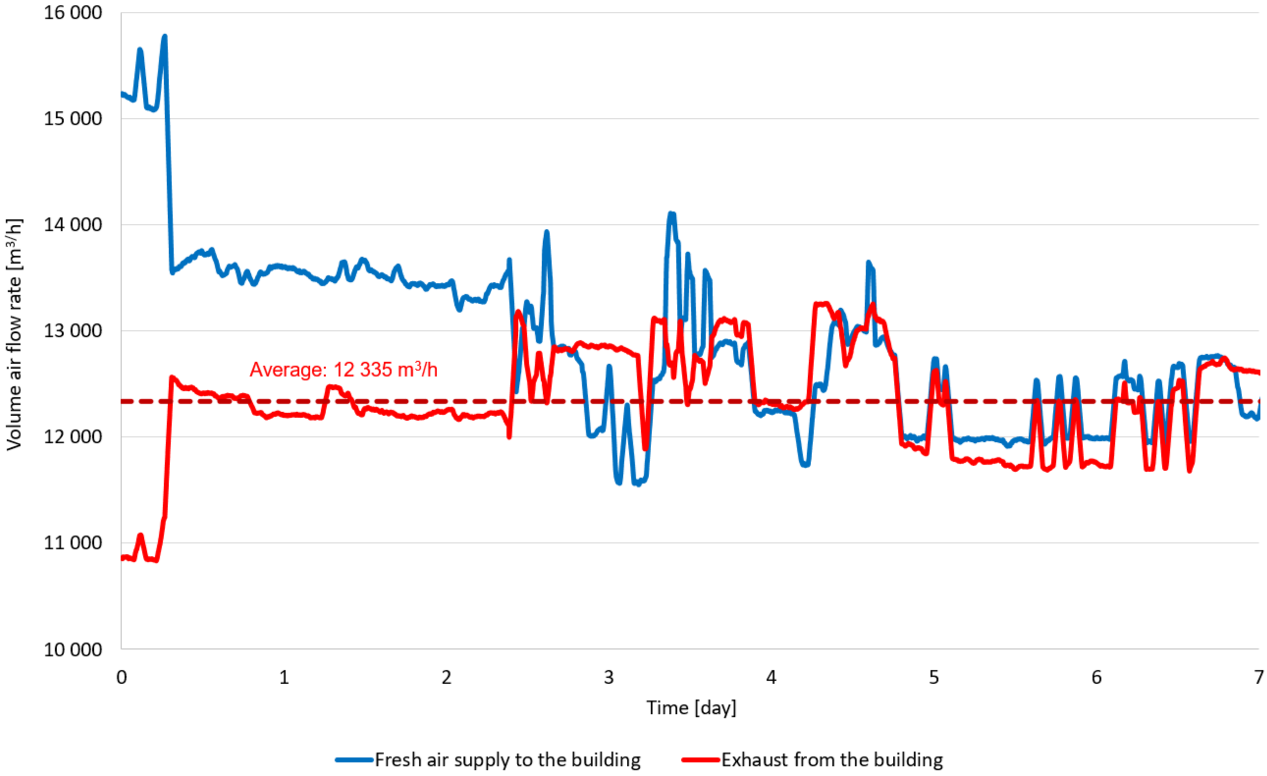

Figure 19: *Supply and exhaust volume air flow rate of the IDCS AHU during a warm summer week.*

One can observe in *Figure 19* that the IDCS manages to provide fresh air to the building at the required volume air flow rate (around 12 000 m^3/h). The discrepancy between the fresh air supply and the exhaust volume flow rate (unbalanced ventilation system) is due to the occasional use of direct exhaust systems in the wood workshops that are not connected to the IDCS AHU.

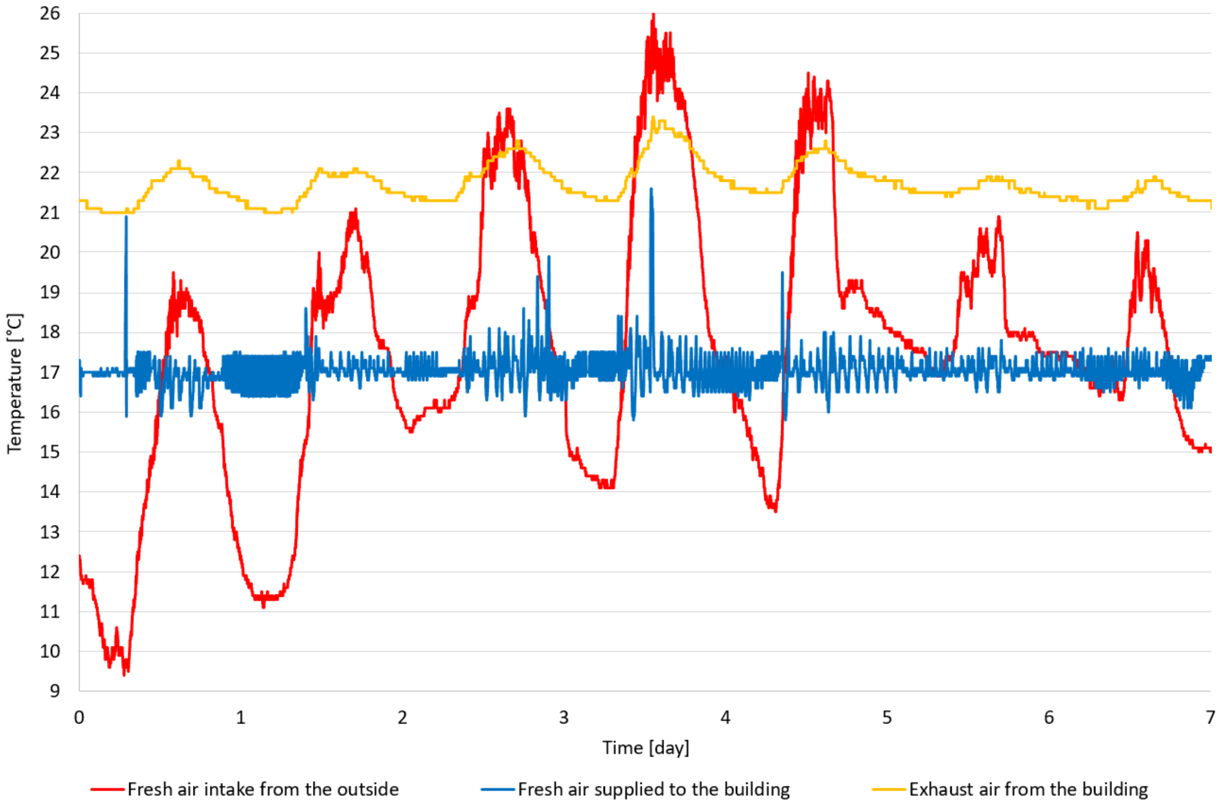

Figure 20: *Outdoor, intake and supply air temperatures for the IDCS AHU during a warm summer week.*

One can observe in *Figure 20* that the IDCS can provide fresh air at the required setpoint temperature of 17°C during the entire warm summer week test period, despite the outdoor air temperature reaching up to 26°C. The exhaust air temperature from the test Zone 6 supplied by the IDCS does not exceed 23°C, which indicates that there is no or limited overheating in the Zone 6 and that the indoor summer thermal comfort is maintained.

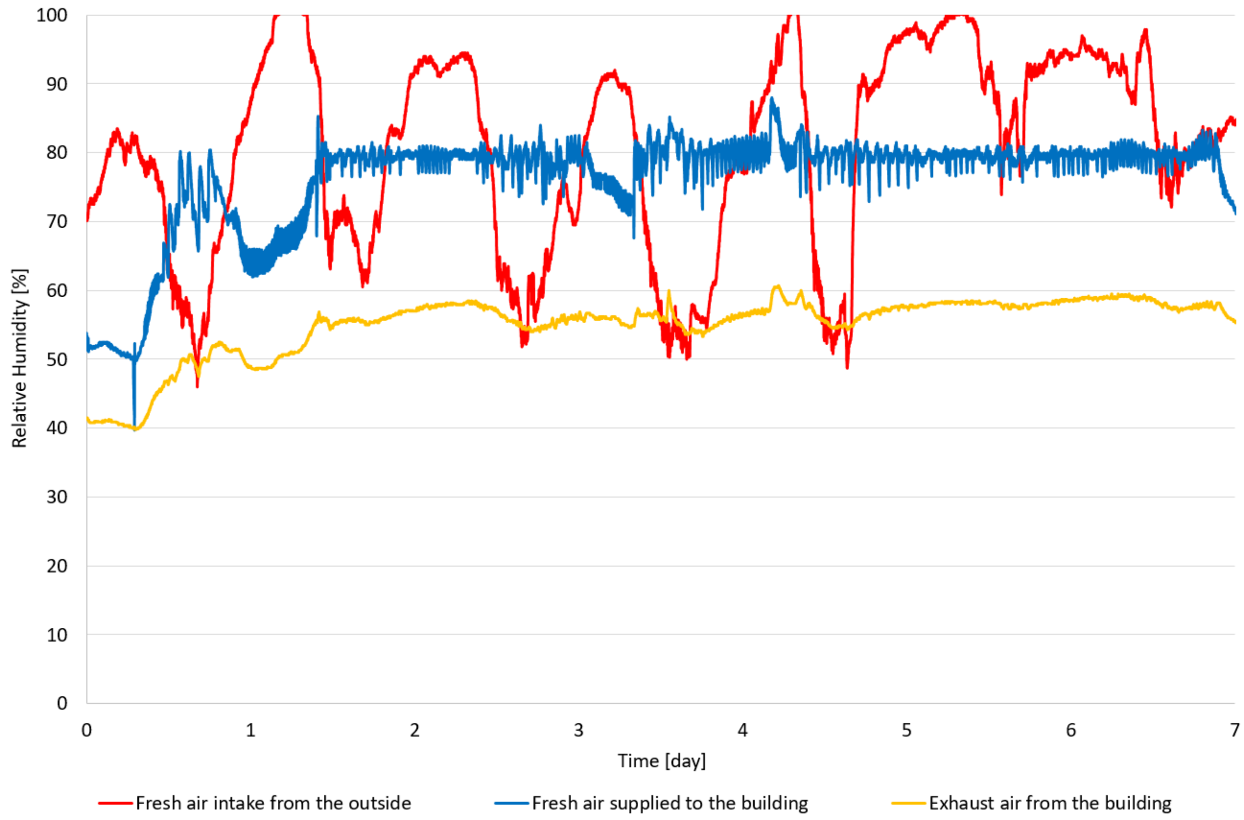

Figure 21: *Outdoor, intake and supply air relative humidity for the IDCS AHU during a warm summer week.*

One can see in *Figure 21* that the IDCS provides fresh air at the set relative humidity of around 75% during the entire warm summer week test period, despite the outdoor air relative humidity fluctuating daily from 50% to 100% relative humidity.

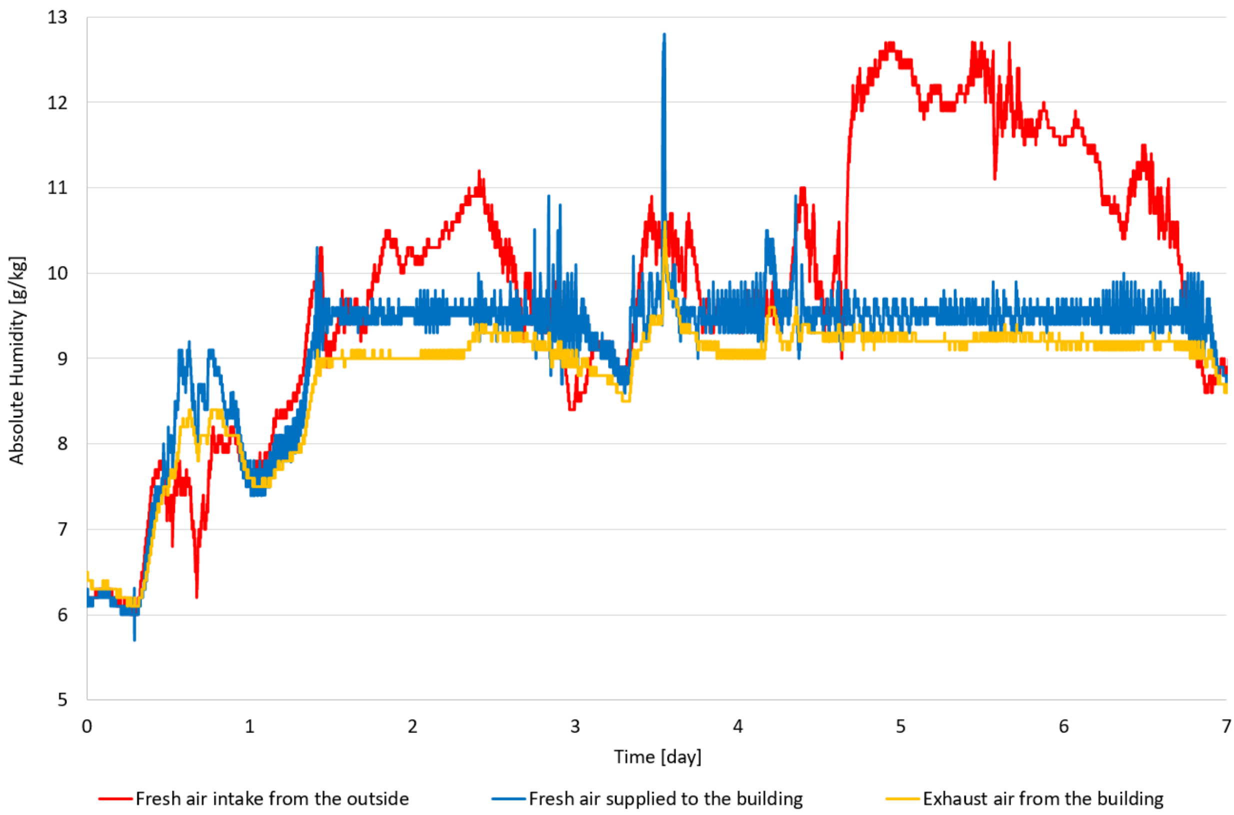

Figure 22: *Outdoor, intake and supply air absolute humidity for the IDCS AHU during a warm summer week.*

One can see in *Figure 22* that the IDCS provides fresh air at the set absolute humidity of around 9.5 g/kg during the entire warm summer week test period. One can notice that the absolute humidity content of the exhaust air from the building is slightly lower than that of the fresh air supply to the building. This might be explained by a certain moisture accumulation inside the indoor environment of the CREATE building. This small discrepancy could also be explained by measurement uncertainty of the monitoring sensors.

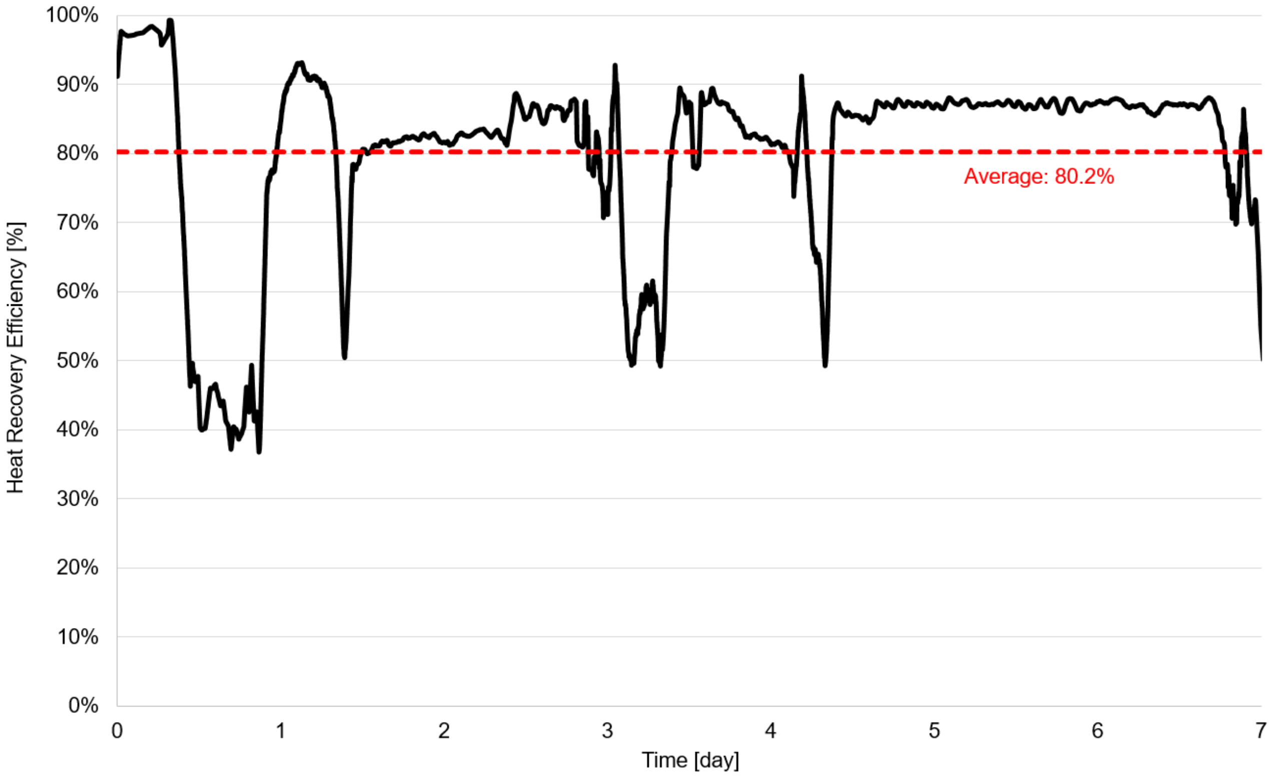

Figure 23: *Heat recovery efficiency of the sensible rotary heat exchanger for the IDCS AHU during a warm summer week.*

One can see in *Figure 23* that the heat recovery efficiency of the sensible rotary heat exchanger of the IDCS is around 80% in average. The fluctuations that one can observed are probably due to the variation in the supply and return fan speed and some regulation instabilities.

9. Conclusions

In this study, the IDCS is installed in a large office building suffering from chronic overheating in the summer and intermediate seasons. This test building is a university building comprising student rooms, teaching rooms, office rooms, meeting rooms and a dining hall. The 2 southern zones are used for a side-by-side comparison: 1 zone remains the same with a conventional ventilation system without active cooling, the second zone is equipment with the IDCS. The indoor environment is monitored in these 2 zones (90 rooms in total) together with the energy performance of the conventional ventilation system in the reference zone and a very detail monitoring of the performance and operation conditions of the IDCS during the summer of 2021. A satisfaction online survey was also distributed among the building's occupants.

The results of the study show that the IDCS performs according to the requirements specified for the supply of fresh air and cooling power. The IDCS can provide a sufficient amount of fresh air to the building with an adequate temperature and relative humidity to cool down the building and ensure a good thermal comfort and no overheating. Although the IDCS performs well, some indoor thermal discomfort remains in certain parts of the test building supplied by the former. After a thorough investigation, it was found that the local ventilation distribution and control system inside certain rooms (outside the scope of the IDCS project's responsibilities) was defective. Despite the latter, the IDCS has proven to be effective at improving the indoor thermal comfort in the test building and reducing the overheating problems.

Further performance analyses of the IDCS study case are collected in a separate report.

10. Suggestions for future work

Suggestions for future work on the IDCS include a detailed study of its relative humidity regulation capacities during the winter season, and its impact on the satisfaction, productivity, well-being and health of office occupants. Although clear links have been established between the indoor relativity and the indoor thermal comfort on one side, and the impact of indoor thermal comfort on the performance, health and well-being of occupants on another side, there is a lack of direct study of the impact of the indoor relative humidity in winter for office occupants.

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