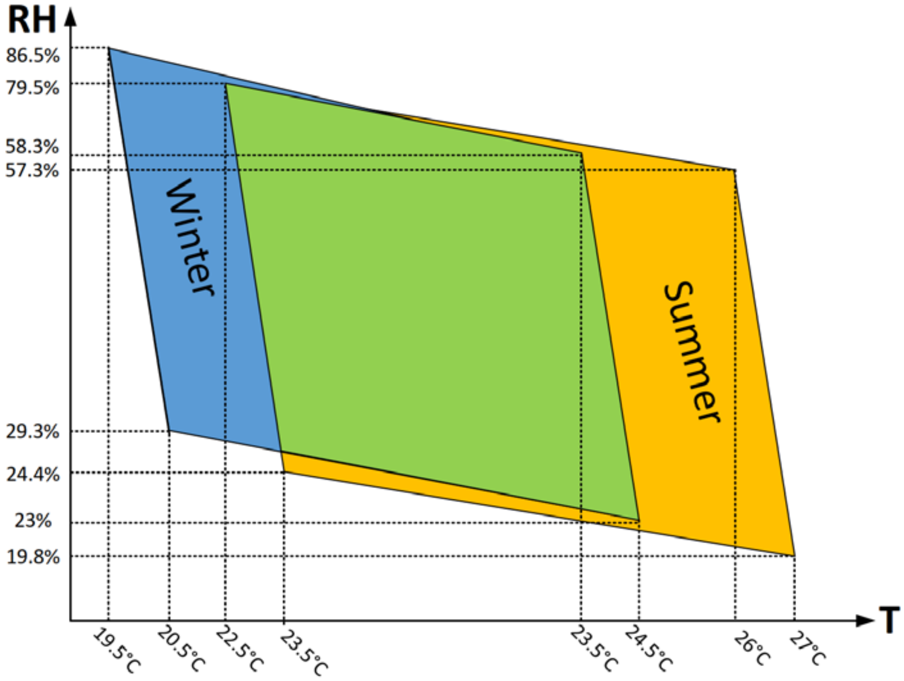

Demonstration of adiabatic evaporative cooling in school

December 2019

Report
2019

Cover photo: Human comfort bounds for temperature and relative humidity
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Preface

In 2015, I was lecturing to people from Menerga (Systemair) about the energy efficiency in ventilation systems. During our talks, we realized that cooling systems in public buildings were often banned by municipal authorities. Perhaps due to service, running costs, energy consumption or the global warming potential of using cooling refrigerants.
But there existed a commercially mature technology, adiabatic evaporative cooling, which could replace cooling refrigerants. It relied on water; and by using harvested rainwater, it could also support climate adaptation.
The solution was already popular in Germany and Belgium, but we needed practical experiences and key figures in a Danish context. Thus, the idea for this demonstration project was born.

The following non-exhaustive list of people have been involved:

- Daria Zukowska-Tejsen, DTU Byg
- Vilhjalmur Nielsen, DTU Byg
- Torben M. Andersen, Menerga
- Peter Thygesen, Menerga
- Michael Vestergaard, Systemair
- Bo Sterner, Systemair
- Peter Lykke Sørensen, Aarhus Kommune
- Jesper Misfelt, Aarhus Kommune
- Jørgen Lindberg, Aarhus Kommune
- Jonathan Kalf Hansen, bachelor student at DTU Byg
- Mathias Håkon-Mose, master student at DTU Byg

Thank you to the school, the management, teachers and students. And thank you to Elforsk for funding this work through grant #349-061.

Kgs. Lyngby, December 2019

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Summary

This report describes a demonstration project where a school building with eight classrooms was retrofitted with a mechanical balanced ventilation system with an integrated adiabatic evaporative cooling unit. Especially in temperate climates, evaporative cooling may have a big potential as an alternative solution to conventional cooling technologies, partly because the market is immature, partly because warmer summers increase the cooling demand. By combining it with harvesting of rainwater, the solution aligns well with a future with higher cooling needs, need for climate mitigation and adaptation, and the overall sustainability agenda. The cooling unit works by storing, filtering and spraying rainwater into the return air. The water evaporates and cools the return air. The return air then absorbs heat from the supply air through an innovative corrosion-resilient plastic heat exchanger. In this way indoor climate problems caused by humidification of the indoor air are avoided. This study reports on a demonstration case running in May&June 2019. The results show that the specific fan power increased approx. 500 J/m^3 when the evaporative cooling pumps were activated and that the available cooling power – depending on the moisture content of the return air – was fluctuating in the range 20-30 W/m^2. The extra electricity to run the adiabatic process amounted to max 6.0 kWh/m^2 per year for a cooling period lasting from May to Sept.

The peak rainwater consumption was approx. 1 m^3/day. The results show that implementation of evaporative cooling with harvested rainwater is a sustainable alternative performing on par with mechanical compressor cooling.

1. Introduction

Buildings policies are becoming more demanding in respect to improvement of energy performance and reduction of CO_2 emissions. In EU countries, 41% of all energy is used by buildings, where ventilation consumes around 30% of the total energy. With the improvement of thermal insulation in modern buildings, the proportion of energy consumption for ventilation and cooling will further increase. This demand is expected to further increase in the coming years due to climate changes (CIBSE TM36, 2005). To minimize the energy consumption, it is vital to secure new and innovative technological solutions, which significantly improve the energy efficiency of current state-of-the-art HVAC systems.

Indoor environment is one of the factors that determine building functionality and economics. Indoor environment affects building occupants and their ability to conduct activities, creates positive or negative impressions on customers, clients and other visitors to a building. Good indoor environment in an office building gives benefits both to employer and employee. Many studies have proven that excess heat negatively affects the health, well-being and productivity of people. Too high temperature affects the performance because warmth lowers arousal, exacerbates sick building syndrome (SBS) symptoms, distracts attention and generates complains (Wyon and Wargocki, 2006). A reduction of indoor air temperatures above 22°C by 1°C can increase the performance of office work by 1% (REHVA, 2006). Thus it can be foreseen that indoor climate in public and private buildings will receive increased attention, which in turn will increase the ventilation and cooling demand. Such demands are too costly to achieve with mechanical cooling solutions that will violate international, national and local energy efficiency targets and does not address the step-wise phase-down of synthetic refrigerants in the EU, see Figure 1. Replacing the synthetic refrigerants with natural refrigerants like ammonia, isobutane, CO_2 or ground water is possible but too costly for smaller scale cooling plants.

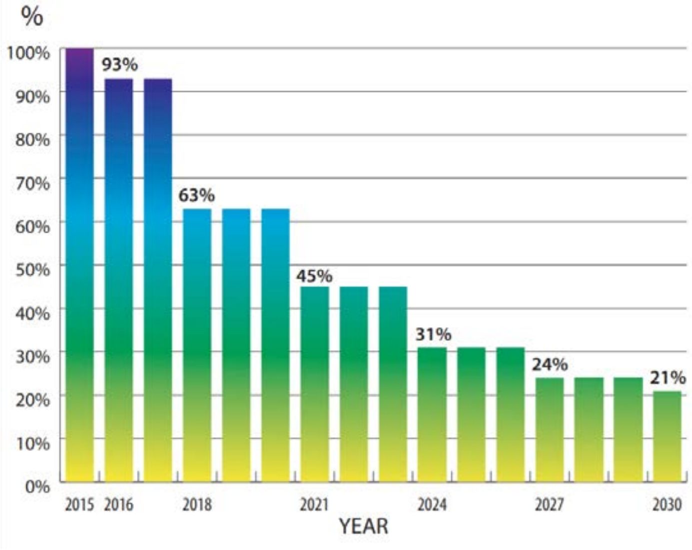


Figure 1. Step-wise phase-down of fluorinated greenhouse gases in the EU. Baseline is annual average of total quantity placed on the EU market 2009-2012 (in CO2 equivalents) (European Partnership for Energy and Environment, 2014)

1.1 Background

The background for the project is that there is a huge potential in using rainwater for adiabatic cooling in Danish buildings as the Danish climate is characterised by having the highest rainfall during spring and summer periods when the need for cooling in the buildings is the highest. Public buildings in Denmark are normally equipped only with ventilation systems, which deliver the amount of air required by hygienic standards but the systems are not designed to cool, which cause problems with overheating. Implementing rainwater based adiabatic cooling in the buildings will improve the indoor environment, possibly with only a small increase of energy consumption due to pumps even in the periods with the highest need for cooling. The results from the project can be used as a proof of benefits such as energy savings compared to traditional cooling systems and improved thermal comfort obtained from such solution, and encourage for replacing existing ventilation systems into adiabatic cooling systems using rainwater.

1.2 Objective

The main objective of this project is to evaluate the opportunity for adiabatic cooling with rainwater in public buildings. The project evaluates the applicability of this technology to the climatic conditions of Aarhus, Denmark, specifically for the public school sector.
The evaluation focuses on:

- system implementation
- energy consumption
- cooling capacity
- water consumption

2. Adiabatic evaporative cooling

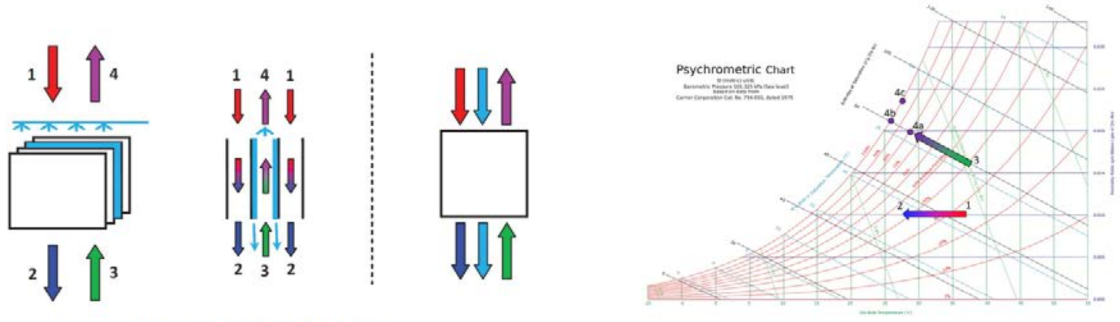
Adiabatic cooling is the humidifying of air under adiabatic conditions, which means that heat energy is neither added nor removed from the system. The process occurs when the air is in contact with water, so the heat required for water evaporation is taken from the air. Consequently air temperature decreases, but moisture content in the air increases.
The study aims at demonstrating the potential of adiabatic cooling with rainwater as an alternative solution to conventional cooling technologies.
Rainwater is collected, filtered and used for cooling by spraying it into the return air from a room. By humidifying the return air and use innovative plastic heat exchangers to transfer the cold to the supply air (indirect evaporative cooling), indoor humidity increase is avoided as well as the associated indoor climate problems of humidified air.

2.1 Indirect evaporative cooling (IEC)

The Indirect Evaporative Cooler (IEC) consists of a dry channel and a wet channel separated with a surface with high heat transfer capacity. As drawn in Figure 2(a) the warm inlet air (1) flows in the dry channels. A secondary air (3) flows in the wet channel where it is sprayed with water and being cooled in the DEC process. As the secondary air is colder than the primary inlet air, the heat transfers between the two separated air streams through the surface between the channels (Duan et al., 2012). The working process can be seen in Figure 2(b) where the primary air (1-2) is cooled at a constant moisture content. While the secondary air stream (3-4) is cooled at constant enthalpy by the evaporated water in the wet channel, just like the DEC. The heat from the primary air is transferred through the surface between the channels and is absorbed by the cool water as latent heat, while some of the water is evaporated and embedded into the secondary air stream, increasing the moisture content. Depending on the efficiency of the humidifier, the temperature of secondary air stream can be at three different levels at the outlet from the evaporative cooler:

- 4a - The air stream is not saturated at the outlet and the temperature is therefore lower than the wet-bulb temperature.
- 4b - The saturation is met at the outlet and the temperature is equal to the wet-bulb temperature.
- 4c - If the saturation happens before the outlet, the heat will be transferred to the secondary air stream as the sensible heat, increasing the enthalpy and increasing the temperature along the saturation curve above the wet-bulb temperature at the inlet.

A main advantage of an IEC is that it cools the primary air without adding any additional moisture to it. This gives the opportunity to use the cooling system in places with restrictions regarding the moisture content in the indoor air. However, a disadvantage of the IEC is that it can only cool the primary air to the level of the secondary air wet-bulb temperature at the inlet. For this reason, these systems are known as wet bulb IEC.



(a) Flow scheme of IEC[23]

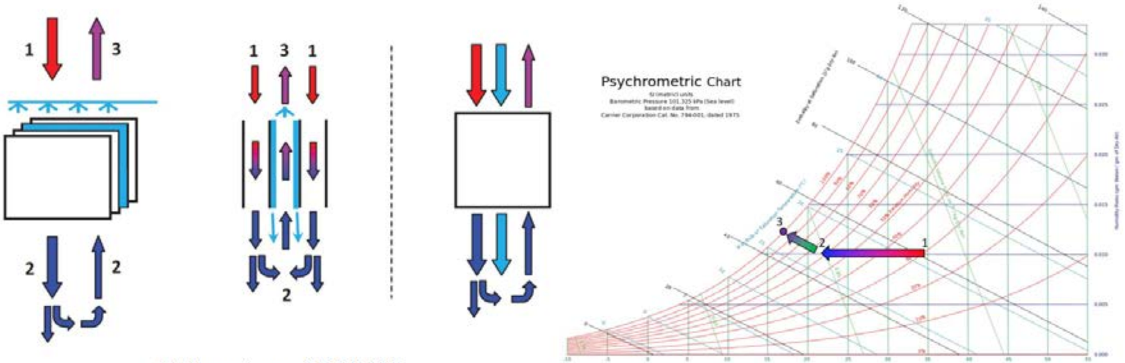
(b) Working process of an IEC

Figure 2. Indirect evaporative cooling (Porumb et al., 2016).

2.2 Regenerative indirect evaporative cooling

Regenerative indirect evaporate cooling (R-IEC) is a result of trying to combat the main disadvantage of the IEC as described above and cool the primary air below the wet bulb temperature of the secondary air at the inlet. As seen in Figure 3(a), the primary air (1) enters a dry channel and flows through the heat exchanger like in the IEC. After being cooled, some of the primary air is led to outlet (2) and used as the secondary air. The process of the secondary air from (2) to (3) is the same as the secondary air in the IEC, with the exception that the temperature of the secondary air in the R-IEC starts at a lower level.

The working process for the R-IEC can be seen in Figure 3(b) where the primary air (1-2) is cooled at constant moisture content and it is cooled to lower temperature than the wet-bulb temperature of the primary air at the inlet, which is significantly lower compared to a classic IEC (1-2). The secondary air follows the same principle as in the IEC and increases its moisture from the outlet (2) until fully saturated (3) at its wet-bulb temperature at the inlet of the secondary channel. By cooling the secondary air before entering the wet channel, the corresponding wet-bulb temperature is also lowered compared to the wet-bulb temperature at the inlet of the secondary air. That means that the temperature limit, which the primary air at the outlet can reach, can be below the wet-bulb temperature. However, as regenerative extraction happens at the outlet of the primary air, the flow rate is also lowered compared to the ordinary IEC (Porumb et al., 2016).



(a) Flow scheme of R-IEC[23]

(b) Working process of an R-IEC

Figure 3. Regenerative indirect evaporative cooling (Porumb et al., 2016)

The R-IEC can be improved even further by adding x amounts of stages where each stage refers to a single R-IEC run through

2.3 Harvesting rainwater

One of the disadvantage of the evaporative adiabatic systems is the amount of water needed to properly run the cooling process. While there is a costs associated with the use of clean water, it is considered a scarce resource in many parts of the world (UN.org., 2019) and it can therefore not be considered as a sustainable way of cooling. A sustainable alternative is to use harvested rainwater. Harvesting rainwater requires a large surface which works as a catchment area, such as a roof, where a run off is made to gather and lead the water through pipes to a storage tank. The storage tank is used to decrease some of the uncertainties regarding be reliant of precipitation. In this way, it is possible to store excess water from rainy days and use it later during periods with no precipitation. The storage tank should be sized in regards to the expected water consumption and harvested rainwater. The amount of harvested rainwater can be described as the effective run-off and calculated from the equation below (Juliana et al., 2017):

$$ER = R_t \cdot A \cdot C$$

where ER is the effective run-off given [m^3], R_t is the precipitation [mm], A is the catchment area [m^2] and C is the run-off coefficient. The run-off coefficient is a value between 0-1, indicating the amount of rainwater caught by the catchment area. The run off coefficient is both dependent on the surface of the catchment area, the rainfall intensity and evaporation from the roof, typically 0.7-0.95 for harder surfaces (Roed, 1985).

The amount of water to be used in the adiabatic loop is based on two factors: how much water is used actually to humidify the exhausted air and therefore transported out of the system in the air and how much water is gathered in the bottom of the system and reused dependent on its cleanness.

Using rainwater as a resource for adiabatic cooling adds a number of additional advantages (Senate Department for Urban Development, 2003). Rainwater contains low level of salt/calcium carbonate so the use of rainwater instead of tap water provides considerable savings, because there is no need for softening or desalination and no effluent is produced. The water consumption and desalination within the conventional cooling process costs about eight times as much as adiabatic cooling using rainwater. Compared with systems using tap water, rainwater systems require only half the amount of water to produce evaporative cooling due to its low electrical conductivity. Additionally, using rainwater instead of tap water in air conditioning saves both water and wastewater while rainwater is returned to the natural water cycle of precipitation/evaporation. This has positive effect on the local microclimate and reduces global warming and condensation processes.

3. Test case description

3.1 School description

A demonstration building used in the project was Solbjerg school located in Aarhus in Denmark. The adiabatic air handling unit (AHU) was installed to service section D of the school, including 8 classrooms and three smaller meeting rooms. The façade of section D is shown in Figure 4.

Figure 4. South-East facade of section D of the school**.**

Section D consist of 2 floors, which are divided in rooms along the South façade and a hallway on each floor to connect the rooms (Figure 7). Only the rooms on the top floor was serviced by the adiabatic AHU (8). The classrooms are equipped with either 3 large windows facing south. All windows have Microshades mounted in between the panes as solar shading. Dimensions of the bigger classrooms are 6.4 x 7.8 x 2.9 m, the smaller ones 6.4 x 7.0 x 2.9 m m.
The classrooms amount to 537 m^2.

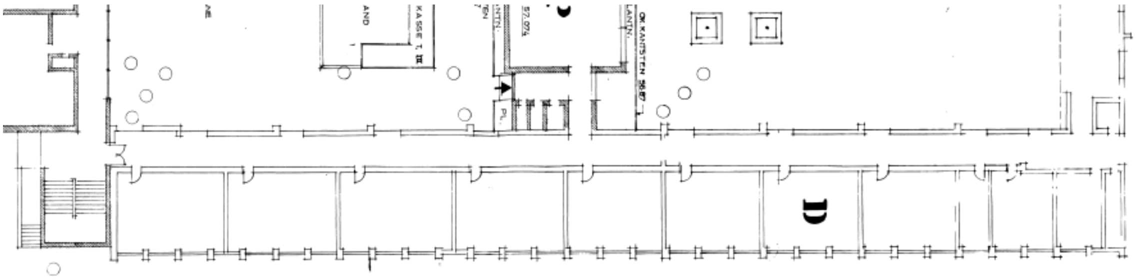


Figure 5. Section D of the school with 8 classrooms (11-18) and three meeting rooms.

3.2 Adiabatic air handling unit

The old building ventilation system was changed to a new adiabatic cooling unit - Adconair adiabatic zero GWP - produced by Menerga. The system utilizes the same principles as both an ordinary IEC and the regenerative-IEC. The evaporative cooling system consists of a double counter flow heat exchanger in polypropylene (Figure 8). Nozzles located upstream of the heat exchanger are wetting the return air in the first part of the heat exchanger. The water is collected in the sump below the heat exchanger and recirculated. The regenerative indirect evaporative cooling (R-IEC) was developed to decrease the primary air temperature at the outlet, below the wet bulb temperature of the secondary air at the inlet. The regeneration consists in extracting a part of the primary air at its outlet and using it as secondary air. In this case, because the secondary air is already cooled, the corresponding wet bulb temperature is sensible lower than the wet bulb temperature of regular (outside) secondary air and the limit at which the primary air can be cooled become considerably lower, see Figure 6 (Porumb et al., 2016)

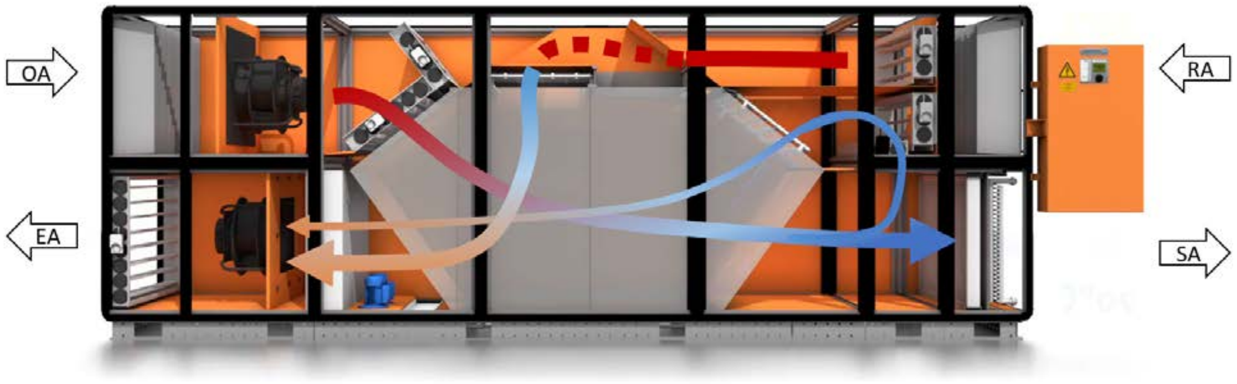
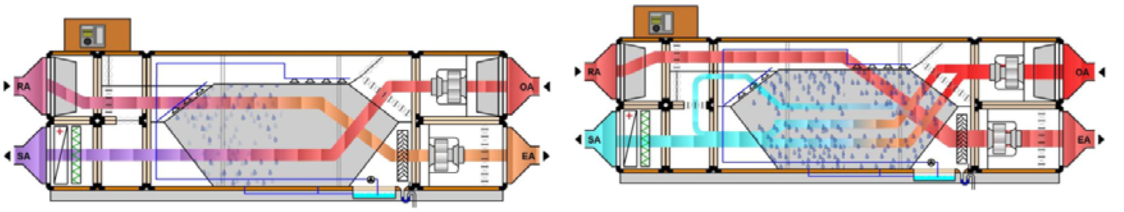


Figure 6. Air handling unit with indirect evaporative cooling process depicted. Regeneration air is returned through the evaporator/exchanger for a second pass hence providing additional cooling of the main supply air stream

The system can run in different modes dependent on the amount of cooling needed and it can utilize the by-pass of the heat exchanger at any point in time if needed.

During normal cooling loads the system runs like a simple IEC as described above and shown in Figure 2(a). In this mode the outdoor air (OA) flows through a dry channel where heat is transferred to a wet channel with cooler air. The cooled air is the return air (RA) from the classrooms. The return air is sprayed with water and humidified to almost 100 % saturation, which leads to its cooling to around the wet bulb temperature of the inlet return air. The cooled return air then flows through the heat exchanger receiving the heat from the warmer outdoor air. Afterwards the warmer return air is exhausted to the outside (EA) and the cooled outside air is supplied to the classrooms (SA).



(a) Solbjerg system running as a standard adiabatic IEC

(b) Extra supply air is extracted and used in the adiabatic loop to cool the return air

Figure 9. Adconair adiabatic zero GWP at Solbjerg school

During the humidification process the return air is cooled to achieve the supply air setpoint. However, in some cases the wet-bulb temperature will be higher than the wanted set point temperature resulting in the system turning on the second mode. This second mode utilizes some of the same principles as the R-IEC, where the cooled supply air is extracted and used in the adiabatic humidification process. Compared to a normal R-IEC, this plant instead mixes the extracted supply air with the supply air, to achieve a lower wet-bulb temperature of the return air, as illustrated in Figure 3(b).

3.3 Cooling capacity

The total cooling capacity E_{tot} comes from the temperature difference between room temperature and supply air temperature (for ease, the temperature of the classrooms is represented by the mass-averaged exhaust air).

$$E_{tot} = \dot{V}\rho c_p\left(T_{exh} - T_{sup}\right)$$

Some of the total cooling capacity is ventilative, some adiabatic. The ventilative part comes from the outdoor air being colder than the exhaust temperature. In a Danish summer climate, this is often the case, but the ventilative cooling is not necessarily enough cooling to the classrooms; the supply air should be even lower than the outdoor air.

The latter is possible by cooling the supply air through adiabatic evaporation. Then, the adiabatic cooling E_{ad} comes from the temperature change of the inlet air across the air handling unit:

$$E_{ad} = \dot{V}\rho c_p\left(T_{out} - T_{sup}\right)$$

The ventilative cooling part E_{vent} is the difference between E_{tot} and E_{ad}:

$$E_{vent} = E_{tot} - E_{ad}$$

3.4 Harvesting rainwater

The components of the water treatment plant are shown in Figure 8. Rainwater from the roof was collected in the existing gutters fixed along the roof and led in a pipe system to an underground rainwater storage tank. The volume of the underground tanks is 10 m^3. A very coarse filter is installed in the pipe to the tank to remove leaves and other solid parts from the collected rainwater. From the rainwater tank, the rainwater is pumped through a coarse and a fine filter (not depicted) to a small water reservoir (“day water tank”) that feeds the adiabatic cooling unit.
A water meter installed on the pipe leading to the heat exchanger registered the amount of rainwater use for cooling. UV disinfection was installed on the day water tank to exclude possible bacterial contamination.

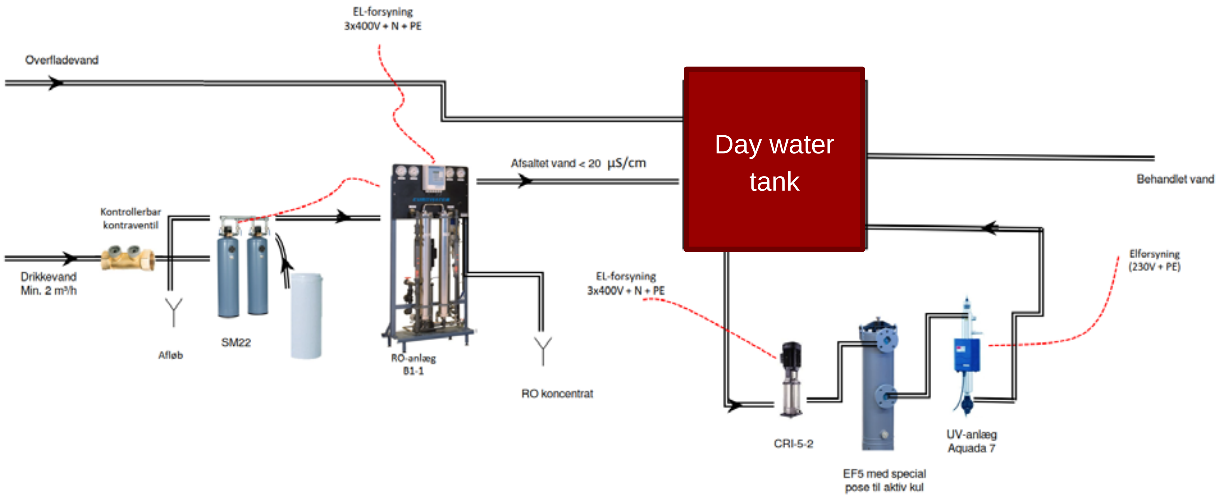


Figure 7. Water treatment plan**t**

To ensure the possibility of using adiabatic cooling also in drought periods without precipitation, additional supply of tap water is implemented. Danish tap water has a high content of minerals, mainly calcium, which would accumulate inside the pipes, water tank, filters, etc. decreasing the life-time of the system. In order to remove minerals from the tap water a reverse osmosis plant is implemented. The aim of reverse osmosis (Kucera, 2016) is to filter solutes and ions from the water. High pressure forces water over a semi-permeable membrane that is porous enough to allow water molecules to pass through, but blocking the passage of solutes such as salt ions. This pressure forces water through the membrane in the opposite direction from the one it would otherwise take. This leaves dissolved solutes and pollutants behind. Reverse osmosis is a highly efficient filtration technique. Depending on the type of membrane and the system used, reverse osmosis system can remove 85% to 98% of total dissolved solids from water.

3.5 Measuring equipment

In order to determine the thermal effectiveness of the technique, measurements were carried out in an adiabatic air handling unit (AHU). To identify the system capabilities, energy meters were installed in the adiabatic cooling system. In order to check the efficiency of discharged air humidification, air temperature and humidity sensors in outside air, supply air to the room, return air from the rooms and exhausted air were connected to BMS and logged.
Sensors in the classrooms: temperature, CO2 and PIR were installed to monitor indoor climate.

4. Results

4.1 Measurements

The installed sensors provide data on the indoor temperature, energy consumption and water use. From this data we calculated the cooling performance of the adiabatic system as well as the efficiency.

The building management system provides information about the indoor climate in the classrooms (Figure 9) as well as the current operation of the adiabatic air handling unit (Figure 10) and water tanks (Figure 11).

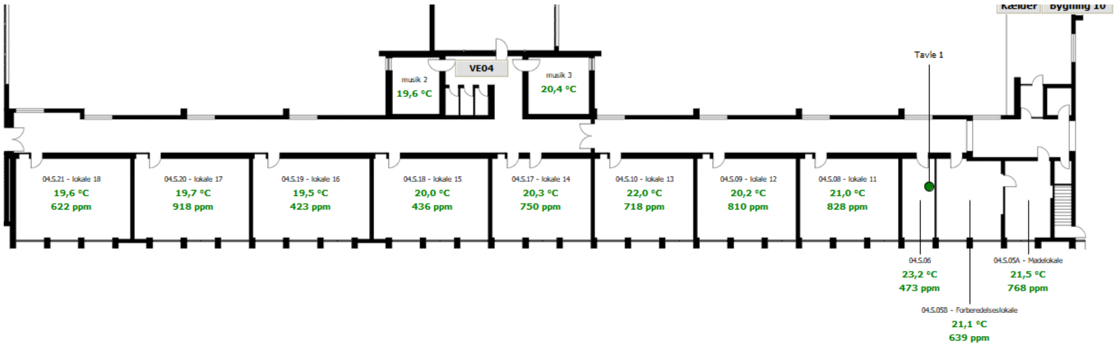


Figure 8. Classrooms are monitored in BM**S**

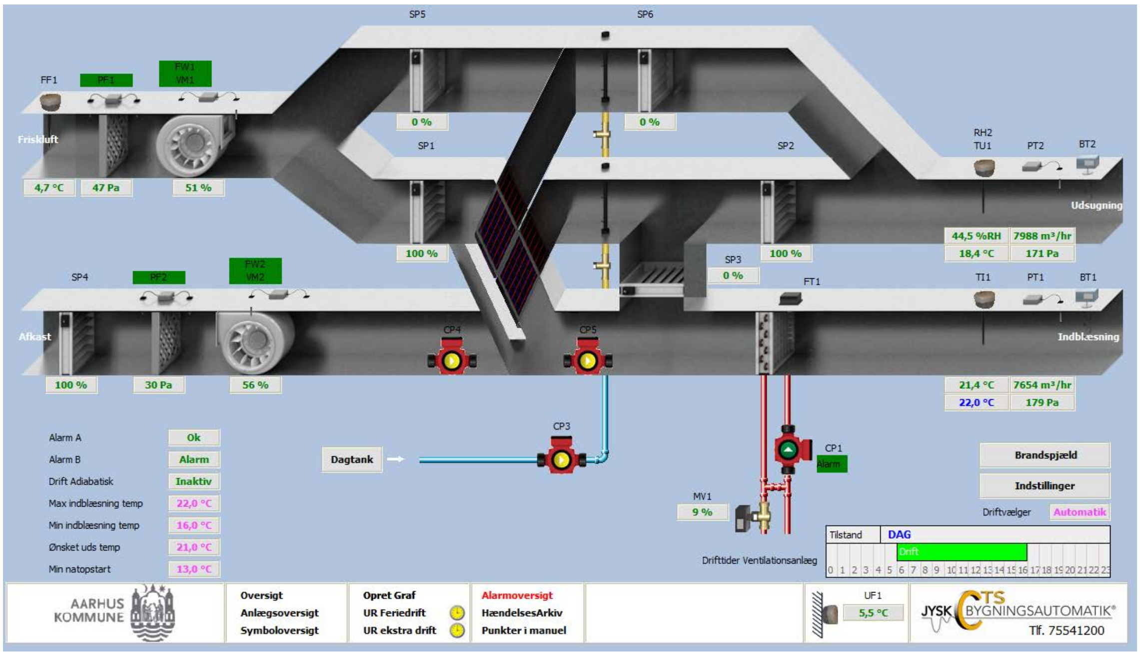
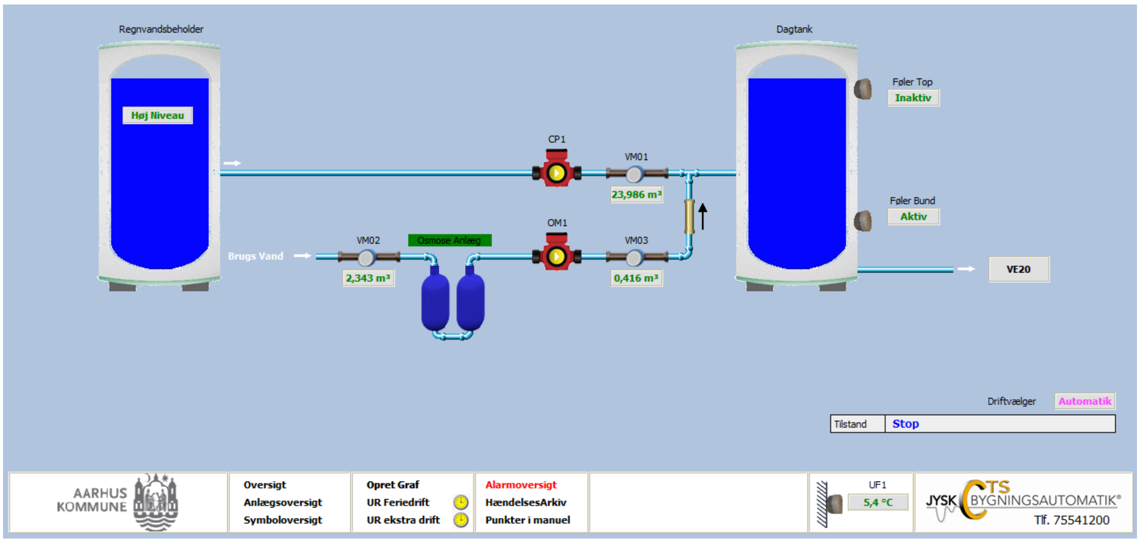

Alarm A Ok
Alarm B Alarm
Drift Adiabatisk Inaktiv
Max indblæsning temp 22,0 °C
Min indblæsning temp 16,0 °C
Ønsket uds temp 21,0 °C
Min natopstart 13,0 °C
Driftvælger Automatik
Tilstand DAG

Figure 9. Air handling unit data is monitored in BMS



VM01 23,986 m³
VM02 2,343 m³
VM03 0,416 m³
Føler Top Inaktiv
Føler Bund Aktiv
Driftvælger Automatik
Tilstand Stop
UF1 5,4 °C

Figure 10. The water tanks, filter status and osmosis plant for tap water is monitored from BMS

4.2 Weather

As Figure 12 shows the outdoor climate in June on site was very different from 2017 to 2019. The 2019 June was significantly warmer than the 2017 June.

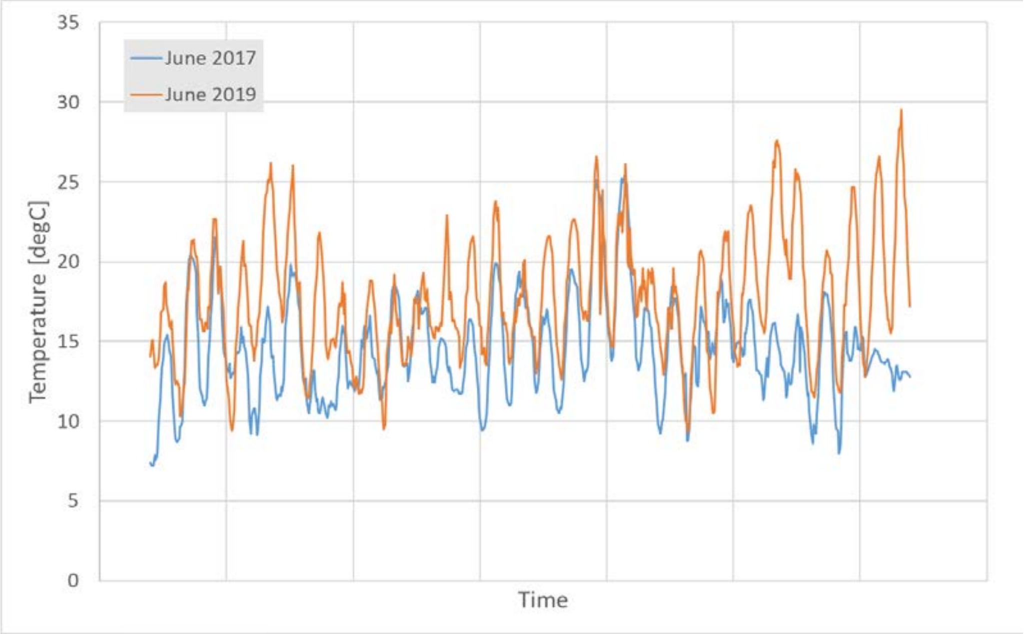


Figure 11. The outdoor temperature in June 2017 and 2019

This is supported by Figure 13, which shows significantly more sunshine in 2019 than in 2017 in the region of Aarhus.

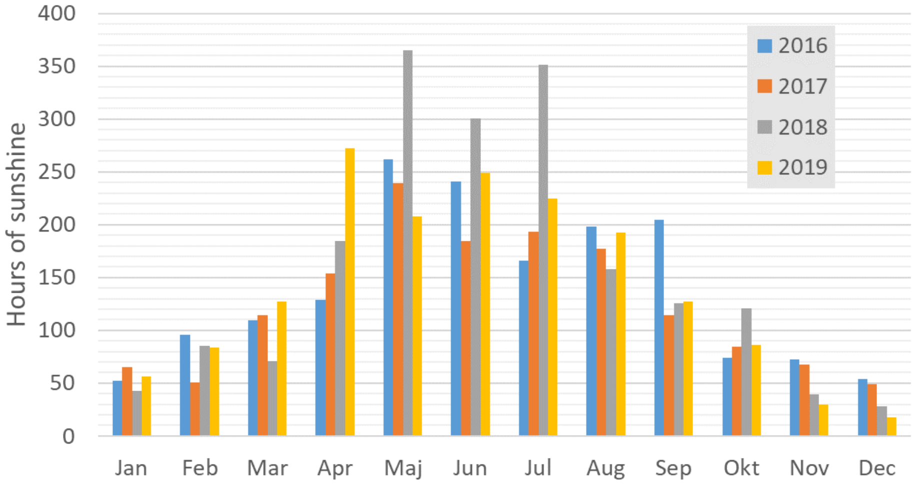


Figure 12. Numbers of sunshine hours in Aarhus Kommune. 2018 stands out as a very dry year. It is also clear that June had significantly more sunshine in 2019 than in 2017. Source: DMI.dk

To compensate for this effect, the indoor temperature is divided with the outdoor temperature to show the ratio of indoor temperature to outdoor temperature.This disregards the solar gain which would also have an effect on the results, but in the Danish summer solar radiation and outdoor temperatures are closely related and by aggregating data over a whole month (June), the magnitude of the error is deemed acceptable.

4.3 Indoor temperature in classrooms

The indoor temperature from Room 11 in June is depicted in Figure 14. The graphs show a clear impact from the implementation of the ventilation/adiabatic system in 2019. The 2018 results are discarded, because the adiabatic systems control were malfunctioning. Consequently, the operation results from 2018 are very uncertain.

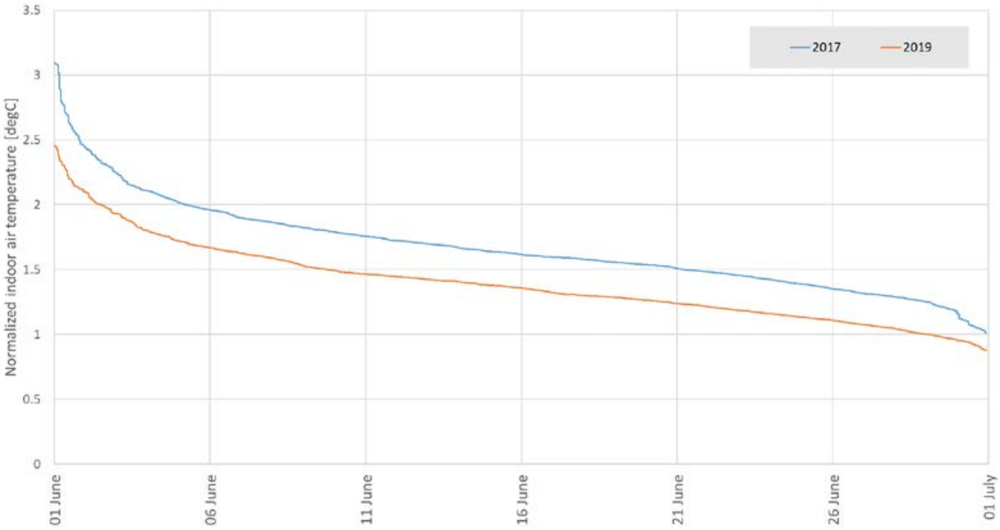


Figure 13. Indoor temperatures from Room 11 normalized by outdoor temperatures.

Despite the high outdoor temperatures in June 2019, the indoor temperatures of most classrooms were in the range 22-24°C as depicted on Figure 15. Class 11 and 15 were approx. 1 °C warmer.

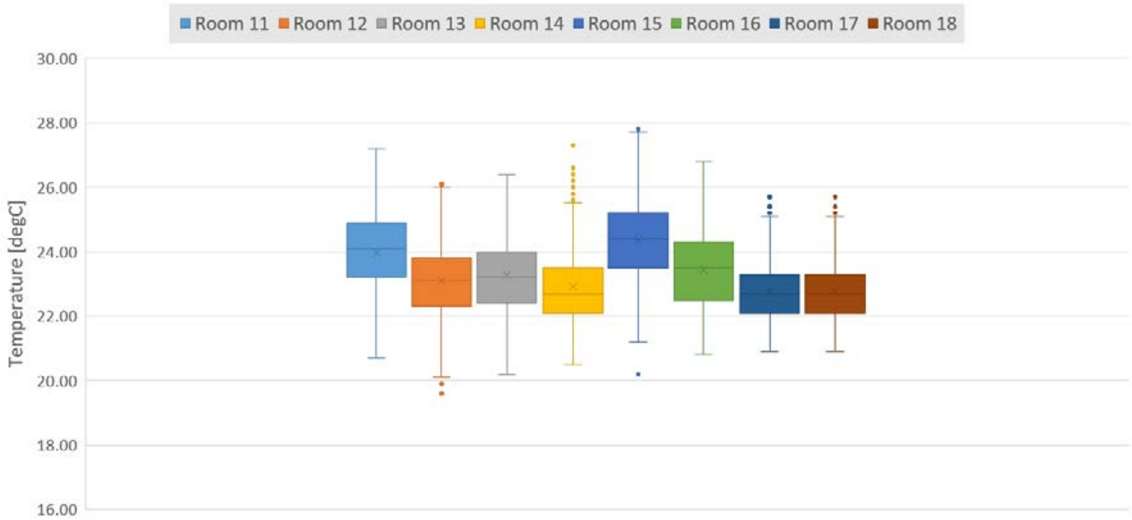


Figure 14. Boxplot of the indoor temperatures in all classrooms in June 2019. The box denotes 75% of all readings, and the whiskers extremes

4.4 Cooling performance

The cooling power is partly ventilative and partly adiabatic. The ventilative part comes from the outdoor air being colder than the return air. The adiabatic part comes from the temperature shift when the outdoor air passes through the AHU when the adiabatic system is active.
Figure 16 shows how the supply air temperature drops approx. 5°C below the outdoor temperature when the adiabatic cooling is activated. It also shows how adiabatic cooling increases the total cooling when activated.
Every morning for a few hours the night ventilation is activated to bring the indoor temperature (exhaust air) down.

The adiabatic cooling power amounts to approx. 20-30 W/m^2 in the figure. Depending on the outdoor temperature, ventilative cooling adds most days an extra 10-15 W/m^2.

The total cooling power as well as the adiabatic part of the total cooling are illustrated in Figure 17. In the month of June, adiabatic cooling ratio of the total supplied cooling was 29%, and in the warmest week, it was 44%.

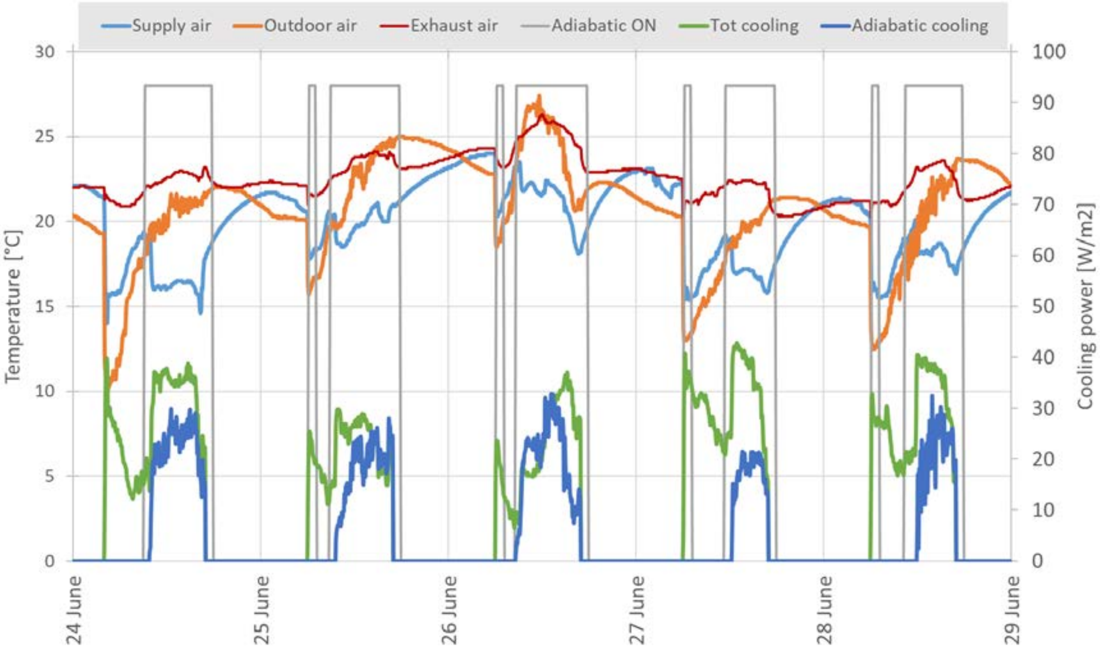


Figure 15. Week of June 2019 showing how the adiabatic cooling, when ON, cools the supply air by a maximum of 5 °C. This amounts to approx. 20-30 W/m^2

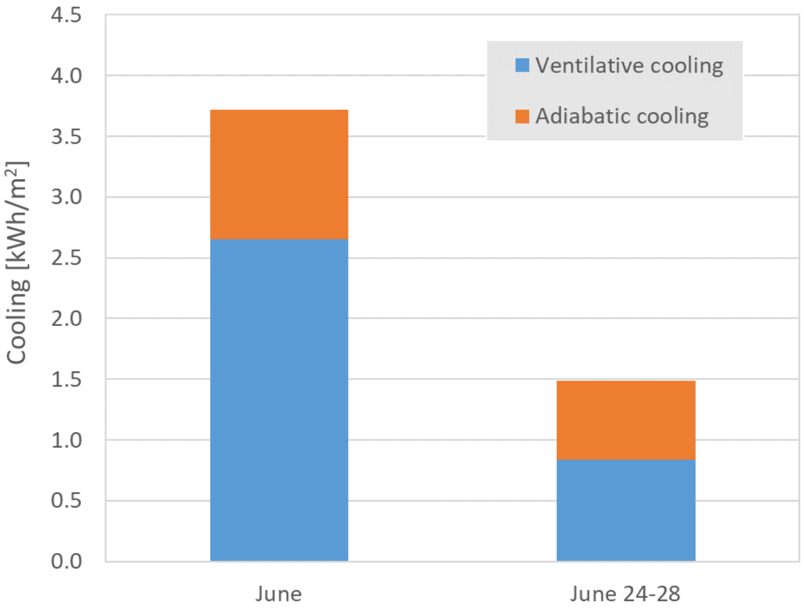


Figure 16. Ratio of ventilative and adiabatic cooling for the whole June 2019 and for five warmest working days 24-28th of June (as depicted on Figure 16). During the warmest days, adiabatic cooling supplied approx. 44% of the cooling

4.5 Energy consumption

Different elements are energy consuming in the system, the AHU fans, the adiabatic spraying pumps, the rainwater pump and the osmosis plant. The energy consumption of these elements are illustrated for the month of May and June 2019 as well as the typical working weeks in Figure 18. The energy difference between the week in May and the week in June is due to the internal spraying pumps in the adiabatic cooling unit.

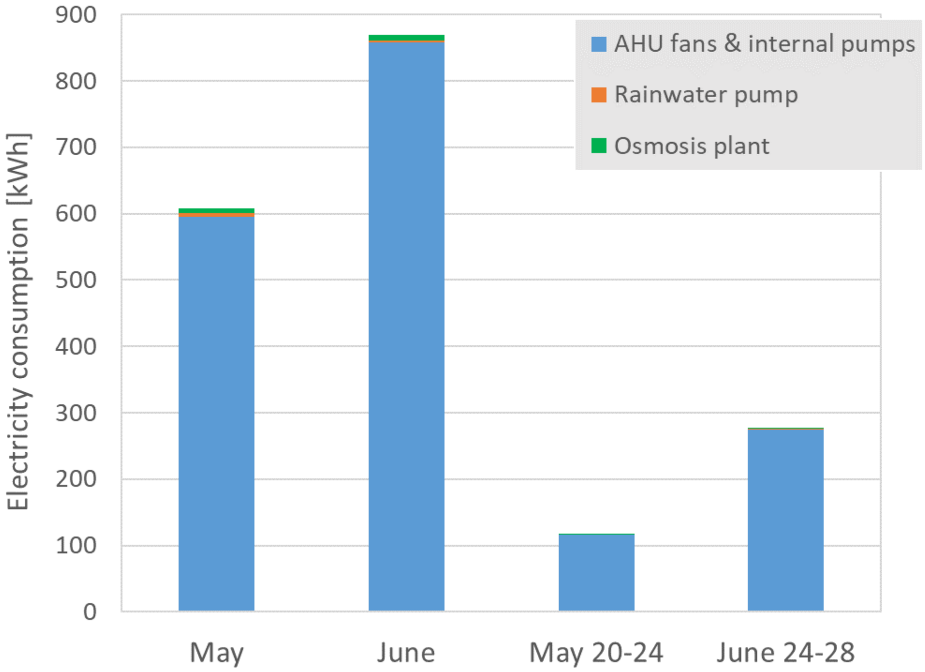


Figure 17. Energy consumption for ventilation, rainwater pump and osmosis system for May (cooling inactive) and June (cooling active)

The extra cooling electricity consumption from Figure 18 is summed up in Table 1. The weeks of May and June are used as reference to calculate the expected yearly electricity usage for cooling.

Table 1. Cooling electricity usage

	Electricity consumption	Comment
Week May 20-24	117 kWh	Ventilation active
Week June 24-28	277 kWh	Ventilation and adiabatic cooling active
Difference	160 kWh	Daily extra electricity usage for adiabatic cooling
Cooling need May-Sept	3200 kWh	Approx. 20 weeks
Yearly cooling electricity	6.0 kWh/m^2	Ventilated area: 537 m^2

To calculate the efficiency of the total system, the specific fan power for the month of May and June is depicted in Figure 19. The SFP from May, which was completely without adiabatic cooling, is approx. 1300 J/m^3, rising to approx. 1800-1900 J/m^3 in the last week of June, where the adiabatic system was active every school day.

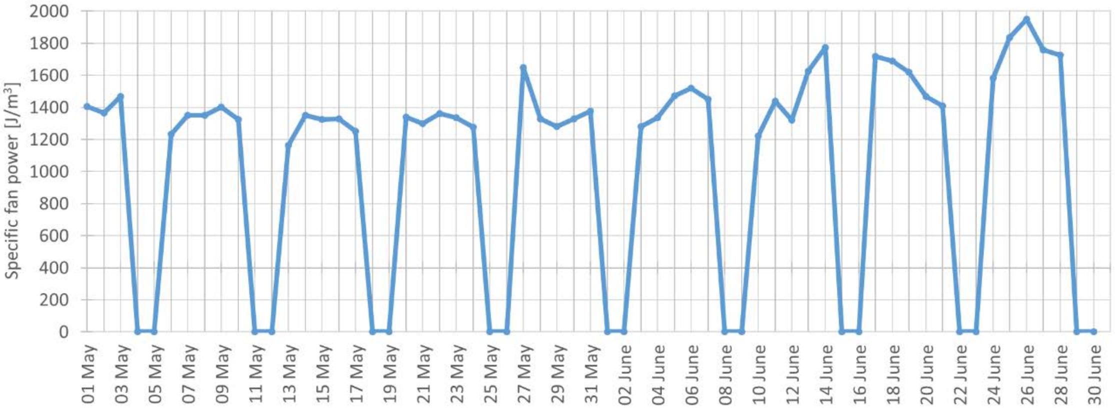


Figure 18. Average daily specific fan power in June 2019 and for five working days 24-28th of June

4.6 Water consumption

The accumulated rainwater consumption is depicted on Figure 20. For the summer of 2019, approx. 24 m^3 of water was used. During the warmest week of June, the accumulated usage was 5 m3, meaning that the consumption is approx. 1 m3/day when the adiabatic system is running at maximum capacity (Figure 21).

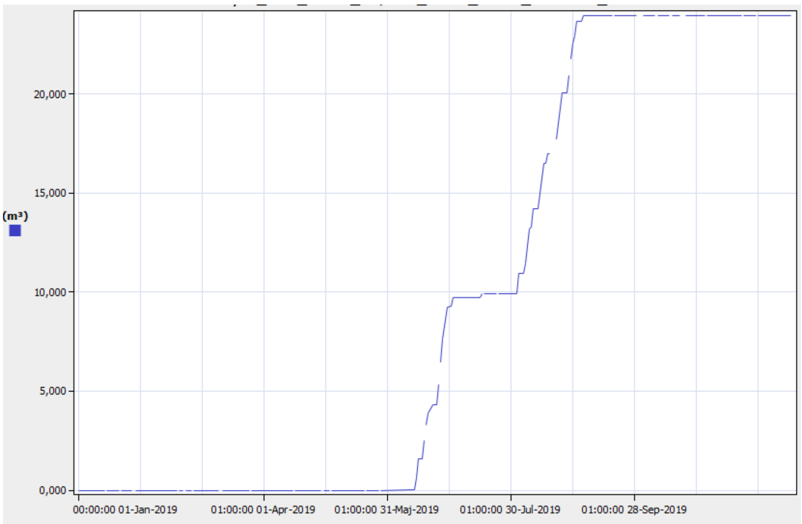


Figure 19. Accumulated rainwater consumption by the adiabatic system in 2019. In the period before summer holidays (June), the consumption was approx. 10 m3. After holidays, approx. 14 m^3 was used.

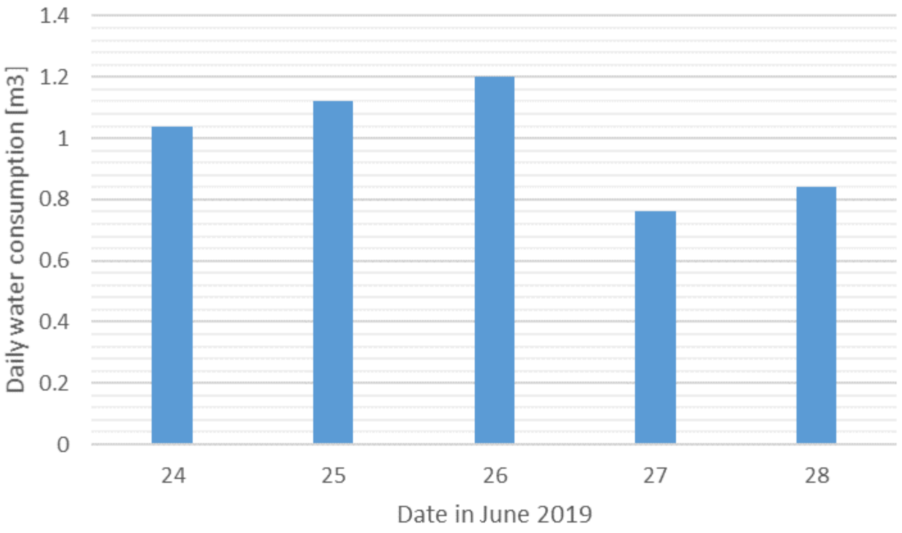


Figure 20. Daily water consumption by adiabatic system during peak load 24-28 June 2019.

4.7 Data platform

The building management system (BMS) at the site monitors and logs all the data points from the air handling unit, the pumps, the dampers and the classrooms. The BMS system is, however, not suitable for broader dissemination. Consequently, a data platform was developed, which relays the data from the BMS system via MQTT protocol to the data platform hosted by DTU Byg's IT-partner.

The platform can be used to make visualizations and simple aggregated indices as is displayed in Figure 20 - Figure 24.

The data is accessible for the public through the following link:

https://iotportal.atea.se/dashboard/b1de6cf0-d961-11e9-9f5f-3954e00dd13b?publicId=f0238020-d463-11e9-b799-effcfa5c42e7

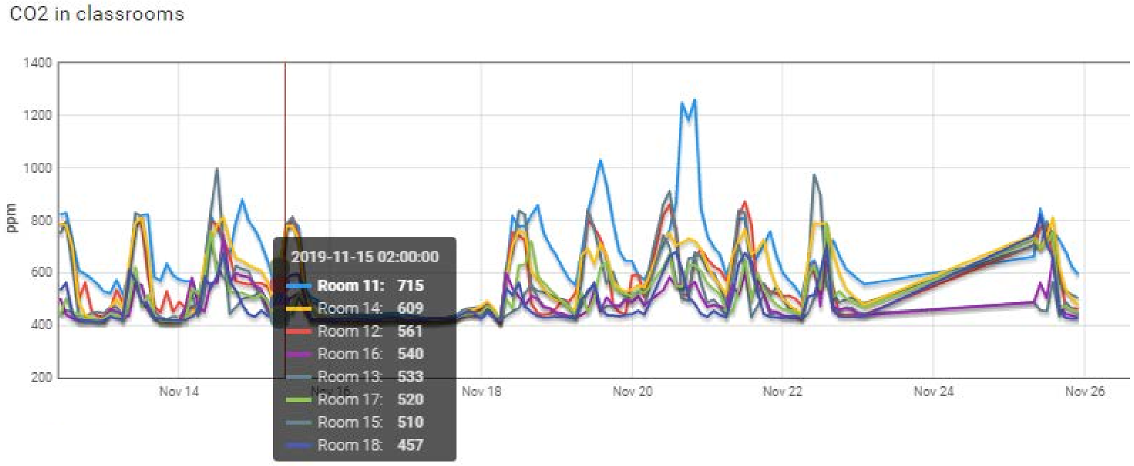


Figure 21. CO2 concentration in classrooms

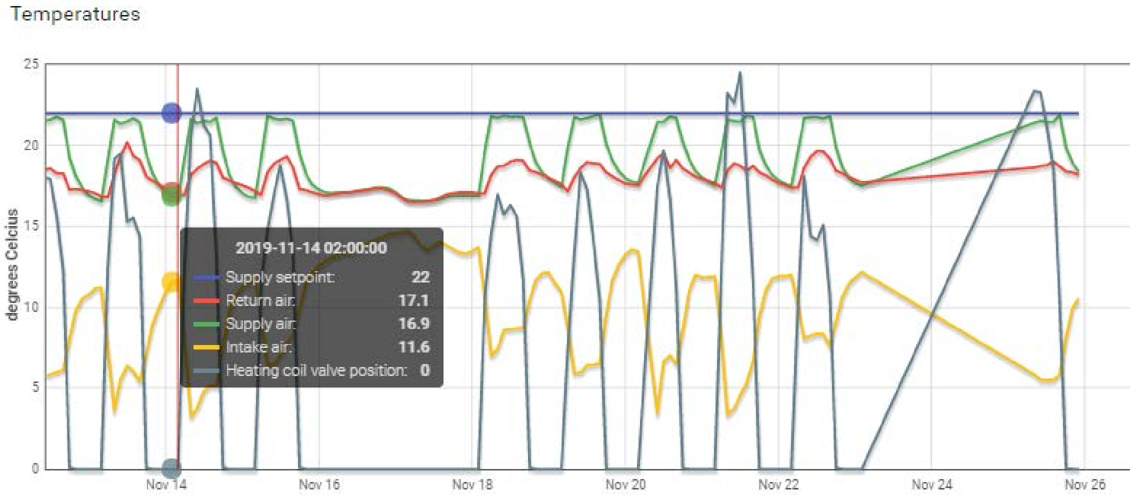


Figure 22. Air handling unit temperatures

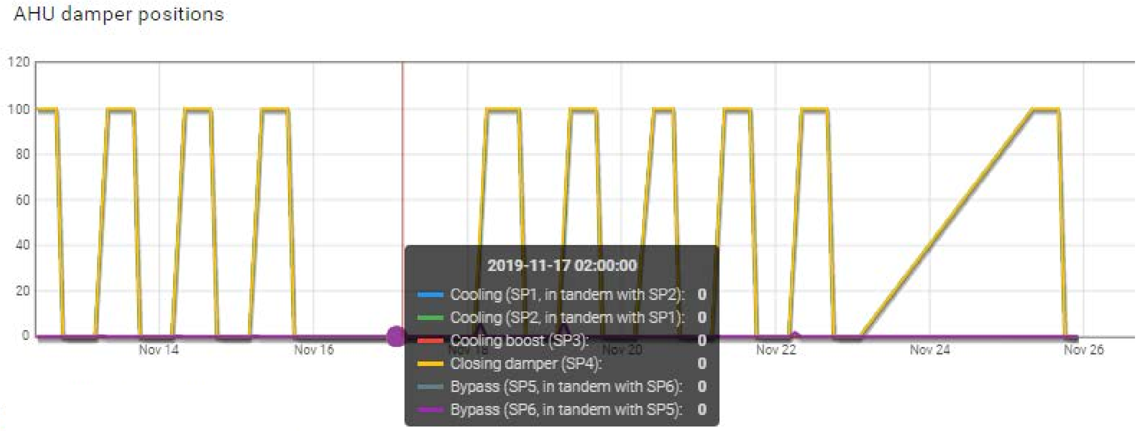


Figure 23. Air handling unit damper positions determines different operation modes like cooling, bypass and heat recovery

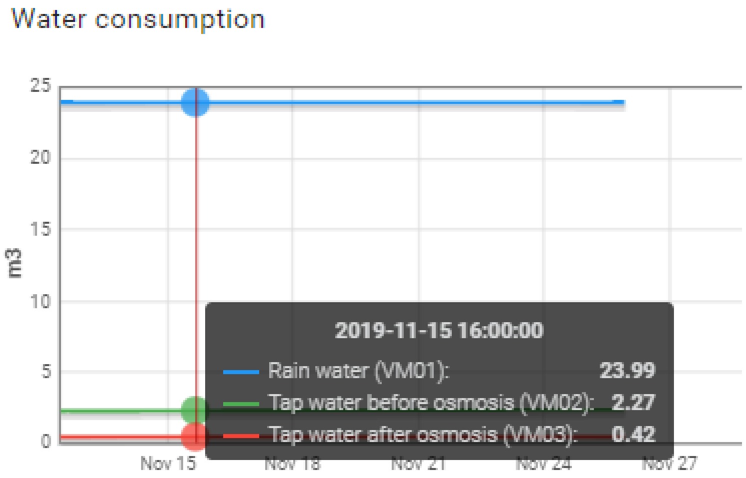


Figure 24. Water consumption of the summer 2019 is displayed.

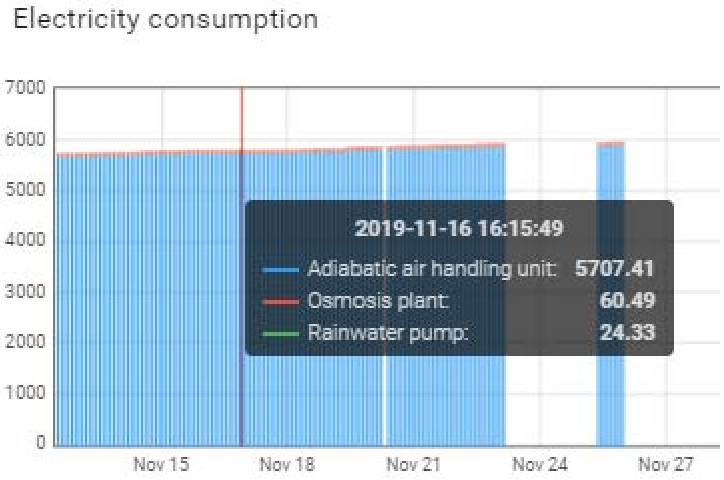


Figure 25. Electricity consumption divided into air handling unit itself (internal fans and pumps for water spray), osmosis plant and the pump that lifts water from the underground rainwater tank to the AHU.

5. Learnings

- The adiabatic cooling capacity is 20-30 W/m^2 in a Danish climate.

- The indoor temperature in the classrooms was significantly lower due to the mechanical ventilation and adiabatic cooling unit.

- This cooling results are also applicable to other public or commercial buildings with similar ratio between internal moisture production and airflow rate. In order words, this is valid for airflow rates designed for CO2 1000 ppm.

- The cooling electricity usage is on par with conventional compressor cooling. This is due to the high pressure of the spray pumps in the adiabatic cooling unit.

- The global warming potential of the adiabatic system is much smaller, because no potent cooling refrigerants are used.

- The summer of 2018 was very dry and even though the rainwater tank was designed for more than 3 weeks of drought, which is a very rare event in the Danish climate, it happened in 2018. The tank was filled with tap water to compensate, but this caused the system to malfunction due to the content of minerals. Consequently, tap water should only be used through an osmosis system that removes the minerals.

- The rainwater tank was dimensioned so the switch to tap water did not occur once in 2019

- This means the energy consumption for the osmosis plant was neglectable, but the osmosis plant does flush with approx. 7.5 l of tapwater per day. It is unclear at this time, if this flush is really necessary given the small number of osmosis operation hours

6. Summing up

The main objective of this project is to evaluate the opportunity for adiabatic cooling with rainwater in public buildings in terms of energy, cooling capacity and water consumption.
The results are only from the month of June 2019, and does not reflect several years. However, the June of 2019 seems to be quite warm compared to 2017 (and on par with 2016), which means the results are generic.

The cooling capacity of the adiabatic systems was 20-30 W/m^2 and the system was capable of reducing the supply temperature by approx. 5°C.

The indoor temperature was acceptable in the range 22-25°C and would have been higher if no cooling was provided. The CO2-concentration (not disclosed in this report) was maximum 1000 ppm.

The water consumption in the warmest week of June was approx. 1 m^3 per day. With the tank volume of 10 m^3, and in the (rare) event of no precipitation for 14 days, the system may run for 10 school days before switching to tap water. The switch did not occur in the summer of 2019.

The energy costs are on par with conventional compressor cooling, but the calculation is sensitive to chosen input.
In terms of operation costs, two inexpensive filters in the rainwater supply should be changed every year. There are no required yearly inspection of the cooling installation as with compressor-driven cooling.

The risk of biofilm forming inside the unit has been in the focus of this project. The day water tank is disinfected by UV-light to minimize the risk of bacteria and vira and members of the project team visited an operating Menerga unit in Belgium using harvested rainwater, to investigate the risks. The Belgian unit was very clean inside, however, more references are necessary to address this concern.

To conclude, the system performs as expected and has had no operation disruption for the whole summer of 2019. This demonstrates that adiabatic cooling is a realistic alternative to compressor cooling for comfort in public buildings, especially in a climate adaptation context where surplus of rainwater can be converted into a sustainable cooling resource.

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