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Long-term testing of the FT-1600 Adiabatic Cooling Aggregate

At Aalborg University – Fib. 10, 0.09

Nielsen, Mads Pagh; Sørensen, Henrik; Sahlin, Simon Lennart

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ADIABATISK KØLING TIL DECENTRALE VENTILATIONSANLÆG

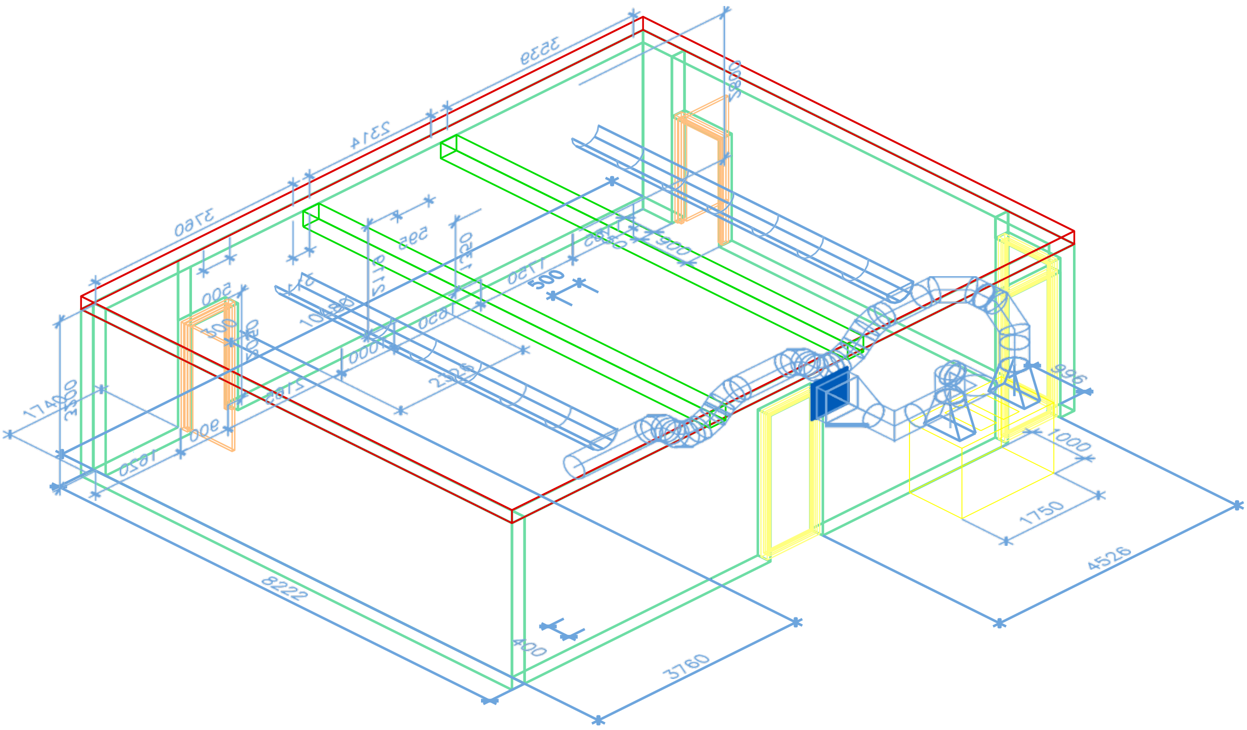
Dansk Energi, Elforsk PSO 350 – 007

Authors:
Mads Pagh Nielsen
Henrik Sørensen
Simon Lennart Sahlin

Table of contents

1 BACKGROUND AND PURPOSE

An FD 1600 prototype system setup by NB Ventilation A/S has been tested at Aalborg University Fibigerstræde 10 connected to lecture room 0.09 in the period from July 10th 2019 till February ?? 2020. The system is shown in the following illustration and photo. It is installed with air inlet and outlet sections through bag filters in order to obtain an equal airflow distribution in the room yet having silent operation with no draft.

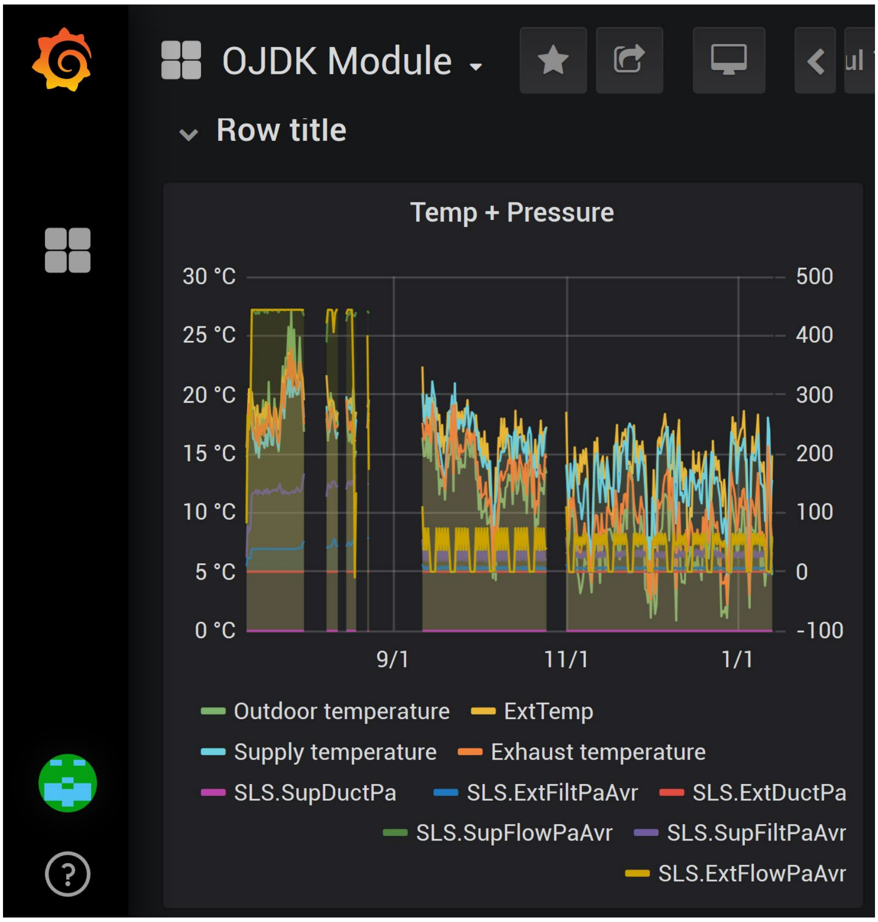


The system as it is currently installed next to room Fib. 10, 0.09.

The used lecture room have a capacity of up to 50 persons and the required air flow was determined to by 1600 m^3/h under nominal operating conditions. Campus Service at Aalborg University established the necessary water supply and electrical connections.

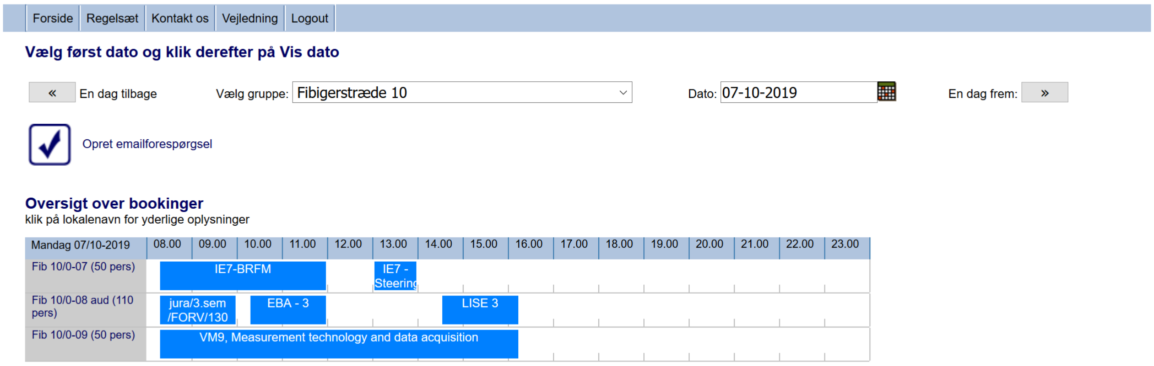
1.1 Data logged from the system

There has been a few outages during this period due to electrical failures (some were caused by lightning strike others due to necessary modifications to the unit). The system also needed the addition of a silencer since fan noise in the early days of operation propagated through the pipes. An OJ.DK control and data acquisition system was installed on the system with a wireless connection (described in detail in Enclosure 1). All temperatures and pressures were logged along with logging of inlet and outlet flows from the system. Later, during August, also the relative humidities at the system inlet and outlet were logged along with the total power consumed by the aggregate (including fans, pump and all electrical installations). The built-in data acquisition system was only capable of storing data for a week at a time. AAU thus developed an online tool to acquire and store data from the OJ.DK-system. All data were logged at a sample rate of 1 Hz. In the current report, however, the data have been converted into minute based average value to simplify the treatment of the very large datasets. An overview of the logged data can be seen on the plot below (including periods with outages in August, September and October):



1.2 *Usage of the lecture room during the data logging*

The usage of the lecture room during the test is illustrated below with screenshots from the Room Booking System at Aalborg University. Typically, the room has been almost full when used for lectures or exams. There has however been a few meetings with only 5-10 persons as well during the period.



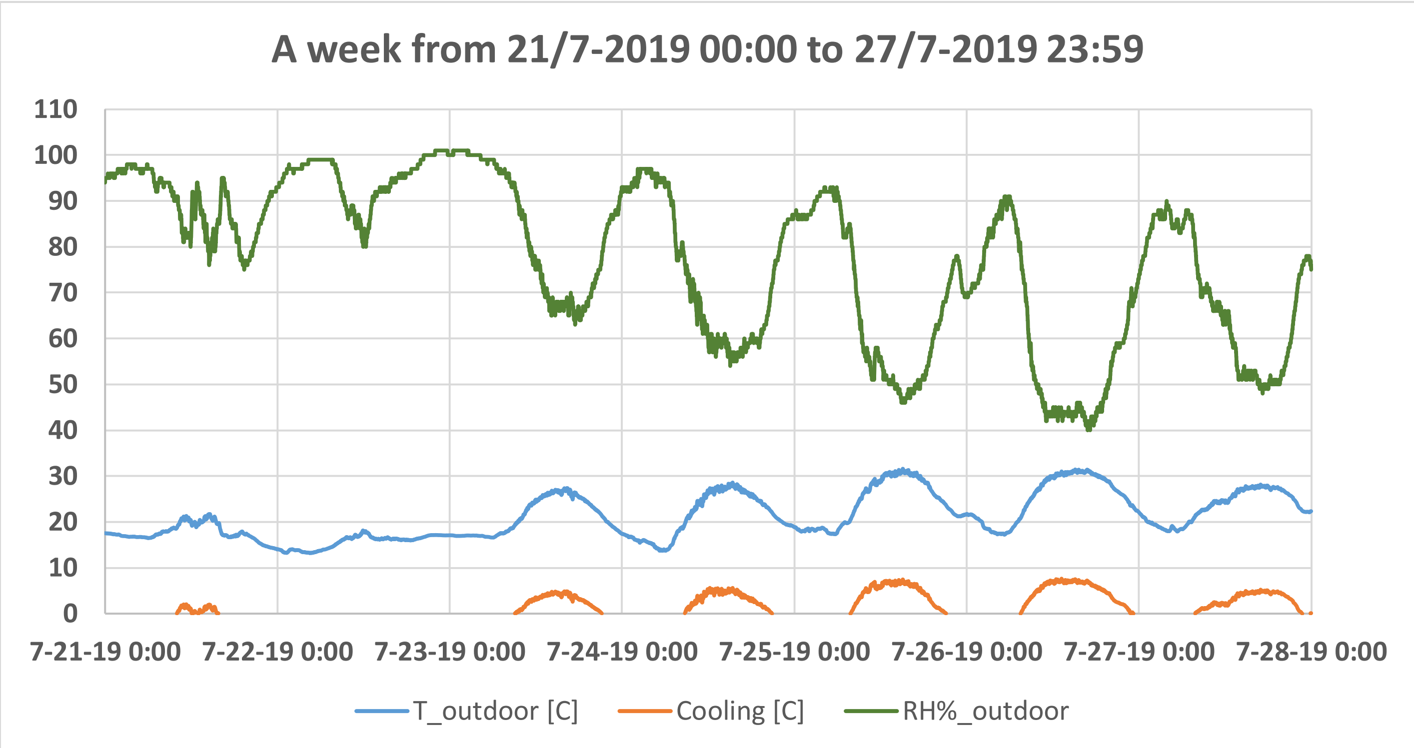
In the period from July 10th till August 8th, the room has not been booked due to Summer holiday. From August 8th till August 26th the room has been sparsely booked and after that, it has been booked almost from 8:00-16:00 every working day until mid-October where it again has been populated more sparsely until Christmas. In January, the room has again been quite densely booked for written and oral student examinations.

2 RESULTS

The results have been summarized into three typical weeks of operation during Summertime, the "shouldering period" during October (in these cases mainly testing for the adiabatic cooling capabilities of the system) and Winter operation, where the heat recovery efficiency of the counter current heat exchanger in the system has been tested.

2.1 Summer operation of the system

In the plot below, results from a warm week from 21/7-27/7 in July are shown. During the week, a maximum cooling by the system of roughly 8°C was achieved on July 27th in the afternoon. The average cooling over the period, when cooling was relevant, can be found to be 3.6°C. Considering the warmest days from the 25th to the 27th only, the average cooling of the system is found to be 4.2°C. The wetbulb efficiency of the system was estimated to be between 90 and 96% during the period indicating that the injection system works quite efficiently.
Estimating the wetbulb efficiency, it was assumed that the absolute water content (the humidity



ratio) in the air is the same inside the room as outside the room. Since a steady-state operation can never be reached in a system like this with relatively high thermal mass capacity and direct solar radiation towards the room and the system, this figure involves a significant uncertainty. However, the absolute temperature measurements given in the above plot have been measured so here the only uncertainty is that of the used temperature sensors (expected to be in the order of +-1°C). The estimation was made using the software EES (Engineering Equation Solver) solving an EES equation set script similar to:

```
"!Calculation of indoor relative humidity based on inputs"
w_outdoor=humrat(AirH2O,T=T_outdoor,P=p_outdoor,R=RH_outdoor) {Absolute humidity of outdoor air, [kg/kg] }
T_dp=dewpoint(AirH2O,T=T_outdoor,P=p_outdoor,R=RH_outdoor) {Dewpoint based on measured outdoor conditions, [C] }
w_indoor=w_outdoor {This condition is valid when T_dp<T_indoor (no condensation), [C] }
RH_indoor=relhum(AirH2O,T=T_indoor,P=p_indoor,w=w_indoor) {Calculation of estimated indoor relative humidity, [-] }
T_wb_outdoor=wetbulb(AirH2O,T=T_outdoor,P=p_outdoor,w=w_outdoor) {Wetbulb temperature at outdoor conditions, [C] }
eta_wb=(T_outdoor-T_supply)/(T_outdoor-T_wb_outdoor) {Wetbulb efficiency, [-] }
```

It can been seen from the psychrometric chart below, that the humidity ratio at standard conditions at 31°C would correspond to ~ 0.012 kg water/kg dry air. This leads to a wetbulb temperature of approximately 21.3°C.

During this warm period, the lecture room was empty so it would be expected that the performance could be worsened slightly if students had been present in the room due to the expectance of a higher relative humidity in the room air.

July 2019 was particularly wet compared to the average year. The shown week is a week with no precipitation and thus relatively low relative humidity's. In the period from July 19th till 22nd, there was constantly precipitation showers while temperatures still exceeded the room temperature set point. It is clear that the cooling performance of the system in this period is significantly lower. The relative humidity is in this period close to 100% during the afternoons and the cooling performance is nearly zero. In these cases, it would be beneficial to control the unit so cooling is not applied, even if the outdoor temperature is a few degrees above the room temperature set point. A control system handling these situations should be developed in order to avoid redundant operation of the system.

{Maybe something about the heat recovery during the period}

{What was the average power of the system during the period?}

2.2 Operation in the "shouldering period"

Unfortunately, only limited periods where cooling has been applied is available in the months of September and October. It was originally the plan to install the system during the Winter of 2019 and it would have been interesting to include Spring-time operating. In September mainly due to outages and in October only a short period from 8th till the 10th October had outdoor temperatures exceeding the indoor temperature. From September 21st to 23rd, the adiabatic cooling system and water injection was in operation for shorter periods during the day. A maximum cooling of 3°C was seen September 21st at around 15:00 o'clock when the outdoor temperature was exceeding the indoor temperature. The relative humidity of the outdoor air was at this time ~ 70%. September 22nd, the maximum cooling was 2°C at approximately the same time and similar humidity conditions.

2.3 *Winter time operation of the system*

Regarding the heat recovery during Winter operation, the system generally shows temperature based heat recovery efficiencies in the order of a little below or slightly above 80% meeting the expectations. The system has typically, in the period, been operated at half of the nominal flow – i.e. 800 m^3/h.

2.4 *General observations made during the system operation and feedback from students and lecturers*

{Need feedback from users – perhaps more details on the number of persons in the room so we could check how that affects the indoor relative humidity}.

{Still processing some results illustrating the power usage of the adiabatic ventilation system compared to a traditional vapor compression air conditioning system}.

2.5 *Evaluation of uncertainties related to the measurements*

{Uncertainties related to the measurements – perhaps some tests of energy balances!}.
{Something on the effect of lacking steady-state operation}.
{The influence of the solar irradiation to the aggregate, pipes and the building}.

3 CONCLUSION

The system was found to meet the expectations during both Summer and Winter operation. During warm days, the system is on an average basis during dry weather conditions able to cool the incoming air by approximately 4°C and up to 8°C when the outdoor temperature exceeds 30°C and the relative humidity is sufficiently low.
During Winter operation, the system generally shows good heat recovery with efficiencies around 80%.
More studies should be performed during the shoulder periods and warm and wet periods with precipitation. And the tests show that the control algorithms could be improved to obtain less periods with redundant operation of the adiabatic cooling system.