NYDALEN VY: A NEARLY ZERO ENERGY BUILDING IN NORWEGIAN CLIMATE WITH NATURAL VENTILATION

Maria Myrup[1,*], Tor Helge Dokka[1], Jannick K. Roth[2], Michael Gruner[3], Maria Alonso[4]

[1]Skanska Norge, Oslo, Norway
[2]WindowMaster International A/S, Copenhagen, Denmark
[3]Pir II AS, Trondheim, Norway
[4]Sintef, Trondheim, Norway
[*]*Corresponding email: maria.myrup@skanska.no*

SUMMARY

Nydalen Vy will be a high-rise building in Nydalen in Oslo, Norway. The building will consist of restaurant and café in the lower 2 floors, 5 floors with office space and on top 10 apartment floors. The building is planned with only natural ventilation in the office floors and hybrid ventilation in the restaurant and the apartments. This paper investigates different solutions to avoid draft risk, especially in high occupancy meeting rooms which is the main challenge in natural ventilated office spaces. A solution with a specifically designed “climate canoe” for inlet air is proposed. Simulation and measurements indicate that this “canoe” should be placed on the interior walls with nearly uniform distributed holes, with a wall heating system below to oppose the down draft.

1 INTRODUCTION

The aim of this project is to reduce the technical installations to a minimum and produce more renewable energy during the year than used for ventilation, heating and cooling of the offices defined as “Triple Zero”. Renewable energy will be produced by building integrated PV.

To achieve this goal, a purely natural ventilation strategy for the office space has been developed. The heating and cooling system is based on a low exergy floor system based on geothermal energy system with heat pump and free cooling.

For cold Nordic climates there is almost no experience with pure natural ventilation in modern office buildings, therefore a lot of analysis, experiments and product development has been done. To validate the solution, especially to avoid draft problems in the coldest periods of the year (minus 15-20 °C), CFD-analysis, laboratory experiments and field experiments have been conducted.

This paper focus on the analysis and experiments made for natural ventilation for the office floors with special focus on meeting rooms. Because of the high occupational loads in meeting rooms a relatively high air flow rate is necessary to maintain good air quality in the meeting room. Therefore, there has been special focus on solutions to avoid draft from the inlet air in the coldest periods of the year. Different solutions to avoid draft has been tested out, among them a solution we call “the climate canoe” in various designs, which is described and tested in this paper.

2 METHODS

To design and validate the natural ventilation system for the meeting rooms especially to avoid drafts in the coldest periods of the year, CFD-analysis, laboratory experiments and field measurements have been conducted. A slightly different design of the “climate canoe”, see figure 1, has been tested in the field, in the lab and with CFD-analysis.

2.1 Field experiments

Field experiments were conducted in a 16 m² large meeting room at Ellingsrud school in Oslo. The room was occupied with 4 persons. The meeting room was ventilated with motor controlled high mounted windows in the room. The mechanical ventilation was shut down. A mockup of the "climate canoe" was constructed and mounted beneath the motor controlled windows. The "canoe" was mounted 60 cm down from the ceiling and 100 cm deep into the room from the façade, and given a curved shape as shown on figure 1. The "canoe" was perforated with 120 holes, each with a diameter of 20 mm. Air velocities and air temperatures were measured 0,6 meters from the façade in accordance with the conventional definition of the occupation zone (ISO7730, 2005). The measurements were done in the heights of 20, 90, 120, 170 and 180 cm above the floor. The air flow rate was estimated based on measured CO_2-consentration, based on a standard 20 l/h CO_2-production per person (EN15251, 2007) and a linear regression of the dilution equation.

Figure 1. Room at Ellingsrud school. Climate canoe mounted in the right picture.

2.2 Laboratory experiments

The steady-state experiments were conducted in a thermally insulated test room with inner dimensions of 7,0 x 3,0 x 2,4 m, with a cold "outdoor" section, and a warm "office" section with inner dimensions of 3,6 x 3,0 x 2,4 m. A partition wall, simulating the building facade, was made of 200 mm XPS (U-value 0,17 W/m²K). An area of 1,8 x 1,8 m of 30 mm XPS (U-value 0,93 W/m²K) represented a glazed façade. The opening was a bottom-hinged inward-opening window with clear opening of 900 x 470 mm (0,43 m²). The "Climate Canoe" was built as a light-weight structure of 4 mm bended plywood with sanded 45 holes of 20 mm diameter (total area 0,141 m²) in the upper third of the plywood.

The supply air temperature was kept at 6,8 °C and the mean room temperature at 25,8 °C, giving a temperature difference (inside-outside) of 19 K. For case C.3a+h, an electric heating foil with 220 W was mounted at the lower 60 cm over the entire width of the façade to reduce the sensed downdraught. Case 3.a was without wall heating, only floor heating.

Exhaust airflow rates were at 29 l/s, while supply airflow rate through vent and "Climate Canoe" was calculated to 23 l/s. Measurements without "Climate Canoe" resulted in a slightly higher supply airflow rate of 24 l/s. Measurements were carried out with hot-globe anemometers SensoAnemo 5100SF and thermocouples type T mounted at a pole that was moved during the measurements by the operator. In total, 42 (36 in case C.3a) measuring points at 10, 90, and 170 cm above the floor, in the center axis and 60 cm offset, at 10, 35, 60, 85, 110, 135 (not case C.3a), and 160 cm distance from the façade were evaluated. Each position was measured for at least 10 min with the operator keeping still in the back of the room, of which (the last) 5 min were used. In addition, temperatures were measured at 6 holes at different heights of the "Climate Canoe". Internal heating loads were assigned to 1 operator, and 3 laptops (total ca. 250 W) with AC adapters along the back wall of the room.

2.3 CFD

The simulations has been done for a real sized meeting room (in Nydalen Vy) with the size of 4,59 m x 6,78 m x 3,5 m (WxLxH). The room is placed with two exterior facades with an U-value of 0,14 W/m²K and with a window U-value of 0,65 W/m²K. For the simulations was used an external wind speed of 1 m/s, and an exhaust air rate of 194,4 m³/h. The room was set for 12 persons with a heat load of 90 W/person and an equipment load of 20 W/person (PC) and additional 200 W. Lighting was set for 4 W/m². For heating was used 20 W/m² for floor heating and the internal wall heating was modelled with a constant surface temperature of 23 °C. In contrast to the field- and laboratory experiments the Climate Canoe is placed on the internal walls with inlet into the Canoe via a hole of the size of 0,09 m^2 in the exterior facades. The reason for this is to reduce draft from the inlet air by the opposing the convective air flow from wall heating. The Climate Canoe is designed with evenly distributed holes (Ø20 mm). The layout of the Climate Canoe is shown in **Error! Reference source not found.**3.

The fluid flow analysis is performed in SOLIDWORKS Flow Simulation 2016. The standard K-epsilon (k-ε) turbulence model is used for the turbulence model in the CFD model. There are more than 400.000 cubic cells mainly located in the room.

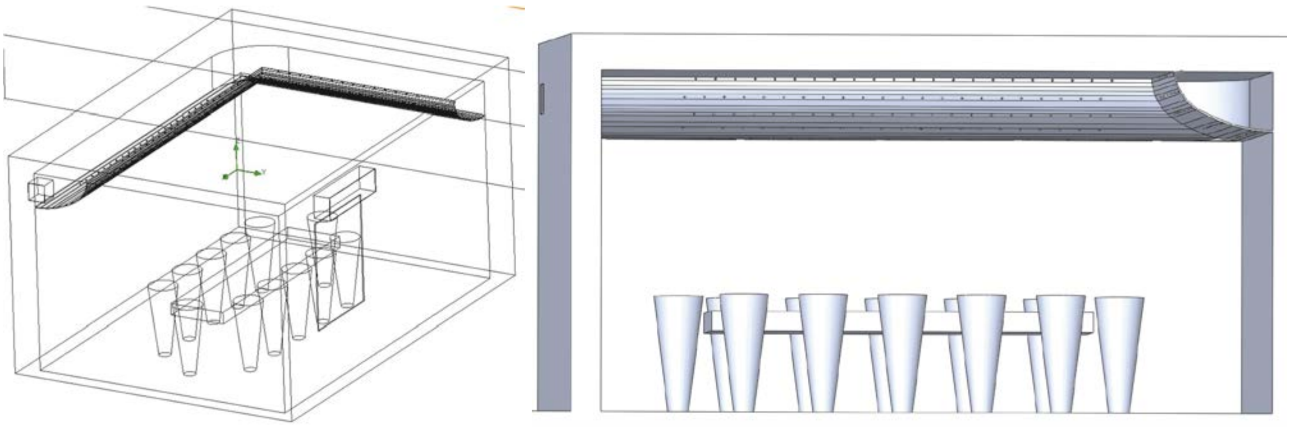

Figure 2: The meeting room used in the CFD-simulations.

3 RESULTS AND DISCUSSION

Since the size of the rooms, the boundary conditions, airflow rates and internal loads is different between the field test, the laboratory test and CFD-simulations, the results can't directly be compared. However, other CFD-simulation has been compared to laboratory experiments to validate the CFD-model with good results (results not shown in this paper).

3.1 Field experiments

Based on linear regression of the measured CO_2-level and the assumptions of full mixing, the natural air flow rate was estimated to be approximately 86 m^3/h, or ca. 6 l/s per person. The average outdoor temperature during the experiment was -8 °C with a measured wind speed of 2-3 m/s. Figure 4 shows the measured air velocities, and calculated draft rate based on ISO7730. The results seems promising with rather low velocities in the occupation zone, but with a somewhat higher velocities close to the "canoe" surface. The measured draft rate (DR) in the seated occupied zone (0-1,2 meter above the floor) is well below the normal requirement of 20 % (EN 15251:2007) nearly all the time, except a few outliers in the start of the test. The test was running for approximately 40 minutes.

However, the person densities (4 m²/person) and hence the air flow rates per m² is somewhat lower than expected in Nydalen Vy, and in addition the outdoor temperatures for design winter conditions will be lower (-20 °C) than during the experiment.

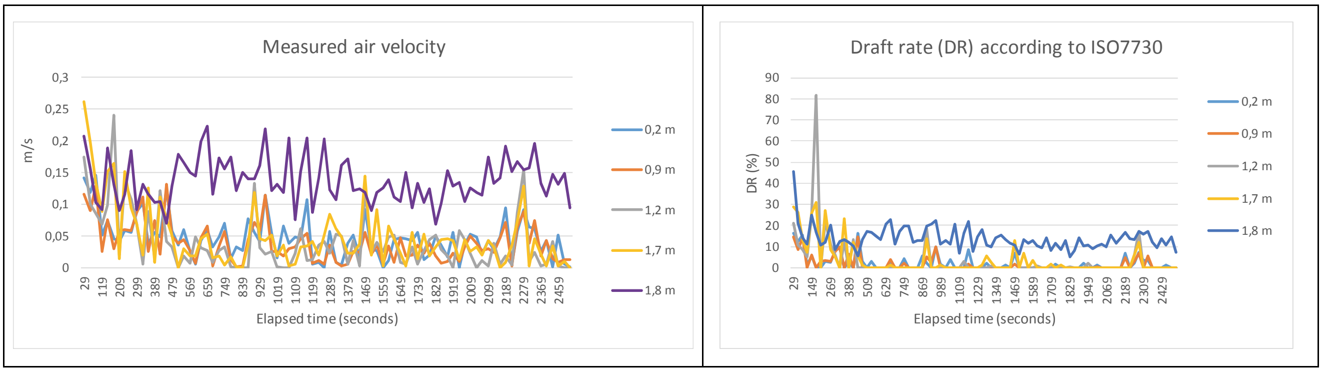

Figure 4. Measured air velocities and draft rate (DR) at different heights above floor (0,2 m, 0,9 m, 1,2 m, 1,7 m, 1,8 m)

3.2 Laboratory experiments

Temperature measurements show that the “Climate Canoe” elevates the supply air temperature by ca. 5-7 °C compared to the temperature entering the canoe. Measured air temperatures in the room were otherwise not less than 1,5 K lower than the temperature in the center point of the room.

Figure 34 summarizes the measured air velocities for the two cases. Figure 45 shows qualitative visualizations of the flow patterns, revealed by smoke tests and the measured velocities.

	_10	_35	_60	_85	_110	_135	_160
V.10	0,09	0,06	0,13	0,19	0,06		0,07
V.4	0,16	0,22	0,12	0,08	0,06		0,09
V.1	0,09	0,12	0,20	0,23	0,24		0,21
V.8	0,10	0,11	0,13	0,32	0,08		0,07
V.7	0,10	0,12	0,15	0,19	0,07		0,06
V.3	0,15	0,15	0,18	0,19	0,21		0,22

Case C.3a

	_10	_35	_60	_85	_110	_135	_160
V.10	0,13	0,13	0,13	0,15	0,25	0,08	0,06
V.4	0,17	0,10	0,09	0,19	0,31	0,25	0,15
V.1	0,12	0,14	0,11	0,15	0,15	0,16	0,16
V.8	0,13	0,14	0,11	0,13	0,31	0,15	0,07
V.7	0,18	0,14	0,07	0,16	0,22	0,27	0,19
V.3	0,08	0,10	0,11	0,13	0,14	0,14	0,15

Case C.3a+h

Figure 3. Measured air velocities at measuring points V.1, V.4, V.10 are 10, 90, 160 cm above the floor in the center axis of the room. V.3, V.7, V.8 are the measuring points 60 cm offset the center axis (resp. 10, 90 and 160 cm above floor). The top row gives the measuring distance from the façade (10-160 cm from the façade). Case C.3a – without heating foil under the window. Case C.3a+h with heating foil under the window.

Both cases show a distinctive flow pattern. In case C.3a, velocities are highest directly under the “Climate Canoe”, a small distance from the façade and at the floor. In case C.3a+h, air velocities are elevated under the “Climate Canoe”, while velocities at the flor decrease. However, the velocities at neck height (90 cm above floor) increases, and is too high compared to normal requirements.

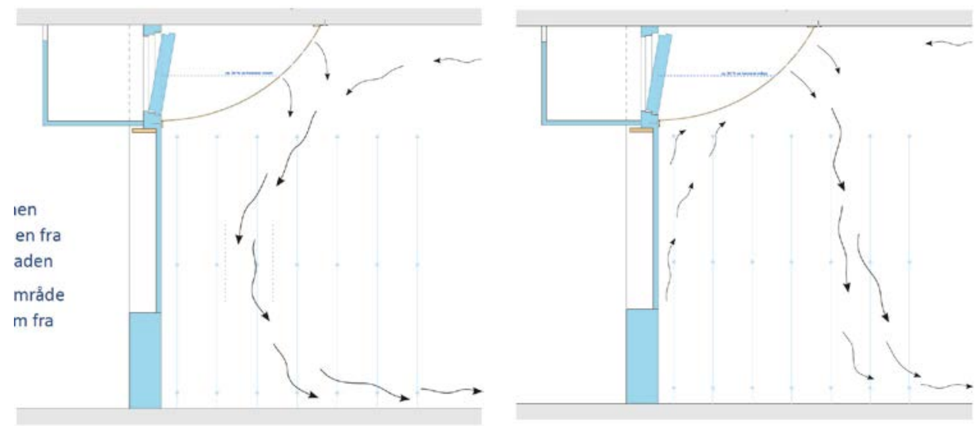

Figure 4. Flow pattern, revealed by smoke test. To the left Case C.3a, to the right Case C.3a+h.

In case C.3a, supply air leaves the "Climate Canoe" primarily at the lower holes (see points approx. 85 cm from the façade). In the center axis of the room, air is drawn to the façade and flows downward at approx. 40-70 cm from the façade

In case C.3a+h, the heating foil affects the flow pattern compared to case C.3a. Warm air rises upwards along the façade and along the canoe, preventing air from the canoe to flow towards the façade. Instead, airflow is deflected at a trajectory downward into the room, counteracting the airflow from the back of the room towards the façade. The effect of the heating foil is similar, both in the center axis of the room and beside it.

Based on this experiments it seems like the wall heating to some degree works, but more deflects than oppose the air flow from the canoe with the distribution of the holes tested here. A more uniform distribution of the holes in the canoe would probably lead to the downward air flow opposes the upward convective flow from the wall heating more directly, and could possibly lead to lower air velocities in the occupied zone. This indication have been used in the design of the CFD-simulation in the next section, with nearly uniform hole distribution and wall heating below the canoe.

For the laboratory tests the draught rate (DR) has not been calculated. The laboratory tests was made with a mean room temperature of 25,8 °C due to get high dT (indoor/out), while the real room temperature in Nydalen Vy will be about 20-21 °C. The calculated DR for an indoor temperature of about 26 °C will therefore not be realistic or relevant.

3.3 CFD

The results of the air velocity, in the middle of the room is shown in figure 6. Other section in the room gives similar results, but section close to the inlet in the façade gives somewhat higher velocities. The result shows that the temperature distribution in the room, despite of a supply air temperature of -15 °C, was good. The main challenge was the air velocity which was the main factor with regard to risk of draft. Therefore, the main focus was pointed towards reducing the air velocity in the room. The results shows that near the occupant's feet (10 cm above the floor) a temperature of 19,2 °C could be measured along with an air velocity of 0,146 m/s. This gives a draught rate (DR) of 14,6 %, assuming a local turbulence intensity (Tu) of 20 %. (Tu = 40% gives an DR = 18,3 %). This is well below the normal requirement of DR = 20 % (EN15251).

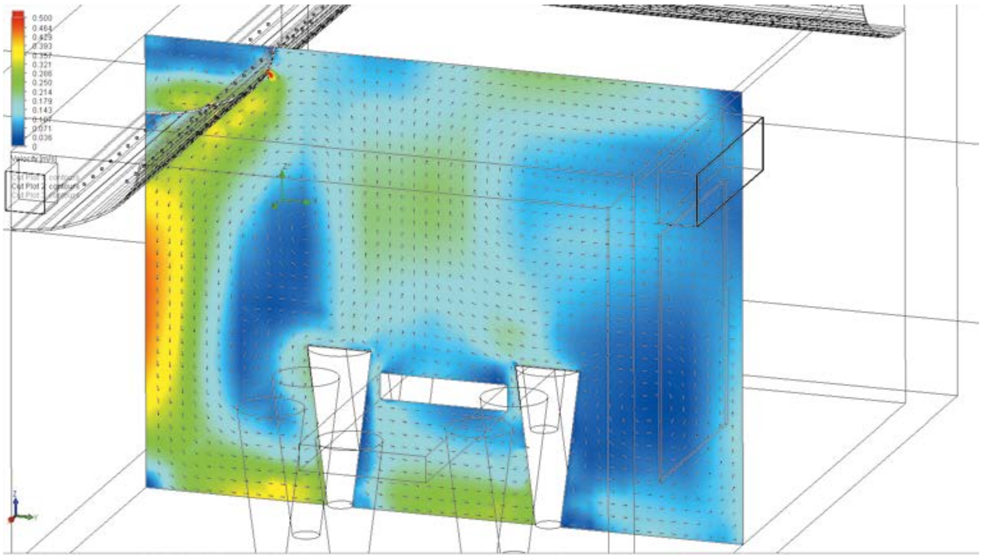

Figure 6. Air velocity plot from the CFD simulations.

4 CONCLUSIONS

Based on the field tests, laboratory experiments and the CFD-simulation the following conclusions can be drawn:

- Pure natural ventilation in modern office buildings in cold Norwegian climate, even in high occupancy meeting rooms, seems to be possible with the right design measures.
- A specifically designed "climate canoe" can to some degree passively preheat the inlet air and reduce the inlet air velocities.
- But to achieve normally allowed air velocities in the occupied zone, a solution with the canoe on the interior walls with wall heating below seems to give the best and most robust result.

Before this natural ventilation solution is implemented in the Nydalen Vy project, a parametric hole distribution design will be carried out, and a few more CFD sensitivity analysis will be conducted. A full scale on-site test of the meeting room is also planned during the construction phase.

REFERENCES

SOLIDWORKS Flow Simulation 2016 (http://www.solidworks.com/sw/products/simulation/computational-fluid-dynamics.htm)

ISO7730:2205 Ergonomics of the thermal environment – Analytical determination and interpretation of thermal comfort using calculation of the PMV and PPD indices and local thermal comfort criteria

EN 15251:2007 Indoor environmental input parameters for design and assessment of energy performance of buildings- addressing indoor air quality, thermal environment, lighting and acoustics.