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"Near-to-Zero-Energy Floor" in a Campus Building from 1971

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Abstract

In 2013, a campus building in Prague, built more than 40 years ago, was partially refurbished. Its old curtain wall with very poor performance was completely removed and replaced by a new element façade of significantly higher quality, which meets today's recommendations concerning the energy efficiency. The comfort requirement was satisfied partially – the effect of overheating was almost entirely eliminated without the need of mechanical cooling. It was still necessary to improve the quality of ventilation. Therefore, a study on the possibility and effects of installing an additional ventilation system was conducted. As a pilot project, a complex solution of one selected floor was implemented. This solution is described and commented upon in this paper.

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1. Building description

The building has a form of a simple cuboid with 15 floors; it was finished in 1971. The majority of offices are oriented to the southwest façade. Seminar rooms and meeting rooms are situated predominantly on the opposite side (northeast). In the middle section of the building we can find service rooms (restrooms, kitchenette, storage space, archive, etc.). Construction consists of monolithic reinforced-concrete skeleton with reinforced concrete ceilings without a suspended ceiling, non-load bearing building envelope of a panel type [1].

This building is used for various purposes and its occupancy highly fluctuates. Normally, the number of persons on one floor varies from nearly zero to around 120 people, when all lessons are being conducted. It must also be taken into account that during the periods without tuition the use of the building is even more intermittent (exams or

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single events). This applies also to the period from January until mid-February, i.e. the period characterized by the lowest outside temperatures. Also during high summer, the building is used only to a small extent.

The construction of the building used a curtain wall which corresponds to existing requirements and the state of the technology. Probably due to high investment costs, the originally planned mechanical ventilation and cooling of the building were not installed. Ever since the building has been in use, problems with overheating and high-energy consumption have been reported. During the retrofit, the old elements were completely removed. The new element façade (Fig.1) has significantly lower thermal transmittance. Motor-operated and locally/centrally controlled venetian blinds are integrated into the southwest elements. Manually operated interior venetian blinds are installed on all windows on both main facades.

Figure 1: Retrofit of the campus building (2013). Left: dismounting of original curtain wall from 1971 (overall U-value approx.3.0 W/(m^{2}K). Right: New curtain wall, triple glazing, venetian blinds motor controlled, overall U-value 0.7 W/m^{2}K), fenestration ratio 60 %

2. Technical data and basic discussion about energy performance

Generally, the fundamental change in the quality of the building envelope implies necessary changes in the heating system and ventilation of the building, otherwise the optimal operation and indoor quality cannot be reached. Table 1 presents the results of indicative calculation of heat losses and heat gains for a typical floor in the building during the heating season. The results of this calculation are always subject to uncertainty associated with highly variable occupancy of the building; it is possible to make only rough estimates of heat gains generated by office equipment, as well as of the volumetric flow rate of ventilation air. It is also evident that even at very cold external air temperatures, internal heat gains (metabolic heat and office equipment) in daytime are significant. On the other hand, passive solar gains are generally low during this period. They are influenced by a low-intensity solar radiation and by the use of the glazing (low g-value) designed to prevent the risk of overheating in summer.

Table 2 illustrates theoretical external air temperature, above which there is no need to use conventional heating (at this temperature, heat gains and heat losses are balanced). Such temperature is surprisingly low, especially due to higher occupancy and the use of heat recovery in the mechanical ventilation system (if applied). At lower ventilation rates (B, D in Table 2), this threshold temperature could be even lower, but in such cases comfort requirements would not be satisfied.

Table 1. Simplified estimation of specific heat losses for one floor, comparison of the original and new solution

	Original state	New state (2013)	Difference [%]
Specific transmission heat loss HT [W/K]	1364	360	-74
Specific ventilation heat loss HV [W/K] at full occupancy (120 person)	550	550	0
Total specific heat loss H [W/K]	1914	910	- 53
Heating load at winter design temperature (-13 °C for Prague) [kW]	65.1	30.9	- 53
Estimated heat gains caused by persons and office equipment (90 students + 30 members of the staff) [kW]	14	14	0

Table 2. Selected theoretical operational mode and rough estimate of the limiting temperature of the external air for heating off

	Number of persons per floor	Ventilation rate [m3/(h.pers.)]	Limiting temperature for heating (heating system no more in use) [°C]	
			No heat recovery from the exhaust air	With heat recovery 70 % (in brackets: use of waste heat from server room)
A	120	25	+6	-6 (-13)
B	120	12.5 [1)]	-1	not applicable
C	60	25	+10	+5 (-8)
D	60	12.5 [1)]	+6	not applicable
E	30	25	--	+12 (-3)
F	0	0	--	-- (+4)

[1)] Estimation for insufficient natural ventilation, often even worse in reality.

3. Mechanical ventilation

The retrofit is based on a solution which uses a central air-handling unit for one floor (Fig.2). Air is drawn in through the blinds on the northwest gable wall in the corridor area, the exhaust air is blown out in a similar way through the southwest gable wall. The air-handling unit is placed under the toilet ceiling. The main duct is located under the ceiling in the hallway on the side of the classrooms (mostly hidden in a suspended ceiling), partly under the ceiling in the classrooms (hidden in the plasterboard construction). In the corridors, the ducts are visible (Fig. 3). Distribution elements in the classrooms are made of textile and are suspended under the ceiling. The air-handling system includes large silencers. The heat for the ventilation air is gained through efficient recovery of the heat from the exhaust air (declared minimum efficiency 86 %) and heating using the waste heat from the server room (approx. 12 kW). It is a separate circuit with a coolant: the server room houses normal external cooling unit which is connected in a reverse mode. For reasons of safety and given the fact that the anticipated demand for the waste heat would probably be limited to periods with very low outdoor temperatures, no changes were made in the cooling system which had already been installed in this room.

The dimensions of the ventilation system are such that for each classroom, the maximum volume of fresh air every hour is expected to be 400 - 500 m^3, while in offices the consumption of 30 m^3 of fresh air per person is expected. The maximum power of the air-handling unit is set at 3 100 m^3/h. The operation is controlled using a system of automatic or manual regulation. Each classroom has its own CO_2 sensor and manual control of ventilation. In the automatic mode, the necessary volume of ventilation air is set according to the values from the CO_2 sensor or on the basis of a superior request. Each classroom is controlled individually and in the equal-pressure ventilation mode. The system uses electronic control elements, ensuring synchronic setting of flaps on the air intake and air exhaust. The information about the flap setting is transmitted to the control computer of the air-handling unit and the unit may thus to a great extent adjust its performance. Ventilation of offices (maximum volume of 500 m^3 per hour for the whole zone) is controlled manually from a single point, or automatically, only on the basis of the time schedule and the set volume of the ventilation air. Operation data and the software for adjusting the ventilation are accessible remotely to the user; it is also possible for the system supplier to access them remotely for the purpose of control and maintenance.

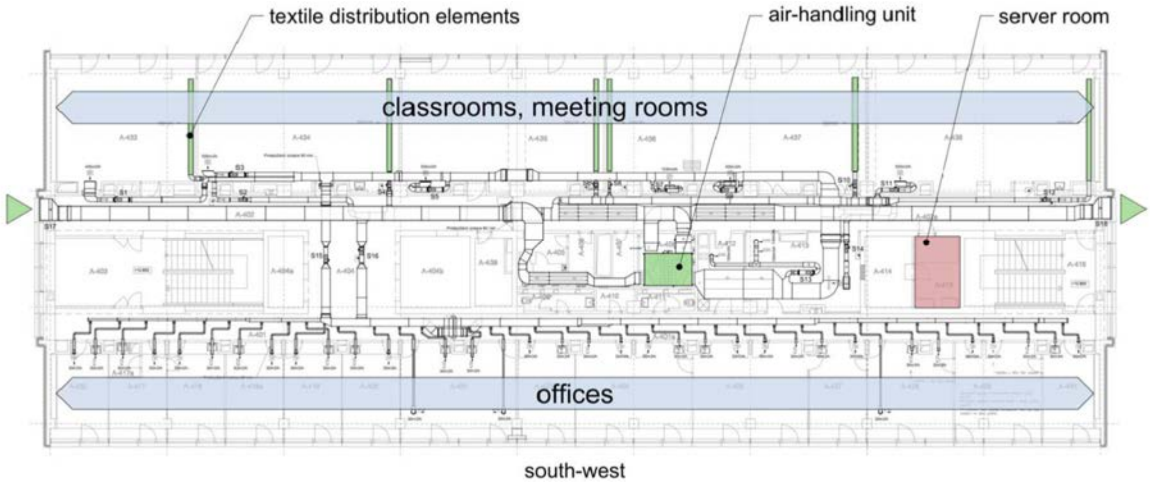

Figure 2 Scheme of mechanical ventilation in one floor

Figure 3 Complicated installation work (ceiling in corridor area, not finished)

3.1. Technical limitations of the installation

The design and realization were very complicated due to space limitations and because of the need to meet the requirements concerning the fire safety of this tall building (ducts passing through fire zones and through protected escape routes via stairs and elevator). In total, there are 8 fire dampers with servomotors. The air-handling unit with floor-plan dimensions of 2.4 m x 1.6 m is only slightly smaller than the floor-plan dimensions of the room in which it is installed under the ceiling (2.7 m x 2.7 m).

3.2. First experience and observations

Since November 2014 series of measurements was started. An initial test using a tracer gas method was performed which monitored the decrease of the concentration of carbon dioxide in periods when the windows were open, as well as in periods when the air-handing unit was in use (Fig. 4). Real situation without proper ventilation is presented in Figure 5 for illustration: small lecture room with the capacity for 43 persons with the volume of air of 193 m^3 only.

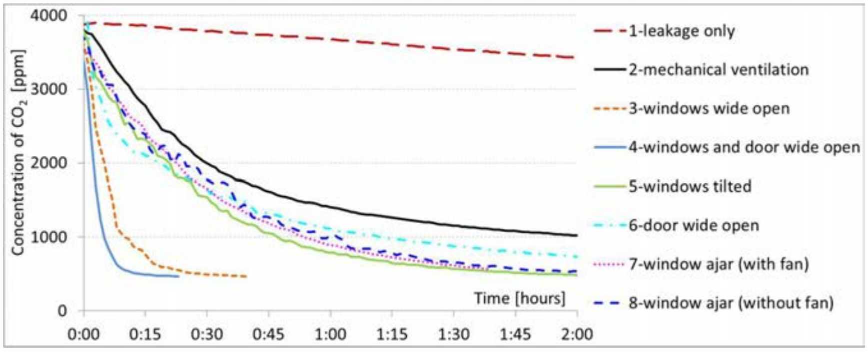

Figure 4 Tracer gas test (decrease of carbon dioxide concentration) in one classroom (1 – infiltration only through leakage (windows and door closed, mechanical ventilation off), 2 – mechanical ventilation was running at its default regime according to CO_2 concentration (windows and door closed), 3 – all four windows were wide open, 4 – all windows and door were wide open, 5 – two windows at opposite sides of the classroom were tilted, 6 – door were wide open while all windows were closed, 7 – one of the middle windows was mildly open and a fan was used to mix the air in the classroom, 8 – ditto 7 but without fan)

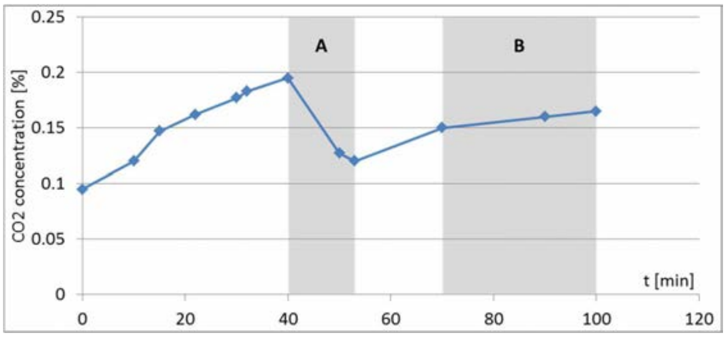

Figure 5 Carbon dioxide concentration during 100 minutes lecture in one small lecture room without mechanical ventilation (30 person present, windows and door closed, A – two windows fully opened for 10 minutes, B – one window in tilted position)

For practical reasons, the CO_2 sensors in classrooms are not installed in their optimum positions in many cases. However, by setting the system individually on the basis of experience, it is possible to set individually a distinct relationship between the voltage signal from the sensor and ventilation requirements within the control system.

3.3. Summer operation

Mechanical cooling is no longer considered necessary and appropriate. Passive solar gains are efficiently reduced through locally and centrally controlled exterior blinds. The metabolic heat load in summer months is rather low (it is the period without tuition and holidays). Ventilation using the outdoor untreated air with increased intensity at night should be sufficient. The positive effect of night ventilation is supported by considerable thermal inertia of the building. However, the experience gained in the neighbouring buildings confirms rather limited possibilities of night ventilation: it is prevented by the location of buildings in a dense urban area.

4. Energy

Energy intensity has not been analysed in a more detailed way yet. In the air-handling system this question concerns only the auxiliary energy used for driving the fans. The only source of heat for reheating the air is the circuit which uses the waste heat from the server room. Given the fact that during this winter until the end of January no extremely low air temperatures were recorded, this source of heat was not used at all in the period concerned. In this context it should be mentioned that a minor lacking portion of energy on this floor can be drawn "parasitically" from heat flows from adjoining floors – exploiting the heat transfer through horizontal structures and airflow through vertical connections.

5. Discussion and concluding remarks

The system has been in operation since November 2014 and we have been gradually gaining practical experience. The solution described in this paper, which was installed additionally after the replacement of the building envelope, is certainly not an optimal one. All aspects of the building concept should always be addressed simultaneously, even if individual steps should be taken gradually due to limited financial resources. In this case, it was not possible to use decentralized ventilation systems in individual classrooms, as no additional intervention into the new building envelope is possible. The implemented solution will be the subject to further long-term monitoring and experiments [4]. Its further modifications will be proposed (controlled setting of heat-source priorities: waste heat will be preferred to the heat of traditional heating bodies).

Such solution can be (in modifications) gradually implemented on other floors of the building, in some cases only on the side with classrooms and smaller lecture rooms. The situation here is becoming more critical compared to large lecture halls, where both designers and investors feel that air-conditioning is necessary.

In the upper floors of the building further approx. 90 kW of heat is available from server rooms. Waste heat could also be used. Therefore, cooling would not result in additional energy demands and environmental burden.

The system of mechanical ventilation with heat recovery installed in one floor is also used as an example to teach future building designers. The design drawings are shown on the notice board, the visible elements are labelled. Students will thus have a better picture of the real dimensions of the installation as well as of the complexity of problems. The operation data is available on a remote PC desktop and it will also be available for teaching purposes.

It is pointless to assess the economic return before the benefits of ensuring a satisfactory internal environment have been financially expressed.

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