AUTOMATIC NATURAL VENTILATION IN LARGE SPACES: A PASSIVE VENTILATION TECHNOLOGY FOR PASSIVE BUILDINGS.

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ABSTRACT

For zero and low energy buildings, high-energy efficiency ventilation is very often confused with a complex mechanical ventilation system with heat recovery. In school gymnasiums, where large volumes have to be ventilated, and where intermittent occupation is very usual, demand controlled natural ventilation has several advantages, making this technique very attractive. High stack height makes natural ventilation very efficient, limiting the necessary number and dimensions of windows. Large air volume, with high height, combined with intermittent occupation, avoids high pollutant concentrations, especially in the occupied zone, because of air stratification, with fresh air near the floor and pollutants/heat on the ceiling. High stack effect, offers free ventilation all over the year. Natural ventilation is very attractive for architects because of no ducts, no apparent mechanical components, and low cost

The article shows the ventilation concept of two gymnasiums, one equipped with demand controlled / summer comfort controlled natural ventilation and the other with a hybrid ventilation system with heat recovery. The monitoring of the naturally ventilated gymnasium results shows the perfect air quality that natural ventilation offers in this type of buildings in winter and summer. Simulations comparing a fully mechanically ventilated hall with a hybrid one and with a purely naturally ventilated hall show the energy performance of the different systems. A life cycle assessment shows that controlled natural ventilation has comparable and even better performances than a heat recovery system. Zero electricity for ventilation all over the year, and no embodied energy for ventilation compensate non-recovered heat.

KEYWORDS

natural ventilation, ventilative cooling, demand-controlled ventilation, passive cooling.

1 INTRODUCTION

Natural ventilation was assimilated in the beginnings of the passive and zero energy trend to high-energy consumption, lack of ventilation control and lack of comfort. For some energy labels, natural ventilation is allowed only under very strict control, automatic window opening in every space for example (like Minergie®). Some energy labels developed in cold countries are extended in southern countries, where intermitted heating and cooling is needed, without reconsidering the ventilation strategies according to the local needs and energy rationality, and they impose mechanical ventilation with heat recovery, just because heat recovery is part of the label (like passivhaus). Energy regulations in southern countries based on EPBD give credits to heat recovery and penalties to natural ventilation (like Cyprus eppd), while recovered primary energy in mild climates is much less than electricity to run a mechanical system (Flourentzou 2013).

New challenges for zero energy buildings, with higher cooling needs in highly insulated and air tight buildings are identified by IEA annexe 62, oblige us to reconsider natural ventilation. High ventilation rates, needed to evacuate undesired heat, make natural ventilation an interesting strategy for a global energy performance. But controlled natural ventilation may be an interesting technique with a very positive global environmental balance even in winter (Flourentzou 2013, Flourentzou 2015) because it has no embodied energy and no electricity consumption to move the air.

Natural ventilation limits are not energy related because the energy balance is globally positive. It will be shown again in this article in chapter 3. Natural ventilation limits are mainly related to ventilation control and thermal comfort. In chapter 2 we will show how smart design may manage control and comfort risks in a large space (gym in a primary school). The first year monitoring shows that controlled natural ventilation may offer perfect air quality and perfect summer and winter comfort, even for difficult occupation schedules with occupation varying between 30 and 200 children.

In chapter 3 we compare a life cycle assessment of purely natural ventilation with hybrid and purely mechanical system.

2 DESIGN OF A NATURALLY VENTILATED GYM

2.1 Architectural constraints and characteristics.

Figure 1. Two joint volumes compose the building. On the left of the picture we can see the gym and on the right the classrooms. The pure line of the building is an architectural wish in the macro scale, to guarantee the wished "monolithic" form in dialogue with the alpine environment and the traditional village urban surroundings.

“Commune de Savièse” organised an architectural contest to build a small 10-classroom building with a gym. *rk studio* proposal got the first price, with a particular unified volume, as a response to the need to integrate a contemporary modern building in a traditional preserved Wallis mountain village on the Alps. The pure line of the form impose several serious constrains on natural ventilation design. The building was first designed as a typical passive building, intended to get a Minergie® label, with two distinct bidirectional ventilation systems, with heat recovery, one for the classrooms and one for the gym. The gym was designed as a closed mechanically ventilated volume and the classrooms had some windows that could open. From the outside the building is in dialogue with its alpine environment, through the pure line of its form, but also from the inside, through the pure form of glazed openings, framing unique fragments of landscape.

Figure 2. The pure line is a desired characteristic also in the micro scale, with construction details offering pure openings to frame landscape from the inside, without obstructions.

The architectural language of the prized project was in coherence with a closed mechanically ventilated building of the initial ventilation strategy. Windows did not have any functional use. However, very soon in the design phase, technical installation high cost became a limit to the project, and the necessary ducts, to bring 6000 m^3/h of air in the gym space, necessary to ventilate up to 200 children in a school cantina, integrated to this space, was a cumbersome element, in opposition to the building’s pure line.

Cost analysis of different solutions and architectural advantages, like duct integration and room savings for installations, motivated the design team to choose purely natural ventilation for the gym and mechanical ventilation only for the classrooms and offices. The cost of the mechanical ventilation system of 2000 m^3/h was around 100’000 CHF, and the duct diameter was 2 X 75 cm for the fresh air and 2 X 75 for the exhaust. Natural ventilation does not represent any extra cost, because the 4 m^2 of necessary openings on the top and bottom of the space are required by fire protection regulations, related to smoke evacuation. The difficulty of natural ventilation is to find a way to integrate architecturally large openings, necessary to create a stack effect of 6000 m^3/h.

Figure 3. The design trick, to respect the architect wish for pure glazed openings was to dissociate air path from light path. On the picture we may see an opaque opening on the top of the space, guaranteeing evacuation of hot air on the top of the space and avoiding the creation of a hot buffer in the roof triangle. Glazing on the bottom offers only light and view.

Figure 4. On the left picture, we can see the building as it was on the architectural contest poster. On the right as it was realised. The only difference is the opaque windows that we may guess on the top of every triangular roof of the gym on the right picture.

2.2 Window position and dimensioning of air path and flow rate

During summer ventilation, fresh air enters from the basement as it is shown on figure 5 and leaves the building from the top openings as it is shown in figure 6. Summer ventilation is controlled according to inside and outside temperature. When inside temperature is higher than 18°C and outside temperature is smaller than inside temperature, bottom and top openings open. Ventilation stops when inside temperature falls < 18°C or when there is strong rain or strong wind.

During winter, air enters from the lateral top openings, which are positioned lower than the top front opening in order to avoid cold draughts. When CO2 concentration > 1000 ppm, top openings open 10%. Openings are closed when CO2 < 600 ppm.

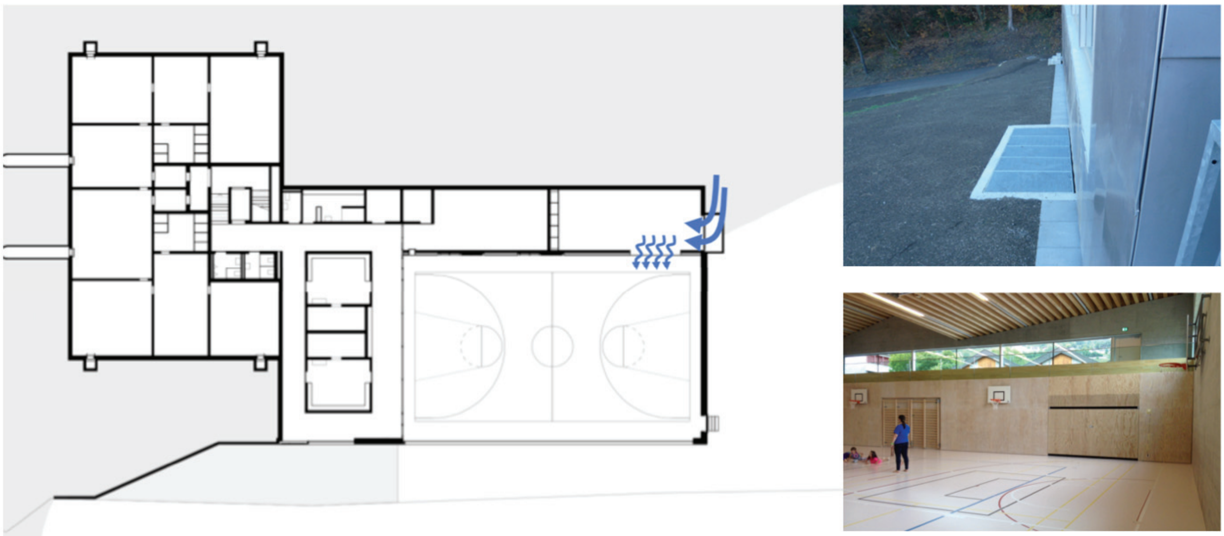


Figure 5. A bottom 4 m² opening brings fresh air in the basement from a light/ventilation well in the sport equipment storing room. Air enters through two automatic windows and passes through the perforated door that we can see on the bottom right picture.

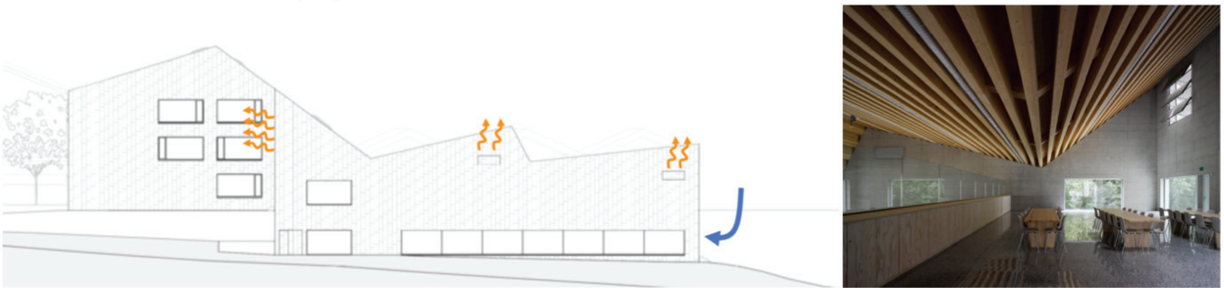


Figure 6. A top 4 m² opening exhausts air on the top of the cantina space on the gym situated on the gym balcony (as it is seen on the right picture) and 2 additional 1m² openings as they are seen on figure 3 allow additional better distribution of air evacuation. On this figure we can see the night ventilation summer strategy with fresh air entering on the basement and going out from the top openings.

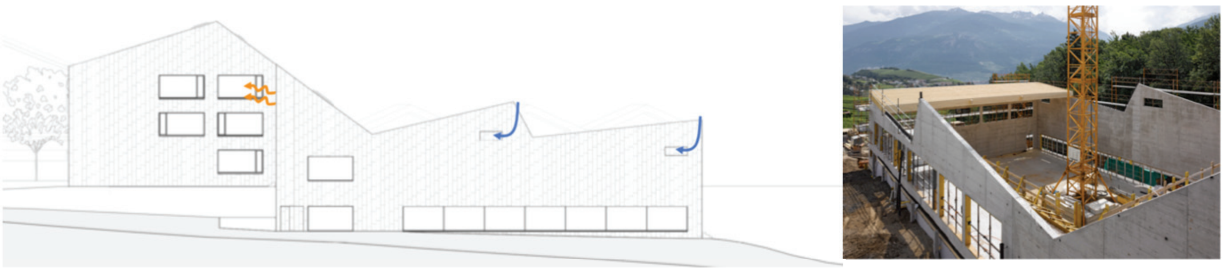


Figure 7. For winter natural ventilation strategy, air enters from the top lateral openings and goes out from the top front opening in order to avoid cold draughts. Cold air entering at 8 m height, is mixed with hot air until it falls to the floor. Users have not reported any cold draughts in the first year use of the gym.

We have simulated natural ventilation airflow with DIAL+ software (Paule 2004) to dimension the openings in order to guarantee enough night ventilation for free cooling of the building. The position of the openings is intended. The bottom opening position in the storing room activates the concrete thermal mass of this extra space and stores coolness during night. It avoids also cold draughts because event in summer there are fresh days that might create cold draughts. The passage of the air through a perforated wooden door makes airflow laminar and well distributed. Positioning of the automatic window in the storing room prevents children to play with it. Extra protection grid for the inside prevents children to access the automatic openings and from outside against rain.
Top openings assure that there is not creation of hot air buffer in the roof triangles. The big exhaust opening position on the opposite side of the air inlet assures swiping the whole space with fresh air. It is positioned on the top of the cantina space to allow direct pollution evacuation where the higher human concentration takes place.

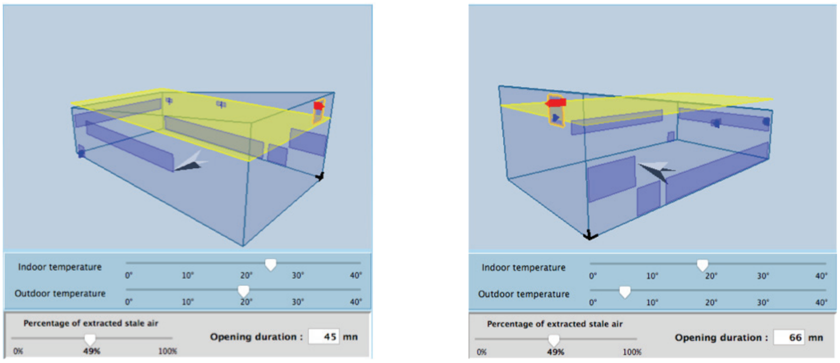


Figure 8. DIAL+ simulations to dimension window openings. In the left image we can see summer ventilation with 7'278 m^3/h entering from the bottom opening and 2 lower top openings under the neutral level at 9.34 m when $\Delta T_{in\text{-}out} = 5°C$. On the right picture, we can see winter ventilation strategy with the neutral level in the middle of the top opening at 10.4m with 2094 m3/h exhaust air and 422 m3/h inlet air from the same opening and 1077m^3/h + 1406 m^3/h from the lateral top openings under the neutral level.

As we can see from figure 8, control of the neutral level is essential to elaborate a ventilation strategy, because it determines where fresh air enters and where exhausted air is evacuated from the building. We see from the DIAL+ images than in summer, the main mass of inlet air enters from the bottom opening while during the winter strategy it enters from the 3 top openings. Fixing the in and out temperature in the software we can have the orders of magnitudes of the airflow rate, but detailed dynamic simulations with a coupled air/heat model determine if the airflow rate is enough, especially for the cooling strategy.

The initial intentions were to avoid solar control and there was no night ventilation strategy. Dynamic simulations showed (figure 8) showed that night ventilation and solar control is essential for the building comfort.

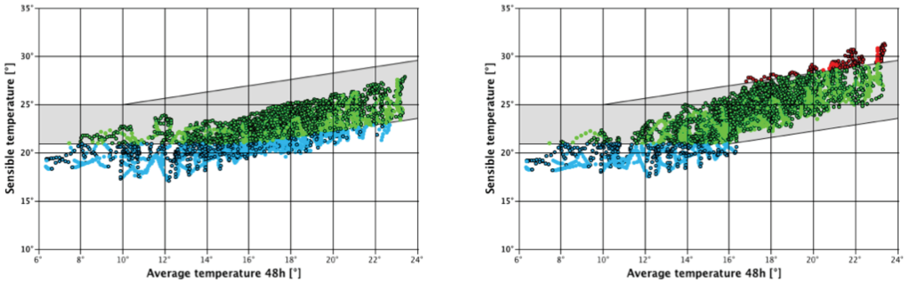


Figure 9. DIAL+ dynamic simulations for summer comfort. In the left image we can see the building behaviour with good solar control and night ventilation strategy 2-3°C under the upper comfort limit of EN 15251 norm. On the right graph, with ventilation only during working hours and no solar control, the building does not comply with the minimum comfort conditions of the norm.

2.3 Results of one year monitoring.

From figure 8 we can see that CO2 concentration never passes over 1100 ppm offering a perfect air quality. This graph was produced during the first 2 months of operation. After that the CO2 threshold for window opening was slightly reduced from 1000 ppm to 900 ppm and an extra opening was planned every working day at 6:00 am for 15 minutes to assure new fresh air every working morning. As we see during 8th and 9th of November, air infiltration assures only half air change day (CO2 concentration falls to 400 ppm after 48 hours).

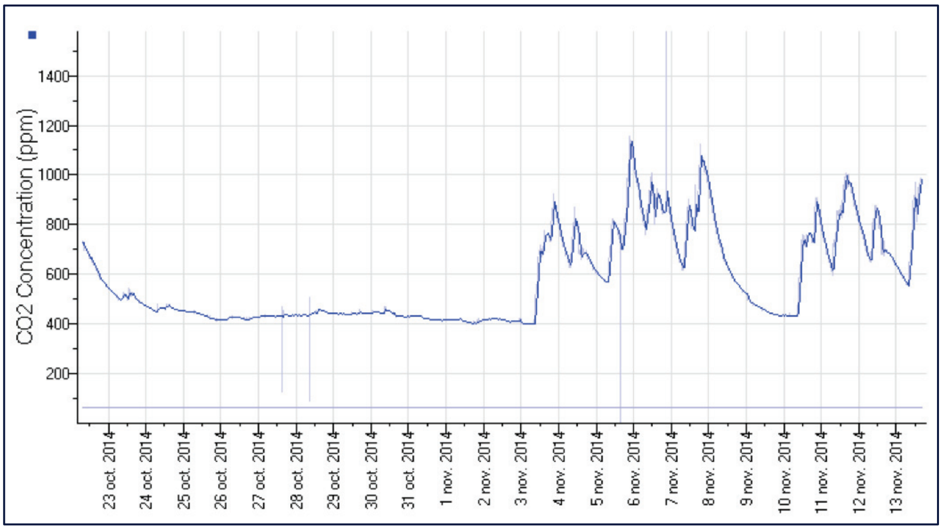


Figure 10. CO2 concentration during the wintertime. From Oct. 23 to Nov. 3 it was a holiday period and 8 & 9 Nov was a weekend.

As we see from the results, a reasonable and controlled infiltration is not "the enemy of energy performance". On the contrary, it offers energy-free controlled ventilation during not working hours of ~1 air change per day. Demand control ventilation limits airflow to the strict minimum. From the graph we may deduce analysing CO2 decays that during the time where the space is occupied with ~40 children, the room is ventilated with 750-850 m^3/h in the month of November and when the space is not occupied with 120-420 m^3/h (mean of 240 m^3/h) of infiltration. From the CO2 decay analysis, we deduce that real occupation is much less than the nominal norm schedule for dimensionning. Less people occupy the space during less time. A demand control strategy is the best solution to transform this reality into energy savings. In this case, although 240 m^3/h of mean infiltration corresponds to $n_{50}<0.5$, the fact that there is a huge volume as fresh air reservoir, infiltration is almost sufficient to provide good air quality. CO2 concentration rises over 1000 ppm only after 15h:00 and openings are open only for few hours to complete ventilation.

The temperature monitoring for summer comfort covered the period of summer 2015, where high temperatures occurred even in the alpine regions. We tested one week without applying night ventilative cooling (10-17 July) and one week applying ventilative cooling (18-25 July). Although during this period the gym is closed without any occupation, we can see that only with solar gains, and although solar shading is automatic, air temperature in the cantina space at the first floor temperature rises up to 27°C, while during the ventilative cooling week, air temperature never rises more than 26°C although outside air temperatures are between 32 to 34 °C. Temperature results are in accordance with simulation results.

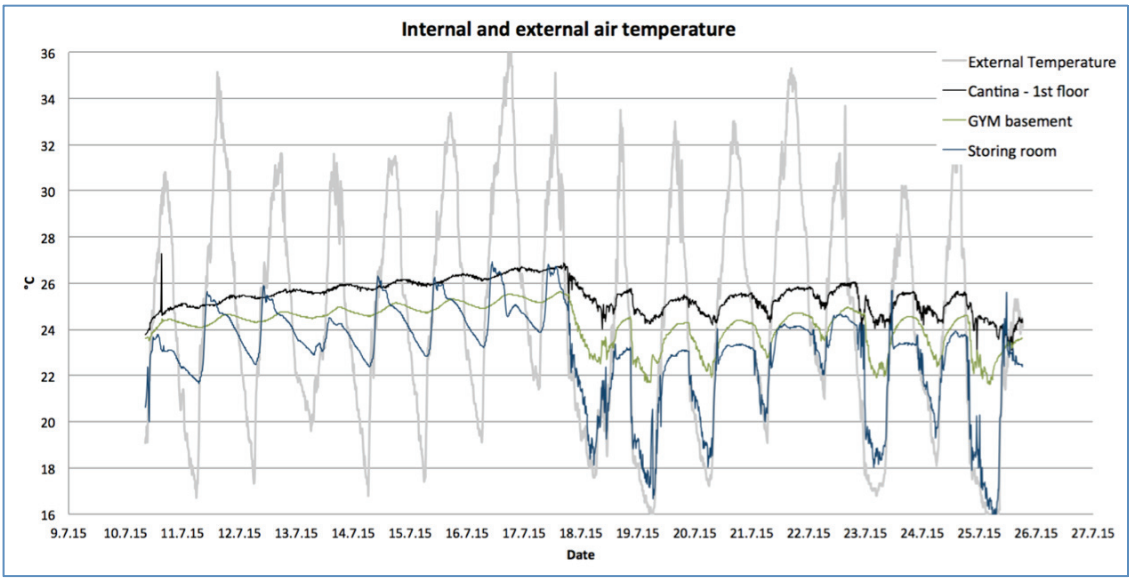
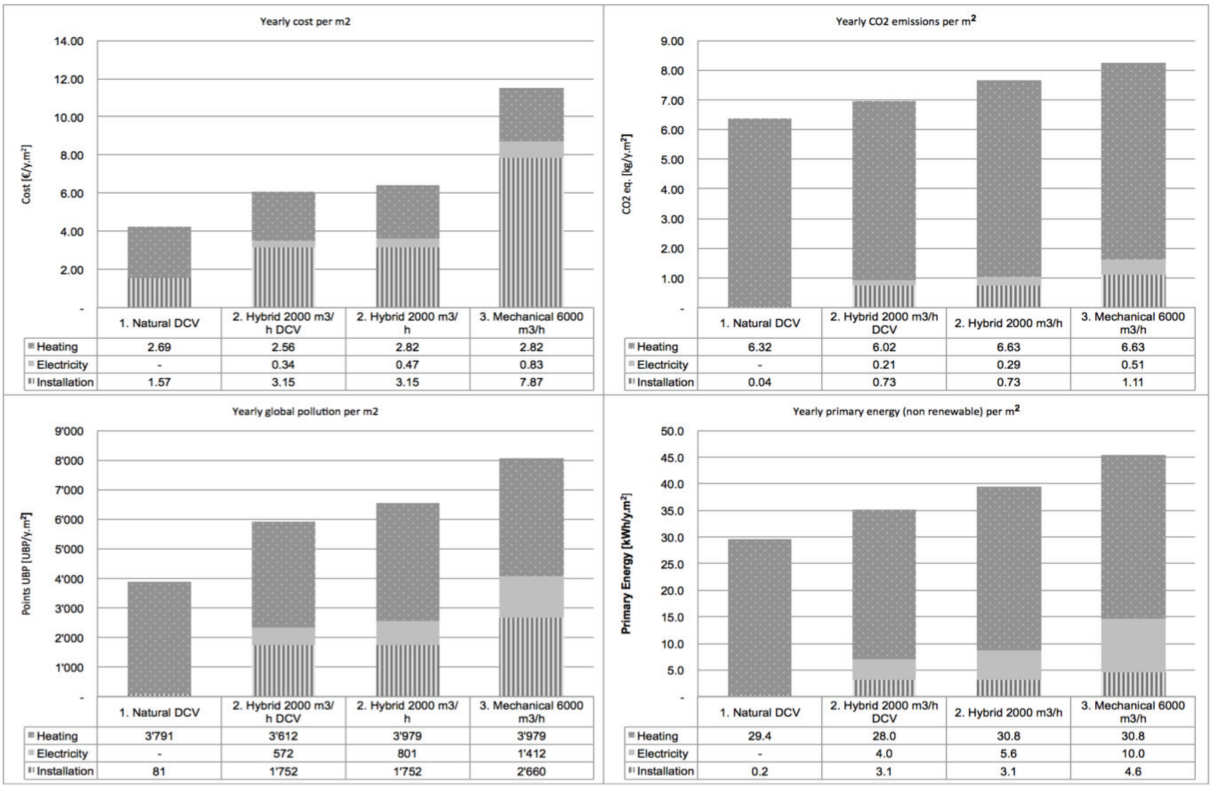


Figure 11. Internal and external temperature during hot summer period. During the first week there is no night ventilation and during the second, night cooling is activated.

3 COMPARATIVE LIFE CYCLE ASSESSMENT FOR 4 ALTERNATIVES

We compare the overall life cycle assessment of heating and electricity consumption, including embodied non-renewable energy, environmental impacts and life cycle costs for 4 ventilation cases. Case 1 is the pure natural ventilation, demand control on a CO2 sensor for air quality and on temperature and climatic conditions for comfort. The system is presented in details in the previous chapters. Case 2, is a hybrid solution, with 2000 m^3/h bidirectional ventilation with heat recovery of overall efficiency 70% and specific power input for ventilation 0.50 $W/(m^3/h)$, also equipped with demand control based on CO2 concentration, as for natural ventilation. During high occupation of the cantina, with up to 200 children, (one hour per day) and for night cooling, the system is naturally ventilated. This solution is applied on a similar project, where the building owner is obliged to install a heat recovery system to meet the requirements of a Minergie P® label, imposed by the Cantonal Energy Law. Case 3 is the same as alternative 2 but without demand control. Alternative 4 is the initial scenario of case 2 that was rejected for its high investment cost.

We calculate heat demand for each case with the Swiss software Lesosai applying the Swiss Norm SIA 380/1, (SN 520 380/1 2009) (this Swiss norm is based on the European norm EN ISO 13790). For natural ventilation we considered 0.5 $m^3/h.m^2$ during occupation and 0.22 during non-occupation due to infiltration. These values come from a detailed analysis of the CO2 concentrations variations and decays in November. During the natural ventilation analysis, mean temperature was at 8.1 °C, similar to the mean temperature during the whole heating season (8.1°C). For heat recovery units, we considered during, use, 30% of the 2000 m^3/h to take into account heat recovery of mean η 70% for mechanical ventilation and 0 out of use hours in addition to 0.22 $m^3/h.m^2$ of air infiltration. For the demand control version of mechanical ventilation, we keep the 0.22 $m^3/h.m^2$ of air infiltration and on the remaining 0.28 $m^3/h.m^2$ fresh air, we apply a factor of 30% to take into account 70% heat recovery efficiency. This makes an overall fresh air ventilation of 0.3 $m^3/h.m^2$ during use for demand control mechanical ventilation and 0.5 $m^3/h.m^2$ for standard heat recovery mechanical ventilation. The data for environmental impacts for the ventilation systems come from KBOB database (KBOB 2014). System costs come from EPIQR method cost database and fuel cost from the federal statistics office, mean price 2010-2014. For natural ventilation we considered equivalent embodied energy for 8 m^2 of doors doubled with aluminium metal sheet cover. We neglected the embodied energy of 8 chain motors, control cables and control electronic box.



	1. Natural DCV	2. Hybrid 2000 m3/h DCV	2. Hybrid 2000 m3/h	3. Mechanical 6000 m3/h
Heating	2.69	2.56	2.82	2.82
Electricity	-	0.34	0.47	0.83
Installation	1.57	3.15	3.15	7.87

	1. Natural DCV	2. Hybrid 2000 m3/h DCV	2. Hybrid 2000 m3/h	3. Mechanical 6000 m3/h
Heating	6.32	6.02	6.63	6.63
Electricity	-	0.21	0.29	0.51
Installation	0.04	0.73	0.73	1.11

	1. Natural DCV	2. Hybrid 2000 m3/h DCV	2. Hybrid 2000 m3/h	3. Mechanical 6000 m3/h
Heating	3'791	3'612	3'979	3'979
Electricity	-	572	801	1'412
Installation	81	1'752	1'752	2'660

	1. Natural DCV	2. Hybrid 2000 m3/h DCV	2. Hybrid 2000 m3/h	3. Mechanical 6000 m3/h
Heating	29.4	28.0	30.8	30.8
Electricity	-	4.0	5.6	10.0
Installation	0.2	3.1	3.1	4.6

*Figure 12. Results of life cycle cost, CO2, global solution and primary energy of 4 ventilation variants, applied on a building, considered to be heated by an **oil heating system, η 0.85**.*

As we see from figure 2, demand controlled natural ventilation of large spaces is largely better solution than non-demand-controlled mechanical ventilation equipped with heat recovery and significantly better even than demand controlled mechanical ventilation with demand control. Although heat recovery reduces thermal losses, it increases electrical consumption for fans and embodied energy and environmental impacts of the system have analogous influence as the higher cost. For large spaces with intermittent occupation, with very high density during short time, a large system for full mechanical ventilation (case 4), increases considerably cost and embodied energy. In case 4 we can see that night ventilation of large space with mechanical fan increases considerably electricity primary energy consumption. These conclusions are valid for a central European climate. We tested if the results are valid for full occupation of the gym during all the day with adults. The difference between the systems is slightly smaller but the order is the same.

Large spaces present 3 significant advantages that make controlled natural ventilation an adequate system assuring best comfort and air quality:

- The height of the building creates a high stack effect making ventilation very efficient.
- The unique large volume creates a large reservoir of fresh air, making possible the exploitation of infiltration for ventilation. In the examined case, infiltration of ~240 m^3/h in a volume of ~5000 m^3, although it represents infiltration of a high airtight building n_{50}<0.5, it is almost sufficient for adequate ventilation of the whole space, occupied sporadically by 25 – 50 children. CO2 concentration very rarely rises over 1000 ppm to activate window opening. Window opens during winter only after the infiltration potential is completely used. This

makes the overall quantity of fresh air of the same order and event better than for a heat recovery system.
- Mechanical ventilation for night cooling cost a significant amount of primary energy. Every time that natural ventilation may be used instead of a mechanical system it should be preferred. For large spaces it is very easy to cool the whole space by controlling only 2-4 openings, reducing cost for the openings and automation. In this case full control is possible with only 4 openings.

The air quality - comfort results and the energy and environmental analysis show that demand control natural ventilation for large spaces is the best solution for passive and zero energy buildings.

4 CONCLUSIONS

Natural ventilation for high single volume gyms, and generally for large spaces, is a very simple concept and the results show that it may offer a perfect air quality in winter and perfect temperature comfort during summer. Natural ventilation is a low cost solution with a lot of architectural advantages (pure line, no space consumption for machines, no ducts in the space). Natural ventilation is an ecological solution because it has very low embodied energy and system environmental impacts.

Design may very easily manage the different possible risks (cold draughts, intrusion risk, weather risks, noise risks) for large spaces with automation of few openings. Automatic control for public spaces is essential for good air quality and comfort control.

The life cycle assessment showed that natural ventilation, with demand controlled airflow is also very energy efficient. For Central Europe climates, its global life cycle energy and environmental performance is equivalent or better than bidirectional mechanical ventilation with heat recovery. It is a perfect solution for passive buildings where airflow may be controlled according to occupation.

The architectural advantages of natural ventilation are undeniable. There are no ducts, and openings may be easily dissimulated if they are not desirable to be present in the space. Dissociation of light path from air path is a smart design technic to obtain the optimum air path and exploit the physical properties of the building structure. In this case for example, dissimulation of 4 m2 of opening in the underground, made possible to exploit thermal mass of the concrete storing rooms where the air passes first and avoids direct droughts near the opening. Compliance to fire regulations gives also interesting synergies to minimise architectural, cost and environmental impact of natural ventilation.

Natural ventilation of large spaces is a ventilation system that must be designed by an architect, or by a collaborative team with at leas an architect and a building physicist.

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