Smart windows and air inlets for residential building extraction ventilation.

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Abstract

Extraction demand control ventilation is a simple, cost-effective and robust technique for building refurbishment of residential buildings. However, extraction ventilation for a central and northern Europe cold climates, taking the air directly from the facade, may result in cold drafts for the occupants. RECO2ST project includes in its refurbishment kit of innovative technologies a smart window, preheating the air, in the gap between a triple glazing construction, with the interior glazing openable for visiting the air passage. The Suisse demonstration case selected a demand control ventilation system as a cost optimum solution. The article presents the results of an in-situ experimental study on the demonstration building in Switzerland where a comparison of the air quality and energy performance are made. The measurements were carried out on three similar apartments, one with the smart window and two others with different smart air inlet strategies. The experimental results demonstrate that all three tested air inlet strategies perform much better than a simple air inlet of 30 cm^2, which is a very common model in the market and creates cold drafts for the occupants. The demonstrated RECO2ST smart window, additionally to this advantage, pre-heats the air and recovers part of the window heat losses and solar gains and the demo case showed that it may be perfectly combined with a DCV extraction ventilation system. The standard air inlet with humidity control performs in reality according to specifications, offers a good air quality and does not provoke cold droughts. Proven smart technologies for air inlets, addressing the issue of cold draft risks, make demand control ventilation, which is a cost-effective solution for residential building refurbishment, more reliable and acceptable for the occupants.

Keywords: Smart windows, air inlets, demand control ventilation, ICONE index

1. Introduction

The study building in Switzerland is one of the 4 demonstration cases of the European study project ReCO2st. The aim of the European research program is to show how it is possible renovate according to nZEB standards, while optimizing costs and ensuring quality of life and comfort for the inhabitants in order to promote energy transition. To do so, ReCO2st applies an easy 3-step approach to building renovations, resulting in major cost savings and higher standards of living, at a near-zero energy performance [1]. During step 1, the refurbishment assessment with EPIQR method [www.epiqrplus.ch], auditors identified in this case study a lack of a convenient ventilation system. During step 2, the “least cost method”, a method developed by ReCO2st to optimize refurbishment scenarios, oriented the choice to the most cost and energy effective ventilation system: a standard demand control ventilation (DCV). The 3rd step of ReCO2st proposes a series of new technologies which are in the pre-commercialization stage, in order to enlarge the choice of refurbishment designers for cost effective innovative solutions. In the framework of this step, the Swiss demo case tested a smart window. In this combination of a DCV ventilation with a smart window we tested the behavior of different air inlets solutions, and the monitoring of the building tested and compared their performance in addition to the control of the major project objectives (60% energy savings, 15% cost reduction, perfect indoor environment quality).

The Swiss building standards specify how a ventilation concept must ensure air quality and prevent damage to the construction resulting from thermal or water influences. In addition to comfort and hygiene, ventilation also plays a significant role in terms of heating energy performance [2]. In order to ensure the health of the occupants of a dwelling or workplace, the airflow must be adapted to the number of people and their activities. However, ventilation rates are generally dimensioned taking into account the worst-case scenario and ensuring a constant airflow [3] for maximum occupancy. These results too much ventilation, especially during the heating period, leading to high energy losses, dry out the indoor air during the coldest periods or cause unpleasant (cold) drafts. Ventilation systems with a modulating flow rate make it possible to overcome these problems. A demand-controlled ventilation (DCV) system tries to achieve high indoor air quality (IAQ) at reduced energy consumption by modulating the air exchange rate based on a measured parameter [4], which results to a diminution of air pollution, generally emitted by human activities [5].

A simple flow extraction ventilation system is much simpler and cheaper technical solution compared to a balance ventilation in residential building refurbishment. However, the risk of cold drafts, introducing exterior air directly to the habitable space, constitutes a real risk. When the system design does not give an adequate solution to this risk, the tenants generally obstruct the air inlets during cold drafts and never unobstructed them, disturbing the ventilation system and deteriorating indoor air quality.

Reduced air flow rates and the aerodynamic form of air inlets of standard humidity sensitive ventilation systems reduce significantly draft risks. The ReCO2st smart window, preheating induced air in the window 3rd glazing cavity intents also to reduce cold drafts in addition to higher energy performance. The demo building monitoring plan compared ventilation efficiency and drought risks of several air inlet solutions in addition to the smart window and the standard humidity sensible air inlet device.

1.1 Indicator used for indoor air quality

CO2 is not a pollutant itself, however its monitoring is easy and CO2 concentration indicates the dwelling stuffiness. Higher concentrations indicate poor ventilation rate and insufficient air renewal. By monitoring the CO2 before and after refurbishment, we quantified a stuffiness index ICONE. This index based on the carbon dioxide concentration (CO2) was developed in 2007 by the scientific and technical center for building in France [6]. ICONE index ranges from 0 to 5 and reflects the balance between air exchange rate and room occupancy density. It takes into account both the *frequency of containment situations, but also their intensity* by proposing two thresholds of CO2 concentration values, at **1.000 and 1.700ppm** and accounting the frequency of occurrence in each range.

ICONE index	***0***	***1***	***2***	***3***	***4***	***5***
State of stuffiness	*Null*	*Low*	*Medium*	*High*	*Very high*	*Extreme*

Table 1: ICONE index and state of stuffiness

ICONE is 0 if 100% of the time the CO2 concentration in the space is lower than threshold 1 (1000 ppm) and 5 if 100% of the time the CO2 concentration is higher than threshold 2 (1700 ppm). The intermediate values depend of the combination of hours below, in between and higher than the two thresholds. A very high ICONE (4 or 5) indicates that air renewal is insufficient to evacuate the bio-effluents produced by the occupants, which accumulate. Therefore, in the presence of a significant source of pollutants in a very confined atmosphere, very high pollutant levels can be observed. ICONE is now used in the mandatory control of indoor air quality in schools and nurseries in France. It is a relevant and useful tool for building managers to improve ventilation conditions [6]. The stuffiness index is calculated according to a standard occupancy schedule, defined by the Swiss standards SIA 2024. It is a very convenient indicator because a single value indicates stuffiness levels according to the intensity and frequency.

1.2 Description of the building

1.2.1 Situation

The building is located in a residential area near the center of Vevey in Switzerland and was built in 1920. Prior to the renovation of the building in 2018-2019, the 15-apartment building had not undergone any major transformation after 1959. Two new apartments were created in the attic of the building.

Figure 1: Building location

Figure 2: North and East façade before and after refurbishment

1.2.2 Building composition

Façades	Windows	Heating	Ventilation
Mineral wool peripheral insulation of the two gable facades (20 cm) and the southwest façade (16 cm). Refection of the northeast façade according to the municipality requirements. Creation of balconies on the south façade.	Complete replacement of windows. Improved sealing, thermal and sound insulation *by insulating* double glazing. PVC base system (PVC-aluminium optional) with tilt and turn. Humidity-controlled air inlets. Smart windows implemented as well.	Wood powered (80%) urban heating will supply heating and domestic hot water.	Single flow mechanical ventilation with humidity-controlled regulation to ensure air pollutant extraction with limited heat loss. Air extraction in water rooms with hygrometric strips. Air intake in living rooms and bedrooms with hygrometric strips. Steady pressure vacuum and air travel under doors.
			

Table 2: Main composition of the building

1.2.3 Energy consumption

The total energy consumption was measured before and after refurbishment using the bills of the energy supplier. Before refurbishment, the building had a gas boiler. After refurbishment, a district heating supplies the building with 80% renewable biomass heat. The results show an energy consumption reduction by more than 50% considering final energy and **more than 75% considering primary energy** (with Swiss national weighting factors)**.**

	Unit	Before refurbishment	After refurbishment
Total heated surface	[m^2]	1222	1434
Total heat consumption	[kWh/yr]	192360	108827
Specific final energy	[$kWh/m^2.yr$]	157.4	75.9
Specific weighted* energy	[$kWh_{CH}/m^2.yr$]	157.4	38

Table 3: Energy consumption before and after refurbishment

* *weighted energy is a kind of primary energy defined by the Swiss standardization authorities. They use 1 for fossil fuels, 2 for electricity, 0.5 for biomass energy and 0 for solar energy.*

2. Description of the ventilation system

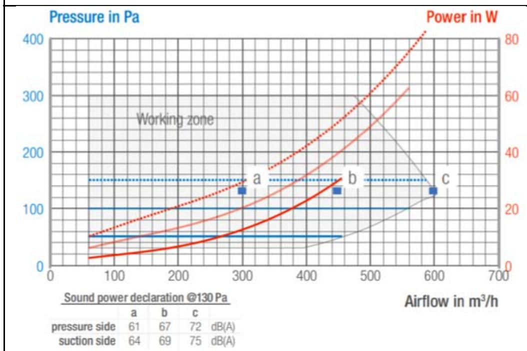
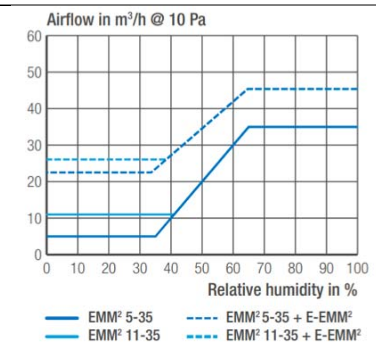
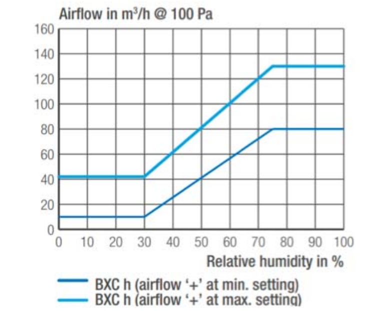
2.1 Implementation of demand control ventilation

Before refurbishment, the building had no ventilation system and air renewal was ensured by opening the windows and envelope leaks through the building. The windows were changed, and three facades were insulated. This had the effect to increase significantly the air tightness of the building envelope and create thermal bridges. It was then necessary to ensure the comfort of the tenants. The Swiss standards SIA 180 indicate that mold problems can occur if humidity is too high or thermal bridges are created. Human activities that generate high density of pollutants (10-minute shower generates 350 g of vapor) [7] need boost ventilation in order to limit the level and duration of pollutant presence. Pollution generated by human metabolism (breathing and transpiration) generates essentially humidity and carbon dioxide [5]. Various research projects have proved that humidity is a good indicator of pollution generated by human activities and human metabolism. According to theses references, it was chosen to install a demand control ventilation system based on humidity, in order to ensure a sufficient air renewal according to the number of people and their activities [8, 9,10].

Consequently, new vertical air pipes have been installed through each slab connecting each bathroom, as the figures below emphasize. On this basis, a single flow demand control ventilation based on humidity was implemented. The total air flow rate is determined by the extract units from the wet rooms (WC, bathrooms). Therefore, the air inlets and outlets will open or close mechanically depending on the relative humidity in the room. The roof ventilator will then adjust its speed to maintain a constant pressure depending on the pressure drop and charge losses across the extractors and valves. The fresh air enters in the less polluted rooms (dry rooms: bedrooms, living room) and is then extracted from the most polluted ones (wet rooms: bathroom, WC). Hence, the pollution generated in the wet room does not spread through the entire dwelling. Moreover, the same air is used to ventilate the dry rooms and the wet one, which has the advantage to limit the energy requirement to heat the incoming “cold” air from the air inlet.

2.2 Characteristic of the main DCV system installed: Humidity sensitive

The building was equipped with humidity sensitive air inlets and extractors. An air inlet on each window of dry rooms as well as an extraction in each toilet/bathroom is present. The humidity sensor consists of a polyamide textile tape contracting and expanding depending on the relative humidity. This change in length triggers a tilting mechanism that opens/closes the air inlets and outlets. It is this mechanism that opens or closes the valves, thus modulating the flow rate in combination with three constant pressure fans installed on the roof. The fans operate at constant pressure (~100 Pa) and will adjust their speed to ensure the same pressure differential, thus adapting their flow rate. Although the air is not preheated, air inlet aerodynamic form directs fresh air towards the ceiling reducing the risk of tenant discomfort with cold drafts. According to the firm, tests were performed on devices installed since more than 25 years which confirmed system reliability. The system simplicity limits divergence or damage risk. The technology based on polyamide strips offers an analog operation with continuous regulation of airflow avoiding binary/discontinuous operation observed with other technologies [11]. The devices are then shown below:

Ventilators type:	Air inlet type:	Air outlet:
 Figure 3: Ventilator installed in the study case	 Figure 4: Air inlet on the window's opening frame.	 Figure 5: Air outlet installed
 Figure 6: Resulting power of the ventilator as a function the pressure and the total airflow rate	 Figure 7: Airflow as a function of relative humidity of the air inlet	 Figure 8: Airflow as a function of relative humidity of the air outlet

Thus, depending on the relative humidity, air inlets allow a flow rate of 5 to 35 m^3/h. The outlets allow an air discharge of 10 to 120 m^3/h, again depending on the relative humidity. Finally, the Swiss standards SIA 382/1, § 1.8.1 and based on *SN EN 13779*, show the following classification of specific fan power:

Category	Unit	SFP 1+	SFP 1	SFP 2	SFP 3	SFP 4	SFP >4
P_{FSP}	$W\ per\ m^3/s$	≤ 300	> 300 à 500	> 500 à 750	> 750 à 1250	> 1250 à 2000	> 2000
P_{FSP}	$W\ per\ m^3/h$	≤ 0.083	> 0.083 à 0.14	> 0.14 à 0.21	> 0.21 à 0.35	> 0.35 à 0.56	> 0.56

Table 4: Classification of fan power based on the reference SN EN 13779

Based on the figure 14 and a ventilation rate flow of 300 m^3/h per exhaust turret, it can be seen that the fan is of class **SFP1+**. In fact, curve b on fig.9, at a flow rate of 300 m^3/h gives a power lower than 0.083 W per m^3/h, corresponding then to this specific category, which is the most optimal from an energy point of view. In addition, the noise emissions are less than 70 db(A), according to the values on the figure 14 from the curve b, which respect the Swiss standards value of 70 db(A). Fan electricity is very often neglected in ventilation system comparison. A ventilation system of SFP1+ fan is a serious advantage and should be a clear objective applying EU ecodesign directive for ventilation. The high energy performance of fans, in addition to 30% reduction of ventilation heat losses is one of the facts that contributed to obtain a class A building after refurbishment and reached all nZEB objectives of ReCO2st, project with a sober technology and cost effective strategy.

2.3 Energy performance of demand control ventilation

A study carried out in 2015 by ESTIA has shown that in terms of primary energy, several ventilation systems provided similar values [12]. It has been shown, among others, that the primary electrical energy for air transport (nonrenewable) is close to the primary energy recovered in heat when the energy vector for heating is highly renewable. This study was performed with a gas boiler for heat production, with higher advantage for heat recovery. If we repeat the same calculation for this case study, with biomass energy for heat production, DCV is clearly more energy effective than balanced ventilation with heat recovery. A DCV has 75 MJ/m^2y of final energy heats losses, compared to 48 MJ/m^2y of a balanced ventilation with heat recovery and 118 MJ/m^2y for a simple 2 speed extraction system. DCV saves 36% of heating final energy compared to a simple system while a balanced ventilation 60%. However, although the balanced ventilation reduces heat losses it increases electricity consumption to 4.2 kWh/m^2 instead of DCV ventilation that reduces electricity consumption from 0.8 kWh/m^2 to 0.5 kWh/m^2. The total balance taking into account the weighting factor of the renewable saved heat energy (0.5) and the electricity weighting factor (2), shows the DCV performing clearly better with a total of 39 kWh_{CH}/m^2y compared to 42.9 kWh_{CH}/m^2y of a HR ventilation scenario and 45 kWh_{CH}/m^2y of a simple extraction system without modulation or heat recovery.

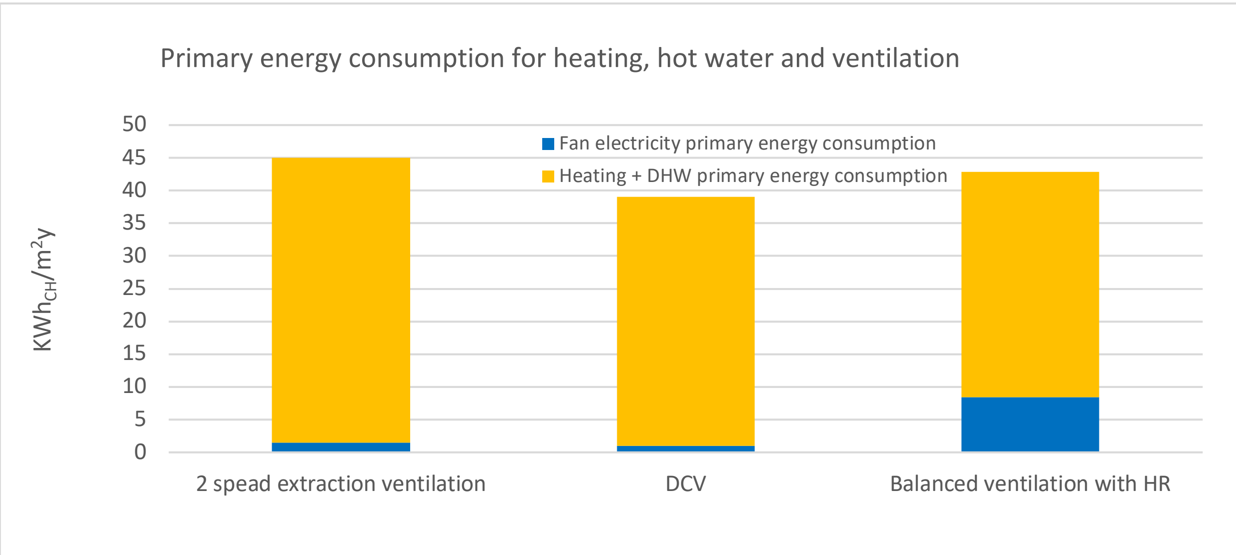


Figure 9. Primary energy consumption for heating, hot water and ventilation of 3 ventilation scenarios of the building.

2.4 Description of the other air inlets types

The building is fully equipped with humidity sensitive system. Each window in the dry rooms has humidity sensitive air inlets. There is also humidity sensitive air extraction in each bathroom. These inlets and outlets have the characteristics presented in chapter 2.2. Several other ventilation systems and air inlet have also been installed in the rooms at the corner of the south and east facades, as shown on the figures 14 and 15.

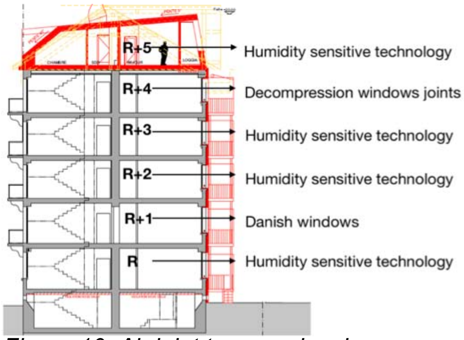


Figure 10: Air inlet type per level

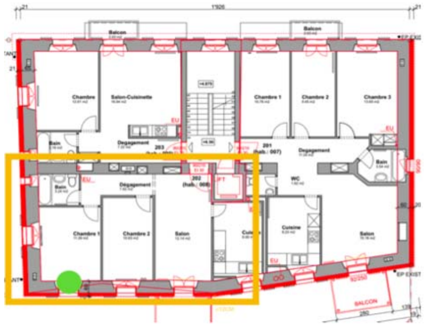


Figure 11: Localisation of the flat at each level (yellow rectangle) and air inlets (green dot)

2.4.1 Simple air inlets

Fixed or self-adjusting air inlets allow airflow to be regulated to the maximum value. However, if the inlets are self-adjusting, it is possible to limit the flow rate somewhat during periods of low air pressure or for high-rise buildings (stack effect). The ventilation flow rate is therefore fixed according to the pressure difference and without adapting to the dwelling use.
This technology was not installed on the demonstration building. Indeed, such air inlets always remain open, thus increasing the risk of tenant discomfort created by cold drafts. Its behavior was analyzed in another building monitored in parallel with the demo case and as it was expected a very high degree of tenant complaints and > 80% of air inlet obstruction was registered.

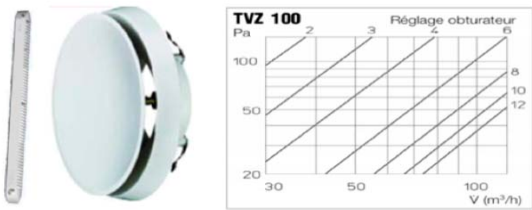


Figure 12: Fixed air inlet and self-adjusting air outlet and its ventilation flow rate as a function of the pressure and settings

2.4.2 Reduced air inlets (7 m^3/h), manual window opening in comfort position

Window-type air inlets with joint decompression have been installed at R+4. Generally, a window can be either open, closed or transom mounted. Thanks to these new windows, an additional position is therefore added to the window handle and enables the window to open slightly, only 5 mm after the joint decompression. This position allows the air passage through the joint, while keeping the window in the closed position called "comfort position".

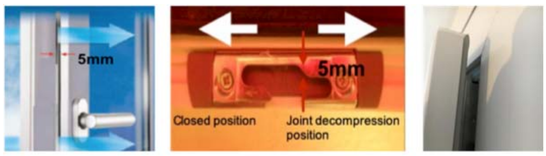


Figure 13: Ilustration of the opening system and its mechanism of the joint decompression window to obtain the desired opening in [mm]

Practice has shown that this ventilation method, if the window is installed according to the rules, is efficient. From an energy point of view, if the window is in the closed position, no ventilation is possible and infiltration is therefore almost zero, thus guaranteeing the good thermal behavior of the windows. On the other hand, in the unclosed position, ventilation is possible, allowing the rooms to be ventilated as required and in accordance with the SIA standards (provided that the spacing in mm corresponds to the ventilation requirements). However, ventilation is dependent on the user's behavior. Indeed, unlike a fixed air inlet or a modulated system based on the relative humidity, if the user leaves the window closed throughout the day, air renewal cannot be guaranteed completed. However, security minimum air flow is guaranteed by the reduced air inlets (7 m^3/h) when tenants do not open or use the controlled airing position of the window.

2.4.3 Smart window

Smart windows have been installed at the level R+1 as shown in the figure 17. The windows have been manufactured by the Danish Horn group in the framework of the ReCO2st innovative refurbishment kit. The main principle of the smart window is the following. The fresh outdoor circulating between two glazing is pre-warmed either by the building heat losses through the window or the sun. As a consequence, the fresh air coming from the outside is preheated which avoids potential cold drafts and tenant discomfort. The implementation of this technology makes it possible to avoid the installation of visible air inlets above the windows. Indeed, in the case of an apartment renovation, the air inlets are mostly visible on the upper part of the windows, above the horizontal part. The object is about 20 cm long, 2 to 3 cm thick and 2 to 3 cm deep, making the device unattractive and somewhat fragile. Unlike other air inlets, the air is preheated with the smart windows to avoid as much as possible the discomfort problems associated with cold drafts. [13]. According to the manufacturer's specifications, this window has an equivalent U value of 0.4 W/m2k if we take into account recovery of the heat losses and solar heat gains.

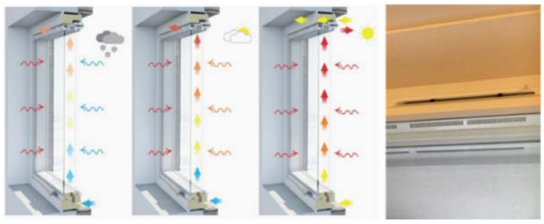


Figure 14: Smart window concept. Fresh outdoor air circulating between two glazing is pre-warmed either by the building heat or the sun.

3. Results of indoor air quality

3.1 Before refurbishment

The measurements were carried out in a test apartment of a couple, in the sleeping room naturally ventilated by windows opening. The ICONE measurements were made using a Class Air probe. These sensors are equipped with C02 probe, highly sensitive, selective and stable sensors according to the scientific and technical center for building in France. Measurements over 222 days every 10 minutes were therefore carried out. These measurements made it possible to establish the initial ICONE state before refurbishment: The results are the following.

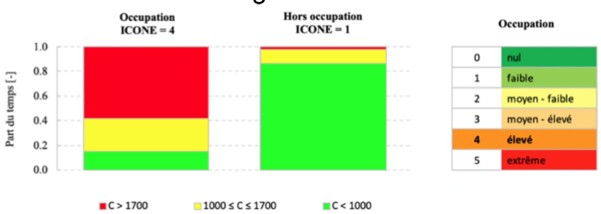


Figure 15: ICONE index before refurbishment in one test room while it is occupied by 2 people (" Occupation") or not (" Hors occupation")

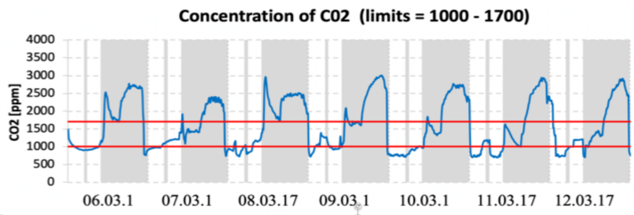


Figure 16: One-week representation of C02 concentration in the room test before refurbishment while it is occupied (gray) or not (white)

As the ICONE index emphasizes, when the room is occupied, a very **high index (4)** indicates that air renewal is insufficient to evacuate the bio effluents produced by the occupants, which can accumulate. However, when the room is empty, the stuffiness index shows a low value equivalent to 1. It can be seen that the air quality is not optimal during occupancy. The graph shows the C02 concentrations during a typical week. In grey are represented the room occupancy according to the SIA 2024 standards and the two limits set by the reference are 1000 and 1700 ppm [6] are represented by the red lines.

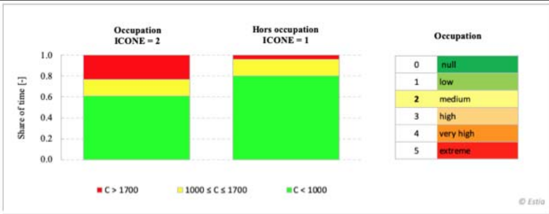
When the room is occupied, the C02 level largely exceeds the limit of 1.700 ppm. The abrupt drop is the equivalent of a window opening that causes the C02 concentration to drop. With a result giving an index of 4, it is possible to see that the air quality is not optimal and that the air is very confined.

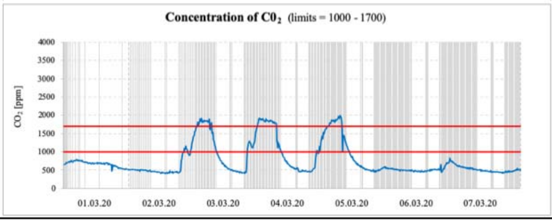
3.2 After refurbishment

The ICONE index after refurbishment are calculated over 30 days and the C02 curves illustrate the behavior of the first week of March. The left column shows the ICONE index for the room with the different air inlets. On the right, the ICONE index for the bathroom is also calculated. This index measures the air quality of the entire dwelling since the air is extracted at the outlets located in the bathrooms and therefore represents the mix of the ambient air in the dwelling. Results for fixed air intakes on a new dwelling are also presented for comparison purposes. A probe to measure the quantity of C02 was placed in a bedroom of the same type. The air inlets in this case had been blocked by tenants because of cold drafts.

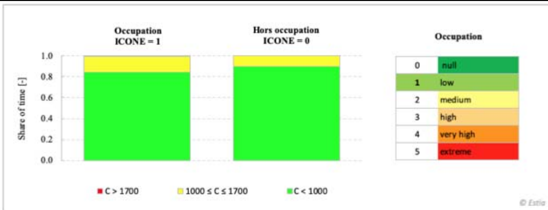
R : Humidity sensitive **; R+1** : Smart windows; **R+4**: Joint decompression windows

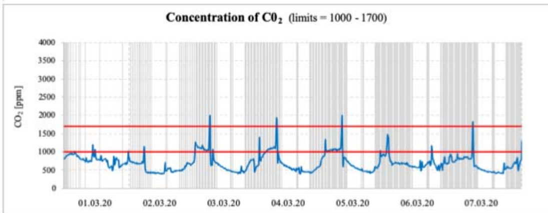
R — Room (humidity sensitive air inlet)



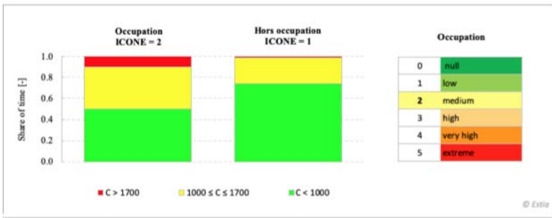


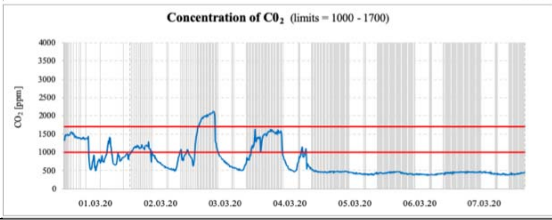
R — Bathroom



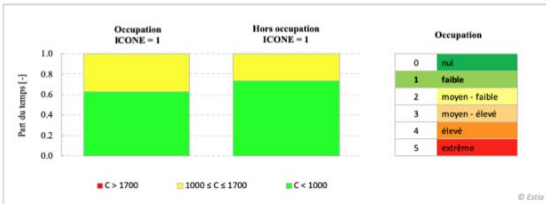


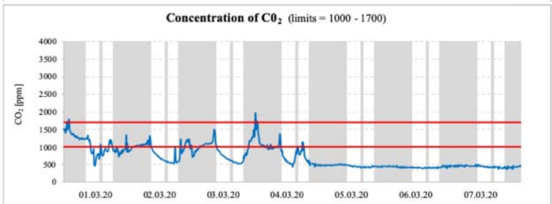
R+1 — Room (smart window)



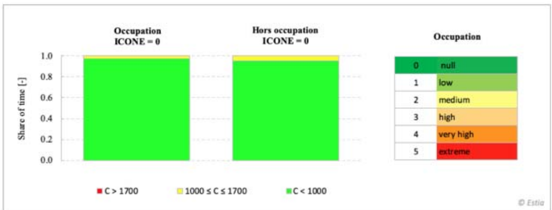


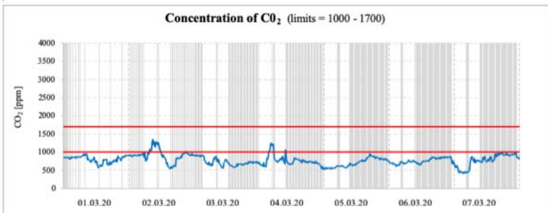
R+1 — Bathroom



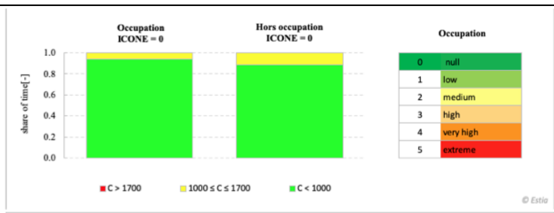


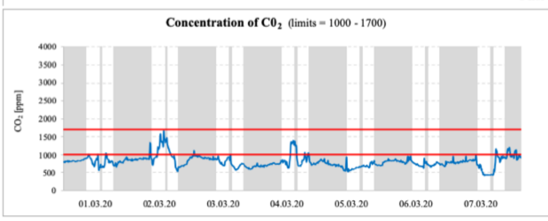
R+4 — Room (windows with airing position)



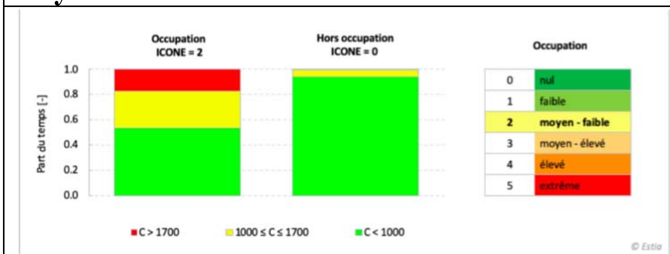


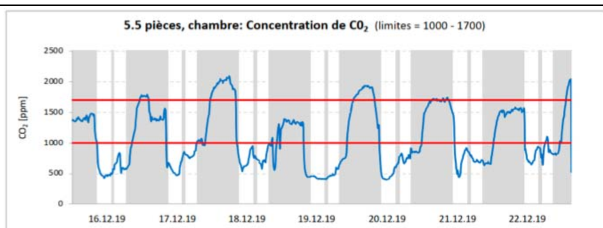
R+4 — Bathroom





Payerne: Fixed air inlet in a standard room





The results are summarised in the following table:

	Before refurbishment			
	Room		Bathroom	
	Occupied	*Unoccupied*	*Occupied*	*Unoccupied*
Natural ventilation	4	1	x	x
	After refurbishment			
Humidity sensitive	2	1	1	1
Smart windows	2	1	1	1
Joint decompression	0	0	0	0
Fixed opening	2	0	x	x

Tableau 5: ICONE index of the study case before and after refurbishment

It was then noticed that **before refurbishment**, measurements showed that the air renewal by natural ventilation was clearly insufficient since the ICONE index measured in the sleeping room showed **a very high stuffiness index** of **4**. If we add to this index the fact that interventions on the envelope took place, thus increasing its tightness, we notice that it was necessary to install a new ventilation system to ensure sufficient air renewal that natural ventilation could no longer guarantee.

After refurbishment, it can be noticed:

- All technologies show stuffiness index of medium-low to null (**2-1-0**). The requirements of Swiss standards are then guaranteed, and the building is properly ventilated.
- All the ICONE indices measured in the bathrooms indicate a low or zero degree of stuffiness (1 or 0). All the air inlets in the building then fulfill their role. Indeed, the bathroom is the air mix of the dwelling since this is where the air is extracted, and therefore representative of the ambient air mix of the dwelling. These containment indices then show the real performance in terms of air renewal of the installed humidity sensitive system.
- The decompression window of the joints indicates values of zero containment. This is the result of a window with overly decompressed joints. A blower door test was conducted in order to determine the reliability of these results. It has shown that the air inlet is nearly equivalent to **200** [m^3/h]. A large opening has been noticed around the window (more than 1 cm, as shown on figure 17) which corroborate the results of the various tests carried. The ventilation flow rate is therefore too high, and a mechanical adjustment is necessary in order to reduce the window opening at the airing position.
- Smart windows indicate a medium to low containment in the bedroom depending on the occupancy period. These results are satisfactory since the ICONE index does not exceed the value of 2. Note that the ventilation of these windows is related to the behavior of the user, who may decide to close them and thus not guarantee a good ventilation rate.
- The humidity sensitive air inlets are also efficient in terms of air renewal. In the same test apartment before/after work, the confinement index is reduced by half with the installation of such a system requiring little intervention. One notices then the performance of humidity sensitive ventilation.
- In the tenant general assembly 4 months after building commissioning no tenant complaint regarding cold drafts was registered and tenants expressed their satisfaction concerning air quality and comfort contrary to the building with fixed air inlets where tenant petitions asked for measures to solve the problem.
- In addition to strong complaints the fixed air inlet had been blocked by tenants because of cold drafts. The ICONE index was still 2 for showing that although the air inlets had been blocked there is still air passage.
- We performed qualitative air velocity measurements at 1m from the window of humidity sensitive air inlets and smart window at a height of 1.5 m and air velocity does never exceed 0.15 m/s. We have also performed infrared images without finding cold regions and this consolidates the lack of complaints by the tenants.

4. Conclusions

The experiments and monitoring of the Swiss Case study in the ReCO2st research project have shown that the sober-technology DCV ventilation system is a very interesting cost-effective solution for residential apartment building refurbishment. The global energy performance of the building meets the nZEB performance. In buildings with high degree renewable heat production, it was shown that a heat recovery unit, generating extra electricity consumption to run a more complex system with much higher pressure drop (ducts, filters, heat recovery unit), consumes more primary electricity than the recovered non-renewable heat in addition to the very high investment and maintenance costs. Concerning the air inlet testing, it was found that fix air inlets generate higher energy consumption and cold drafts pushing the tenants to obstruct air inlets to avoid them. Humidity sensible modulating devices and the ReCO2st smart window, as well as the manual control system provide good satisfaction to the tenants with no cold drafts. The energy performance of the humidity sensible air inlets is due to its capacity to better modulate inlet air flow and this of the smart window to recover window heat losses and solar gains, preheating the incoming air. In the case of manual controlled window un-tightness with a minimum safety air flow it is interesting to give to the tenants a role in the ventilation of their apartment, without a risk of over-ventilating or under-ventilating with very low airflow.

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