THEORETICAL AND REAL VENTILATION HEAT LOSSES AND ENERGY PEFRORMANCE IN LOW ENERGY BUILDINGS

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ABSTRACT

Ventilation in low energy refurbished buildings is the cause of a big part of energy losses. In order to reduce this impact, some energy regulations prescribe a solution (such as the Swiss energy Law, prescribing heat recovery) and others prescribe a system global performance (such as the EU delegated regulations No 1254 and 1253 / 2004 determining a global energy performance label of the ventilation system). In this article we analyse global theoretical performance of 6 ventilation systems in an apartment residential building and we compare real performance of a demand controlled ventilation system, incompatible with the Swiss prescriptions, with the performance of heat recovery system, compatible to the prescriptions, in two case studies of low energy refurbishment.

Theoretical performance comparison shows that different energy saving strategies may produce similar effects. Very low fan electricity consumption combined with reduced demand-controlled airflow rate may produce energy savings comparable to heat recovery. This phenomenon is accentuated with high performance heat production systems, with low embodied primary energy (such as high performance heat pumps, renewable district heating or wood boilers). In these cases, primary energy for electricity, necessary to recover heat, added to system embodied energy, may be higher than the recovered non renewable primary energy.

The comparison of real energy consumption of the systems in the case studies shows that the small differences between theoretical energy performances between heat recovery and demand-controlled ventilation, is negligible compared to the energy losses due to occupant behaviour (window opening, high internal temperature), while the investment cost of the two systems may vary by > 450% and the life cycle cost by >150%.

This comparative studies show that it is preferable to prescribe an energy performance of the global system, instead of prescribing a specific system or strategy, especially in an energy environment where primary energy for heating and cooling production is continually becoming better and ventilation technology is continuously evolving.

KEYWORDS

Ventilation, heat recovery, nearly zero energy buildings.

1 INTRODUCTION

We are interested on ventilation energy performance and two different prescriptive approaches are concerning it. The first approach, the one of the UE regulations (EU 1254/2014) and (EU 1253/2014), are interested on the system performance. They attribute an energy label to ventilation units and prescribe minimum and benchmark performances. The second approach, this of the existing Swiss cantonal regulations (MOPEC 2014), imposes a system. Swiss regulations prescribe heat recovery for ventilation systems with more than 1000 m^3/h and functioning more than 500 hours.

Regulations prescribing a solution deprive liberty of action, considering implicitly that the prescribed solution is the only way to achieve an objective in all the possible cases. However, the overall energy efficiency of heat recovery, prescribed by the Swiss regulations, depends on the amount of extra primary energy, necessary to run the heat recovery system and on the amount of primary energy, necessary to produce energy for ventilation heat or cooling losses. In this article we are interested only on heat losses in residential apartment buildings.

Obligation for heat recovery was considered necessary, and “the only solution”, in the 90s, when unidirectional ventilation units were consuming electricity, more or less, the half of electricity consumed by a bidirectional heat recovery system and when heat production was essentially provided by oil or gas boilers of low efficiency. Today, technological progress makes affordable and tends to generalise heat pumps of high COP for heat production, wood boilers, and district heating. Recovered heat losses contain much less primary energy than in the 90s. Today in the European market, annual COPs of heat pumps vary between 3 and 4.5. Considering a non-renewable primary energy factor of electricity 2.7, one kWh of recovered heat losses contains only 0.6 to 0.9 kWh of primary energy, compared to 2.7 kWh contained in 1 kWh of electric energy to run the fans. Even fossil energy sources are more efficient than in the 90s with condensation boilers of 8-10% higher efficiencies. Technological progress changes also the situation in regard to the energy necessary to provide controlled ventilation. DC motors for extraction fans offer very high efficiencies with low pressure-drop and specific power input may be less than 0.1 W/(m^3/h). Hybrid systems, with boosted stack effect extraction, offer even more interesting energy performances with mean specific power input less than 0.05 W/(m^3/h), not functioning for 1000-2000 hours per year when stack effect is sufficient. These specific power inputs must be compared to 0.32 to 0.45 W/(m^3/h) of very good bidirectional ventilation units. Demand control options may reduce drastically the mean airflow rate by 30-50% according to occupation (Flourentzou 2011), (CSTB 2013). Some systems, like demand-controlled ventilation may combine all these new advantages, offered by innovative technology: reduced airflow rate, low fan energy consumption. With demand controlled stack natural ventilation, electricity for fan is completely avoided. Overall energy balance and energy performance is required in order to quantify these advantages, using updated information according to the current state of technology. Energy balance, taking into account heating and cooling produced by a standard heat pump, combined with life cycle assessment of the ventilation system, showed that, for office buildings, ventilation heat recovery is energy effective in northern climates (like Oslo) while in southern climates (like Nicosia) is definitely not energy effective (Flourentzou 2013). For central Europe climates, heat recovery effectiveness depends on the heat production energy performance and energy source primary energy factor. This study showed that for office building heated and cooled by mean performance heat pumps (COP 3.5), energy balance of heat recovery bidirectional units is neutral. Extra primary energy consumption for running the fans, defrosting and extra embodied energy for the system, is just compensated by recovered heating and cooling energy. Here we will be concentrated in multifamily residential buildings in a central European medium climate (Geneva).

In the first part of the article we are interested on the global energy performance of different ventilation systems. We will first evaluate their performance according to ecodesign directive. We will also perform a detailed life cycle evaluation, taking into account the primary energy for fan electricity, primary energy for ventilation heat losses, including infiltration, primary energy for defrost, as well as embodied energy for the ventilation system.

In the second part, we will compare the global energy performance of two real high-energy-performance case studies and we evaluate the real energy consumption of the ventilation system. One of the compared buildings is equipped with a heat recovery unit and the other with demand-control hybrid ventilation.

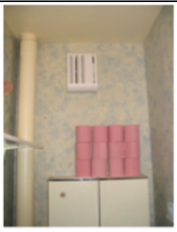
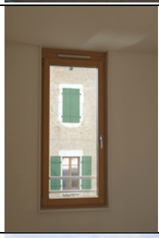
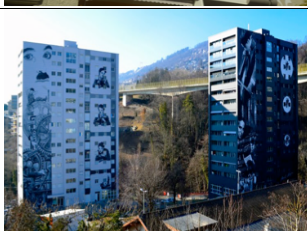
2 GLOBAL ENERGY PERFORMANCE OF VENTILATION SYSTEMS

2.1 Compared ventilation systems

Table 1. The 6 analysed ventilation systems. SPI is the nominal specific power input at reference airflow rate, η is the nominal heat recovery efficiency and CTRL is the control parameter.

		SPI [W/m^3h]	η_t	CTRL
1. Nat	Stack natural ventilation – adaptive local demand control	0.00	-	0.65
2. Hyb	Hybrid extraction ventilation – adaptive local demand control	0.05	-	0.65
3. DCV	Extraction unidirectional ventilation unit – adaptive local demand control	0.16	-	0.65
4. old UVU	Old (extraction) unidirectional ventilation unit– high/low velocity	0.08	-	0.95
5. new UVU	Modern (extraction) unidirectional ventilation unit– high/low velocity	0.09	-	0.95
6. HR BVU	Bidirectional ventilation unit with heat recovery	0.44	0.84	0.95

Table 2. Building and ventilation main characteristics

1			Natural ventilation	Renovation 2006
			Heating reference area	4000 m^2
			Number of apartments	62
			Maximum airflow rate	Stack effect
			Control	Local adaptive
			Ventilation power	0 W
			Heating system	Gas
2			Hybrid ventilation	Renovation 2010
			Heating reference area	2481 m^2
			Number of apartments	31
			Maximum airflow rate	6000 m^3/h
			Control	Local adaptive
			Ventilation power	15X16 W at 4500m^3/h
			Heating system	Gas
3		 	Extraction ventilation	Construction 2008
			Heating reference area	1222 m^2
			Number of apartments	12
			Maximum airflow rate	2070 m^3/h
			Control	Local adaptive
			Ventilation power	2X115W at 2200m^3/h
			Heating system	Wood pellets
4			Extraction ventilation	Construction 1985
			Heating reference area	9’812 m^2
			Number of apartments	31
			Maximum airflow rate	30’400 m^3/h
			Control	H.Speed/L.Speed
			Ventilation power	2’880W at 30400 m^3/h
			Heating system	Gas
5			Extraction ventilation	Renovation 2015
			Heating reference area	9’812 m^2
			Number of apartments	31
			Maximum airflow rate	9’140 m^3/h
			Control	H.Speed/L.Speed
			Ventilation power	759 W at 9140 m^3/h
			Heating system	Gas
6			Heat Recovery	Renovation 2011
			Heating reference area	5’739 m^2 X 2
			Number of apartments	70 X 2
			Maximum airflow rate	5’880 m^3/h
			Control	H.Speed/L.Speed
			Ventilation power	2’580 W at 5880 m^3/h
			Heating system	Oil / wood (in 2016)

The 6 selected systems cover a large spectrum of ventilation systems. Buildings of cases 1, 2 are high-energy standard buildings, recently refurbished (Minergie labeled GE-147 and GE-146). The existing ventilation system, for both, was a stack effect extraction system, with a concrete individual duct bringing fresh air in the WC and kitchen from the basement and extracting in the same rooms to the roof (typical Swiss system in the buildings constructed 1920-1960). The existing system was transformed to adaptive humidity sensitive extraction system. The ducts bringing the air in the WC from the basement were cancelled. New air inlets on the windows, equipped with humidity sensitive devices, adapt the airflow rate between 5 and 35 m^3/h according to the room occupation. In the first case, the ducts on the roof are not changed, and air extraction is purely stack. In the second case, hybrid low-pressure drop coaxial ventilators boost stack effect when is needed.

Case 3 is a recent low energy building (Minergie labelled GE 073), with extraction ventilation – demand controlled with humidity sensible devices in every room (local demand control).

Cases 4 and 5 is actually a single building, constructed in the 80s with a standard ventilation system for its period, but case 5 represents the project for replacement of the current oversized extraction ventilation units ~2.4 $m^3/h.m^2$ with a new system, equipped with low energy ventilators, and air flow re-dimensioned according to the current standards ~1.2 $m^3/h.m^2$.

Case 6 is a recently renovated couple of buildings, according to high-energy standards. The buildings are equipped with bidirectional ventilation system with heat recovery.

Cases 2 and 5 were monitored for one year to understand the difference between projected and real energy consumption (chapter 3).

2.2 Ventilation performance according to EU ecodesign directive

European regulation EU 1254/2014 describes the labelling framework, characterising ventilation unit energy performance. This regulation defines the Specific Energy Consumption indicator (SEC), which is the difference between a negative reference SEC and specific energy consumption for fans, heating and defrosting. Electrical energy consumption is calculated in terms of primary energy consumption with primary energy factor 2.5 and heating energy is considered without correction factor, except of a global heating efficiency of 75%. Regulation EU 1253/2014 indicates the minimum requirements to be applied by the member states until 2018 (class D or better) and fixes as benchmark class A for bidirectional ventilation units and class B for unidirectional residential ventilation units of <1000 m^3/h.

$$SEC = t_a \cdot pef \cdot q_{net} \cdot MISC \cdot CTRL^x \cdot SPI - t_h \cdot \Delta T_h \cdot \eta_h\text{-}1 \cdot C_{air} (q_{ref} - q_{net} \cdot CTRL \cdot MISC \cdot (1-\eta_t)) + Q_{defr} \quad (1)$$

Equation 1. SEC - Specific Energy Consumption [kWh/m².y] according to [EU 1254/2014]

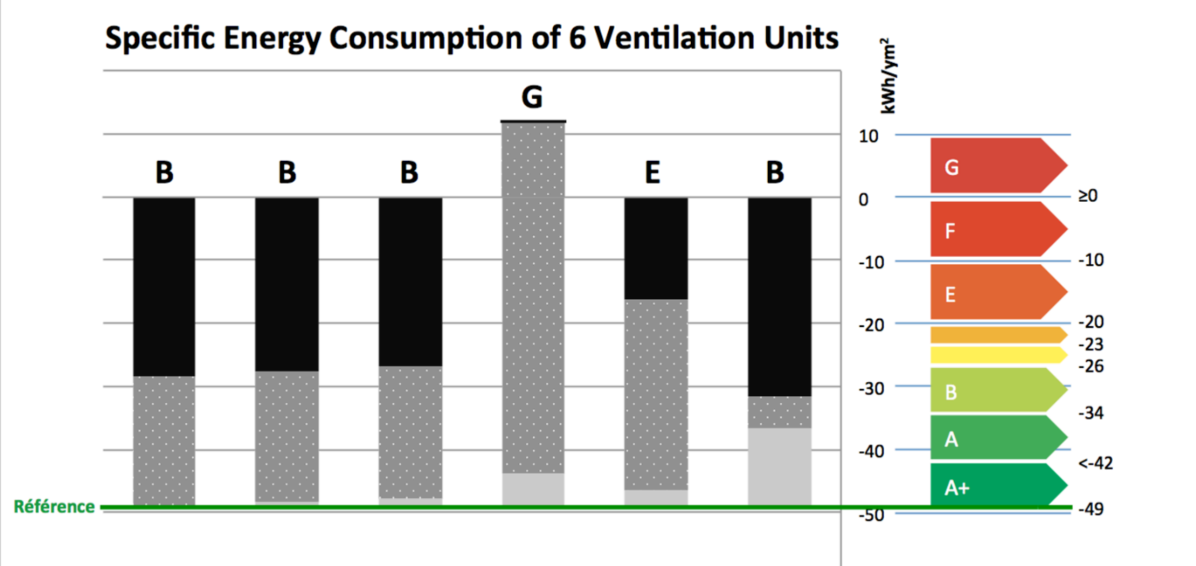
The first term of equation 1 is expressing the specific fan primary energy consumption. T_a is the annual operating hours (8760 h per year), pef is the primary energy factor (2.5), q_{net} is the net ventilation rate demand per m^2 of heated floor area (1.3 $m^3/h.m^2$), MISC is an aggregated general typology factor (1.1 for ducted units and 1.21 for non ducted units), CTRL is a ventilation control factor (1 for manual control, 0.95 for clock control, 0.85 for central demand control and 0.65 for local demand control) and x an exponent taking into account the non linearity between thermal energy and electricity saving (1 for on/off single speed, 1.2 for 2-speed, 1.5 for multi-speed and 2 for variable speed). SPI is the Specific Power Input at the reference airflow rate ($kW/(m^3/h)$).

The second term of the equation is expressing the difference between a reference heat energy loss due to reference natural ventilation and the effective heat energy loss. T_h are the hours of heating season (5112 h for the medium climate), ΔT_h is the average difference in indoor - 19K- and outdoor temperature over a heating season, minus 3K correction for solar internal gains (9.5 K for average climate), η_h is the average heating efficiency (0.75), C_{air} the specific heat capacity of air (0.00034 kWh/m^3.K), q_{ref} is the reference natural ventilation rate (2.2 m^3/h.m^2) and η_t is the thermal efficiency of heat recovery. The third term, Q_{defr} is equal to zero for unidirectional ventilation units and for regenerative heat exchangers (the only ones used by the systems compared in this article).

All the parameters are fixed by regulations, except of SPI and η_t, which are specified by the ventilation unit providers. q_{net} is fixed to 1.3 m^3/h.m^2 for systems dimensioned according to current regulations but case 4 is adapted for an existing over-dimensioned system with measured q_{net} of 2.4 m^3/h.m^2.

We have calculated SEC for the 6 ventilation systems and we show the results on figure 1. As SEC is a relative indicator, compared to reference SEC due to reference natural ventilation flow rate heat losses, the result is generally negative. Positive SECs are the worst systems of class G. Benchmark SEC according to UE1253/2014, for bidirectional ventilation units, is -42 kWh/y.m^2, i.e. Class A and -27 kWh/y.m^2 for unidirectional ventilation units, i.e. Class B.

As we can see on figure 1, all tested Adaptive Control Ventilation Units (Units 1, 2, 3) are of class B with SEC between 26 and 18 kWh/y.m^2, while the tested bidirectional ventilation unit (SPI 0.45 10^{-3} kW/(m^3/h) heat recovery of nominal value 84%) obtains also class B, with SEC -31.5 kWh/y.m^2. Clock demand, unidirectional ventilation without demand control, even with a good fan of SPI 0.1 kW/(m^3/h) obtains class E, while existing systems are of class G.



	1	2	3	4	5	6
-Fan	0.0	0.7	1.4	-5.2	2.5	12.4
-Heat	-20.7	20.7	20.7	-43.9	30.3	-4.8
SEC	-28.3	-27.6	-26.9	12.0	-16.3	-31.7

Figure 1. Results with the SEC and energy class of the 6 ventilation units. On the left of the graph representing the SEC, Fan and Heat energy consumption we can see the ecodesign label thresholds and on the bottom the table with the calculations for each unit..

We applied EU 1254/2014 methodology not for formal purposes. Although some of the examined residential ventilation units are over 1000 m^3/h, not subject of the regulation obligations, calculations give a comparative approach, using a coherent formal methodology. Purely stack effect extraction ventilation, equipped with adaptive control, case 1, is also out of the regulation perimeter, but we have assimilated this system to a unidirectional ventilation unit with a fan consuming 0 energy.

This comparative calculation shows first that existing oversized ventilation systems present a very high energy saving potential. Oversizing in the past was common not only because of cheap energy. Smoking in public spaces and at work, in most European countries, was prohibited between 2006 and 2010. Many of the existing ventilation systems were dimensioned for smoking places and today they are oversized.

In the graph we can also see that adaptive demand control ventilation is of Class B. Low energy consumption for fans, combined to reduced airflow rate, give a good global result. Innovation for better control and promotion of natural or hybrid demand controlled ventilation, with very low or zero fan energy consumption, are good and low cost solutions.

The comparison shows also that heat recovery of high thermal efficiency is not sufficient for high global energy performance. The compared unit has good heat recovery efficiency (84%), but the relatively high Specific Power Input (0.44 W/(m^3/h) degrades the global Specific Energy Performance to class B. For high-rise buildings and for buildings with complex apartment arrangements where verticality is not possible, ducts create high-pressure drop and it is not possible to have sufficiently low fan energy consumption to obtain class A (SPI<0.32 W/(m^3/h).

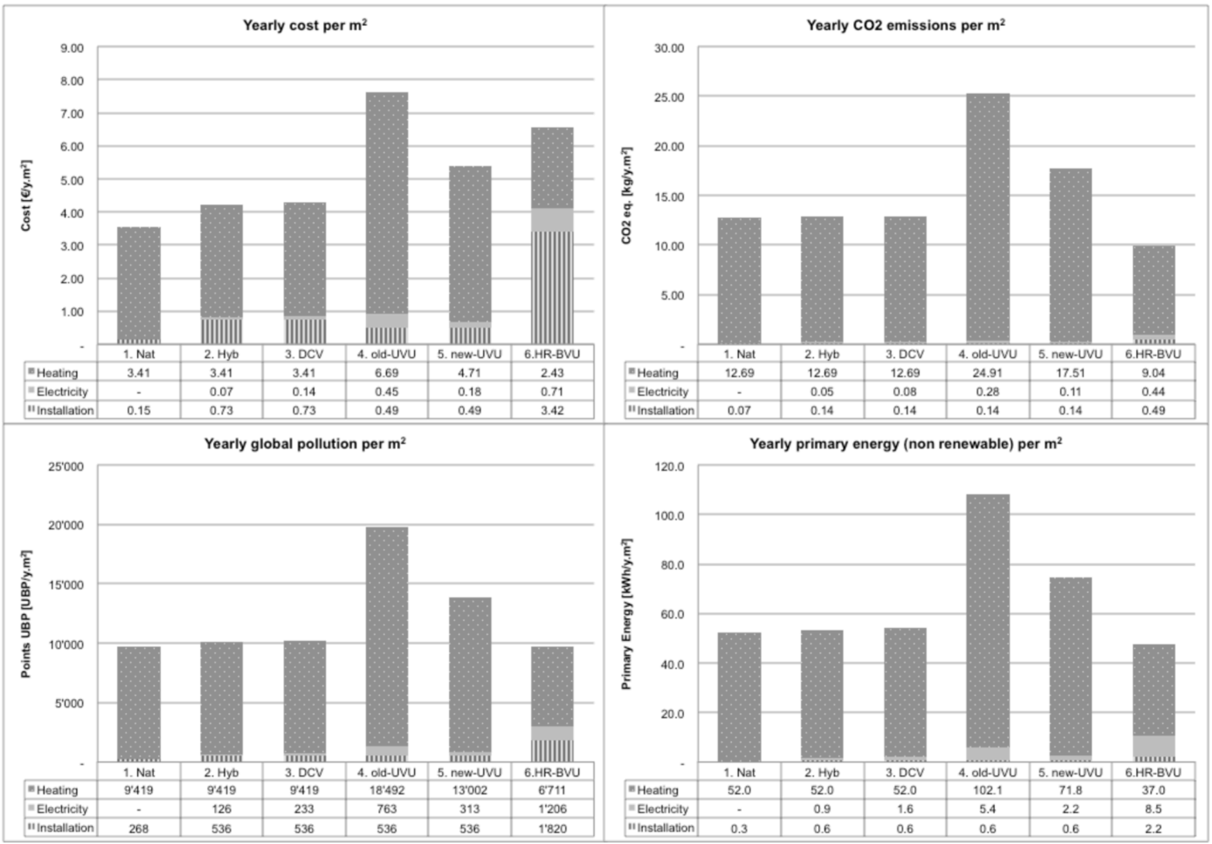
2.3 Ventilation performance according to life cycle assessment.

As EU 1254/2014 regulation uses a lot of default reference values, we try to confirm the conclusions with a life cycle assessment, taking into account design characteristics rather than reference values. We will also examine the effect of heating primary energy effect on ventilation overall performance. Instead of an overall heating efficiency of 75% and electricity primary energy 2.5, we will consider real primary energy of two energy systems: oil boilers of global system η 0.85 and a heat pump of global system COP 3.5.

We compare the 6 ventilation systems of table 1 applied on the renovated building case 6 of table 2. We apply the same dimensioning airflow rate for all systems, i.e 30 m^3/h per bedroom and living room (120 m^3/h in 4 room apartments and 90 m^3/h for 3 room apartments). 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).

Table 3. Values of q_{system} (net airflow rate due to ventilation system), $q_{infiltration}$ (infiltration and parasite airflow rate), AHD - annual heat demand, calculated with Lesosai software, and AEC – annual electricity final energy consumption of fans.

		1. Nat	2. Hyb	3. DCV	4. old UVU	5. new UVU	6.HR-BVU
q_{system}	$m^3/h.m^2$	0.70	0.70	0.70	2.40	1.2	0.32
AHD	$MJ/y.m^2$	130.4	150.1	150.1	256.0	180.0	106.2
AEC	$kWh/y.m^2$	0	0.33	0.61	2.0	0.82	1.73



Yearly cost per m²

	1. Nat	2. Hyb	3. DCV	4. old-UVU	5. new-UVU	6.HR-BVU
Heating	3.41	3.41	3.41	6.69	4.71	2.43
Electricity	-	0.07	0.14	0.45	0.18	0.71
Installation	0.15	0.73	0.73	0.49	0.49	3.42

Yearly CO2 emissions per m²

	1. Nat	2. Hyb	3. DCV	4. old-UVU	5. new-UVU	6.HR-BVU
Heating	12.69	12.69	12.69	24.91	17.51	9.04
Electricity	-	0.05	0.08	0.28	0.11	0.44
Installation	0.07	0.14	0.14	0.14	0.14	0.49

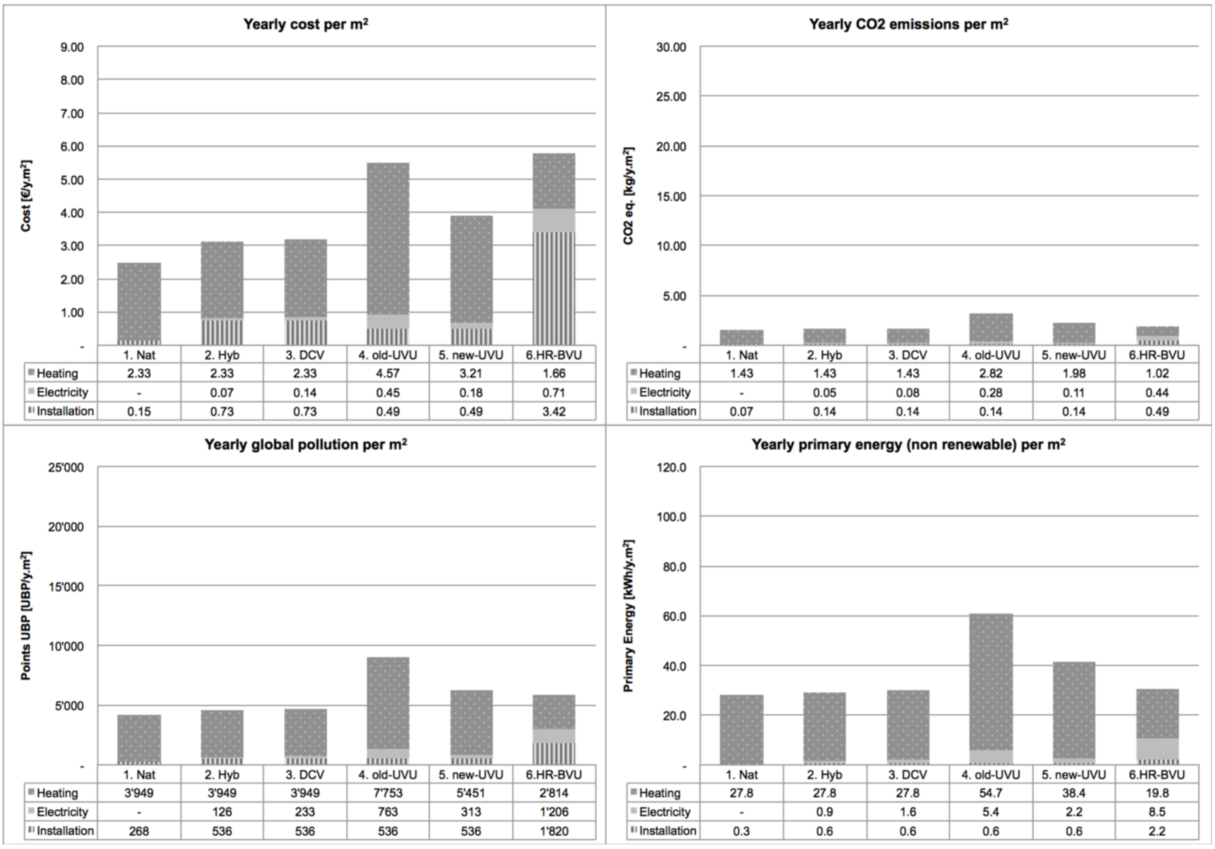
Yearly global pollution per m²

	1. Nat	2. Hyb	3. DCV	4. old-UVU	5. new-UVU	6.HR-BVU
Heating	9'419	9'419	9'419	18'492	13'002	6'711
Electricity	-	126	233	763	313	1'206
Installation	268	536	536	536	536	1'820

Yearly primary energy (non renewable) per m²

	1. Nat	2. Hyb	3. DCV	4. old-UVU	5. new-UVU	6.HR-BVU
Heating	52.0	52.0	52.0	102.1	71.8	37.0
Electricity	-	0.9	1.6	5.4	2.2	8.5
Installation	0.3	0.6	0.6	0.6	0.6	2.2

Figure 2. Results of life cycle cost, CO2, global solution and primary energy of 6 ventilation systems, applied on a building, considered to be heated by an ***oil heating system, η 0.85****.*



Yearly cost per m²

	1. Nat	2. Hyb	3. DCV	4. old-UVU	5. new-UVU	6.HR-BVU
Heating	2.33	2.33	2.33	4.57	3.21	1.66
Electricity	-	0.07	0.14	0.45	0.18	0.71
Installation	0.15	0.73	0.73	0.49	0.49	3.42

Yearly CO2 emissions per m²

	1. Nat	2. Hyb	3. DCV	4. old-UVU	5. new-UVU	6.HR-BVU
Heating	1.43	1.43	1.43	2.82	1.98	1.02
Electricity	-	0.05	0.08	0.28	0.11	0.44
Installation	0.07	0.14	0.14	0.14	0.14	0.49

Yearly global pollution per m²

	1. Nat	2. Hyb	3. DCV	4. old-UVU	5. new-UVU	6.HR-BVU
Heating	3'949	3'949	3'949	7'753	5'451	2'814
Electricity	-	126	233	763	313	1'206
Installation	268	536	536	536	536	1'820

Yearly primary energy (non renewable) per m²

	1. Nat	2. Hyb	3. DCV	4. old-UVU	5. new-UVU	6.HR-BVU
Heating	27.8	27.8	27.8	54.7	38.4	19.8
Electricity	-	0.9	1.6	5.4	2.2	8.5
Installation	0.3	0.6	0.6	0.6	0.6	2.2

Figure 3. Results of life cycle cost, CO2, global solution and primary energy of 6 ventilation systems, applied on a building, considered to be heated by ***heat pump COP 3.5****.*

On figures 2 and 3 we can observe several interesting results not coinciding with common belief, part of it adopted by some national regulations.

- Optimisation of ventilation offers a significant energy saving potential. Especially case 5 shows that optimisation of existing oversized ventilation units has much higher environmental impacts due to high energy consumption for heating. Independently of the heating energy source, cases 4 and 5 present, always, higher environmental and primary energy impacts.

- Demand control ventilation is a very good optimisation strategy. It combines low embodied energy, with low electricity consumption and reduced heating energy demand, presenting global performance comparable to bidirectional ventilation units with high performance heat recovery. With high performance energy sources (like heat pumps), it presents a global performance even better than some heat recovery systems.

- The most penalising factor for bidirectional ventilation units is electricity consumption. With large buildings, air transport distances are long and pressure drop high, implying high SPI and electricity consumption. As we see on figure 3, when the recovered heat contains low embodied energy, heat recovery is not the best optimisation strategy.

- Bidirectional ventilation system life cycle cost is always higher, even than a correctly unidirectional ventilation unit without adaptive control. It is cheaper only than an oversized old system, and this only when the building is heated with fossil fuel.

- Even when heat recovery unit is preferred in terms of primary energy, the global environmental impact is always higher than the demand control ventilation. System environmental impact is high, higher even than environmental impact of electricity consumption. Low system environmental impact of demand control natural ventilation, combined with no electricity consumption, makes this technique globally the cheapest and environmentally most friendly ventilation technique for the medium European climate (Central Europe).

- Life cycle analysis is coherent with ecodesign delegate EU regulations 1253/2014 and 1254/2014, especially for fossil fuel heat production. As the perimeter of these regulations is limited to ventilation system, they cannot make the difference between a building heated with oil and another heated with a high performance heat pump, with wood, or with district heating / waste source. But as we can see on the results, heating system source is a capital parameter to take into account in the optimisation strategy.

- Demand controlled natural ventilation present very good environmental performance, but someone must take into account the risks of backflow from the roof in some weather conditions. Ventilation quality is not the same with the other compared systems.

All these comparisons are first of all comparisons of the selected parameters. Selected parameters are never neutral. For these study we have selected systems, which are the most common to the Swiss refurbishment reality in 2015, with parameters prescribed by regulations and confirmed - validated by occasional measurements on the real building.

A key value for the results of figures 2 and 3 is q_{system}. Dimensioning of the nominal airflow rate was done according to the Swiss regulations, prescribing 30 m^3/h per bedroom and living room. In reality the building of case 6, table 2 was functioning before refurbishment with an oversized unidirectional ventilation unit extracting air from kitchen and bathrooms as in case 4. During the refurbishment project a study compared 3 alternative systems, those of case 3-DCV – demand control ventilation, case 5-new-UVU – resized unidirectional ventilation unit, working on high speed during working hours and low speed during night, and case 6-HR-BVU, regenerating heat recovery with bidirectional ventilation unit. All of them dimensioned with maximum airflow rate according to Swiss regulations (30 m^3/h per room – 0.95 m^3/m^2h).

The design team have chosen bidirectional heat recovery ventilation, because of two reasons. The owner wished very high-energy-standard refurbishment. But also, because of regulations, prescribing a heat recovery for ventilation in new buildings and refurbishment projects. The only way to avoid a bidirectional ventilation unit with heat recovery was to install a heat pump on the exhaust air to recover ventilation losses and preheat hot water, but as the building will be connected in the near future to a district heating with wood energy source, preheating of hot water with a heat pump was considered a "double investment".

q_{system} of case 6 (0.31 m^3/m^2h) is calculated by multiplying the dimensioning airflow rate with the mean heating season recovery efficiency (0.7). Measurements on a whole heating system validated exactly this hypothesis. q_{system} of adaptive ventilation – cases 1, 2, 3 (0.70 m^3/m^2h) is considered based on product specifications certified by CSTB (CSTB 2013), taking the most pessimistic value (0.5-0.7 m^3/m^2h). This value is based also on a diploma work that simulated and validated with measurements on the building of case 1 (Ferrini 2008). Case 4 was measured and case 5 is the dimensioning max airflow rate with additional flow rate of 26% infiltration penalty due to lack of control.

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.

3 THEORETICAL AND REAL PERFORMANCES

A whole year project observed the behaviour of case 2 and case 6 refurbished buildings to compare difference between projected and real energy consumption presented on figure 4.

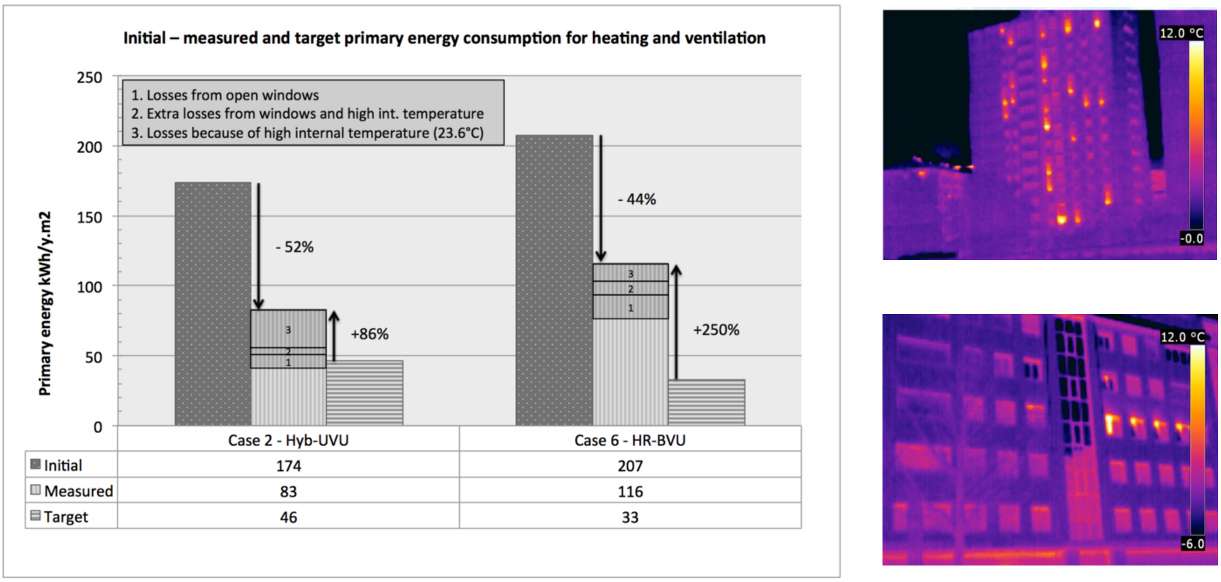


Figure 4. Initial (before refurbishment) primary energy consumption for heating and ventilation compared to measured and target energy consumption. As we see, for case 2 a reduction of 52% does not meet the objectives and energy consumption is 86% higher than the planned target. For case 6, energy consumption is 250% higher than planned. User behaviour (1, 2, 3) explain a big part of extra consumption.

As we see from figure 4, real consumption is much higher than the expected one although there is a significant reduction. The mean internal temperature during heating season was measured to 23.6°C causing 47% extra losses to building 2 and 23% to building 6. Observation of the buildings with a thermocamera showed a mean 10% of windows open for case 2 (extra 0.32 $m^3/h.m^2$ of air flow rate) and 18% of windows open for case 6 (extra 0.62 $m^3/h.m^2$ of air flow rate) provoking respectively 17% and 31% heat losses. If we take into account that apartments are overheated to 23.6°C, heat losses from the windows are even higher. These extra losses due to user behaviour are not depended on the ventilation system, although the extra window ventilation is added to the system airflow. However, the small differences between the global performance of demand control ventilation and heat recovery bidirectional ventilation are insignificant near to the real airflow in the buildings.

Ventilation system quality was almost perfect in both cases, planned and real airflow rates and efficiencies were very near, electricity energy consumption was near to planned and the building envelope insulation was correctly realised. Air quality in both building was controlled during the heating season and was also conform to the objectives with CO2 concentration < 1000 ppm for case 2 and < 1500 ppm for case 6. Performance differences are only due to occupant behaviour and for case 6 due to the heating system problems.

4 CONCLUSIONS

Chapter 2.2 showed that EU regulation is a good tool to choose a ventilation system. The comparison of 6 common ventilation systems in apartment buildings show that it is difficult to get class A, for ventilation systems with specific power input higher than 0.32 $W/(m^3.h)$. Demand control ventilation systems have slightly higher specific energy consumption, but very near to the compared heat recovery system are classified both to class B.

A life cycle environmental assessment in chapter 2.2 give similar results with the EU regulation for buildings heated with standard oil heating systems, but it shows that the optimisation strategy for ventilation depends also from the heating energy source. Heat recovery has better energy performances with oil fuel. However with low primary energy sources, such as a heat pump of COP 3.5, demand control ventilation – DCV benefits (low embodied energy and low electricity consumption) are more environmentally and energy effective than heat recovery benefits. Cost effectiveness of DCV is undeniable in all cases.

Chapter 3 showed that user behaviour with windows, although independent from ventilation system characteristics, has much more effect on building energy consumption than system differences. These losses are not taken into account in several energy regulations.

The conclusions of this analysis show that performance oriented regulations (like the EU regulations) are much more environmentally and energy sound than system oriented regulations (like Swiss regulations), that in sometimes they do not promote the best solution and sometimes prohibit good solutions.

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