PERFORMANCE PREDICTION OF DWELLING VENTILATION WITH SELF-REGULATING AIR INLETS

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ABSTRACT

This paper presents simulation results of the performance of ventilation systems with self-regulating inlets in different types of typical Flemish dwellings. Normal free air inlet vents have one major disadvantage: the complete dependence on the variable outside weather conditions (wind and temperature). The use of *self-regulating inlets* should minimize this impact, optimize the indoor comfort (no draught) and reduce the waste of energy by ventilation.

The multizone infiltration and ventilation simulation model COMIS has been used to investigate the impact of the use of self-regulating inlets. Different types of self-regulating inlets, corresponding to the different classes of inlets as mentioned in the new Flemish *Energy Performance Regulation* have been implemented in the ventilation model of different types of dwelling.

The paper presents the model premises and discusses the results of the simulations. To assess ventilation performance, the infiltration and ventilation flow rates, the *indoor air quality* and the reduction of *ventilation heat loss* by the use of self-regulating inlet vents are predicted and compared for the various types of inlets.

KEYWORDS

Self-regulating inlet, ventilation heat loss, Energy Performance Regulation, indoor air quality

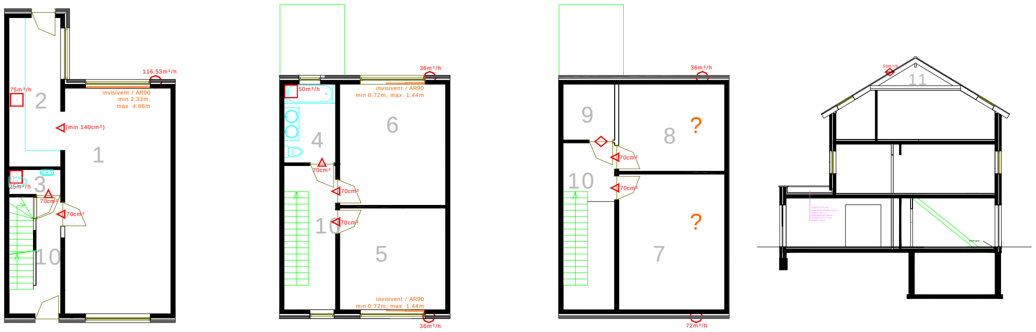
INTRODUCTION

This research is part of the research project ‘EL²EP residential buildings’ that aims at developing a methodology for a global optimization of residential buildings with an extremely low energy consumption and pollution level. The methodology looks for as well an economic, energetical and ecological optimum. These optima must also guarantee a good performance in relation to comfort, health, functionality and durability.

The optimization of the ventilation system takes up an important place in this research. Ventilation and infiltration heat loss is one of the major energy waists in a building. Otherwise is good ventilation primordial to guarantee a good indoor air quality. Free air inlets or ‘trickle vents’ are one of the possible ways to supply fresh outside air in dwellings. Normal inlet vents have one major disadvantage: the complete dependence on the variable outside weather conditions (wind and temperature). The purpose of self-regulating inlets is to minimize this impact and ideally deliver an almost constant fresh air supply indoors. The use of these self-regulating inlets should thus optimize indoor comfort (no draught) and should minimize the waste of energy by ventilation. This research evaluates the impact of the use of these self-regulating inlets regarding the energy savings and the indoor air quality. This is done with simulations on two typically Flemish building types.

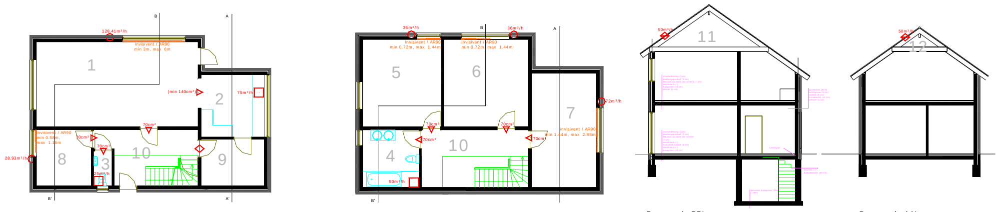
CASE STUDY HOUSES

This research focuses on two of the moist common Flemish dwelling types: the multiple-storied detached house and the row house (35 % and 31 % of total Flemish housing stock). For reasons of equivalence each dwelling type has the same quantities volumes (= 450 m³), surfaces of room and have common properties (inclined roof, open kitchen).



GROUNDFLOOR FIRST FLOOR SECOND FLOOR SECTION

ROWHOUSE



GROUNDFLOOR FIRST FLOOR SECTION A SECTION B

DETACHED HOUSE

FIGURE 1: Dwelling types

TABLE 1

test values for the air-tightness of dwellings

n_{50} (1/h)	Leakage air change rate for a pressure difference of 50 Pa
5.3 / 9.5	Average air-tightness of new Flemish row house / freestanding house (BBRI 1998).
3	Minimal air-tightness for house with balanced mechanical ventilation (NBN D 50-001)
1	Minimal air-tightness balanced mechanical ventilation with heat recovery (NBN D 50-001)
0.6	Minimal air-tightness for passive house standard

The air-tightness of a building has a great impact on the ventilation performance of a building. Therefore the investigation is done at four different levels for each dwelling type.

Climatic data is taken from the Test Reference Year Ukkel, witch gives hourly information about outdoor temperature, wind velocity and wind direction. The row house is implanted in a city landscape (wind velocity profile exponent $\alpha = 0{,}35$). The detached house is situated in the flat open country ($\alpha = 0.20$).To deal with a realistic use of the house, both houses are occupied by a four-headed family (two adults and two adolescents) and an indoor temperature schedule determine an optimal day and night temperature for each room.

VENTILATION MODEL AND SYSTEM

The ventilation of the dwellings is investigated with COMIS. This multizone infiltration and ventilation simulation model predicts the airflows in and trough the building, taking in account several intern and extern conditions.

The implemented ventilation system is designed with the Belgian Ventilation Standard (NBN D 50-001). This Standard stipulates that every normal room should receive enough (fresh) air as figured in TABLE 3. To create a almost permanent airflow the supply of the fresh air should take place in the dry rooms (living room, bedrooms, study) and the exhaust of the vitiated air in the humid rooms (kitchen, bathroom, toilet, washroom). Transfer between dry and humid rooms occurs through ventilation registers or gaps under the doors of the intervening rooms (hall) between the dry and the humid rooms.

TABLE 2
required airflow rates according to the Belgian Ventilation Standard and Flemish EPR

Required airflow rates according to the Belgian ventilation standard NBN D 50-001 (1991) and flemish EPR*		NBN D 50-001				ROW HOUSE		DETACHED HOUSE	
		type of ventilation requirement	basic requirement airflow	min	max	floor aera of room	nominal air-flow rate	floor aera of room	nominal air-flow rate
Type of room	ROOM		m^3/hm^2	m^3/h	m^3/h	m^2	m^3/h	m^2	m^3/h
dry rooms	living room	inlets	3.6	75.	150.	32.37	116.53	35.67	128.41
	bedroom 1		3.6	25.	72*	14.59	52.51	16.97	61.07
	bedroom 2		3.6	25.	72*	17.36	62.48	18.23	65.62
	bedroom 3		3.6	25.	72*	19.46	70.06	18.27	65.78
	study		3.6	25.	72*	12.48	44.93	8.04	28.93
humid rooms	open kitchen in livingroom	exhausts	3.6	75.	150.	10.42	75.	10.24	75.
	toilet		3.6	25.	25.	1.71	25.	1.68	25.
	bathroom		3.6	50.	75.	5.48	50.	8.04	50.
	washroom		3.6	50.	75.	3.9	50.	7.68	50.
intervening rooms	hall					29.91		28.53	
	all transfer openings			25.			25.		25.

SELF-REGULATING INLETS

Free air inlets or 'trickle vents' are one of the possible ways to supply fresh outside air in the dry rooms of the dwellings. Most common they are integrated in the upper part of the windows. Wind pressure and temperature differences between in- and outside create a pressure difference over the inlet witch causes an airflow through the inlet.

$$Q = C_q \Delta P^n \quad \text{(eqn. 1)}$$

The power law (eqn. 1) expresses the dependency of the airflow Q (m^3/s) from the pressure difference ΔP (Pa). The flow exponent n express the type of flow: values from 0.5 (turbulent) till 1 (laminar). The mass flow coefficient C_q ($m^3/s.Pa$) is related with the size of the opening and the density of the air flowing through the opening.

This means that sometimes the naturally created pressure difference is so low that the supply of fresh air in a room is insufficient. At other times the supply of fresh air is much higher than necessary for an acceptable indoor air quality. Self-regulating inlets minimize this impact and ideally deliver an almost constant fresh air supply indoors, independent of the pressure difference across the inlet. A self-regulating inlet will reduce the section through witch the incoming airflow at increasing pressure differences. Theoretically the mass flow coefficient C_q will thus decrease at high pressures. Most of the existing self-regulating inlets create this effect by a flap witch is, due to the pressure of the airflow pushed or rotated in front of the opening and so reducing this opening.

FLEMISH ENERGY PERFORMANCE REGULATION (EPR)

From January 2006 the new Flemish Energy Performance Regulation (EPR) will come operative. The imposed minimal thermal isolation requirements and the maximal E-value (representing the primary energy consumption) tries to minimize the energy consumption of the building and their installations. The included ventilation requirements guaranty a good indoor air quality. The ventilation requirements of the EPR oblige to apply the Belgian ventilation standard NBN D 50-001 (1991).

Using self-regulating inlets reduces the E-value of the building. To calculate the E-value of a building and its installations, the average infiltration and exfiltration airflow $\dot{V}_{in/exfil,heat}$ and the average dedicated ventilation airflow $\dot{V}_{dedic}$ (through inlets and exhaust openings) have to be determined. If we only take in account variable air-tightness and self-regulating inlets, EPR propose the following (simplified) formulas:

$$\dot{V}_{in/exfil,heat} = 0{,}04 * n_{50} * V_{EPW} \qquad \text{(Eqn. 2)}$$

$$\dot{V}_{dedic} = \left[0{,}2 + 0{,}5 * EXP(-V_{EPW} / 500)\right] * V_{EPW} * \left[1 + 0{,}5\left(\frac{r_{nat.\sup} + 0{,}2 + 0{,}025}{0{,}425}\right)\right] \qquad \text{(Eqn. 3)}$$

TABLE 3

Classification of self-regulating performances of inlet in function of the pressure difference

pressure difference P (Pa)	Airflow relatively to the nominal air flow q_N at 2 Pa								
	Class P0	**Class P1**		**Class P2**		**Class P3**		**Class P4**	
0 Pa ≤ P ≤ 2 Pa		≥ 0.8√(P/2)	≤ 1.2 q_N	≥ 0.8√(P/2)	≤ 1.2 q_N	≥ 0.8√(P/2)	≤ 1.2 q_N	≥ 0.8√(P/2)	≤ 1.2 q_N
2 Pa	q_N	q_N		q_N		q_N		q_N	
2 Pa ≤ P ≤ 5 Pa		≥ 0.8 qN	≤ 1.8 q_N	≥ 0.8 qN	≤ 1.8 q_N	≥ 0.8 qN	≤ 1.5 q_N	≥ 0.8 qN	≤ 1.2 q_N
5 Pa ≤ P ≤ 10 Pa		≥ 0.7 qN	≤ 2.3 q_N	≥ 0.7 qN	≤ 2 q_N	≥ 0.7 qN	≤ 1.5 q_N	≥ 0.8 qN	≤ 1.2 q_N
10 Pa ≤ P ≤ 25 Pa		≥ 0.5 qN	≤ 3 q_N	≥ 0.5 qN	≤ 2 q_N	≥ 0.5 qN	≤ 1.5 q_N	≥ 0.8 qN	≤ 1.2 q_N
25 Pa ≤ P ≤ 50 Pa		≥ 0.3 qN	≤ 3 q_N	≥ 0.3 qN	≤ 2 q_N	≥ 0.3 qN	≤ 1.5 q_N	≥ 0.3 qN	≤ 1.5 q_N
50 Pa ≤ P ≤ 100 Pa		/	≤ 3 q_N	/	≤ 2 q_N	/	≤ 2 q_N	/	≤ 2 q_N
100 Pa ≤ P ≤ 200 Pa		/	≤ 4 q_N	/	≤ 3 q_N	/	≤ 3 q_N	/	≤ 3 q_N
correction factor $r_{nat.sup}$	**0.2**	**0.18**		**0.14**		**0.08**		**0.02**	

TABLE 4

average infiltration and ventilation airflow of row house $\dot{V}_{in/exfil,heat} + \dot{V}_{dedic}$,

air-tightness n50 (1/h)	**Class P0**	**Class P1**		**Class P2**		**Class P3**		**Class P4**	
	V_{P0}	V_{P1}	V_{P1}/V_{P0}	V_{P2}	V_{P2}/V_{P0}	V_{P3}	V_{P3}/V_{P0}	V_{P4}	V_{P4}/V_{P0}
5.3	300.3	296.7	*99%*	289.5	*96%*	278.7	*93%*	267.9	*89%*
3	269.5	265.9	*99%*	258.7	*96%*	247.9	*92%*	237.1	*88%*
1	242.6	239.0	*99%*	231.8	*96%*	221.1	*91%*	210.3	*87%*
0.6	237.3	233.7	*98%*	226.5	*95%*	215.7	*91%*	204.9	*86%*

The V_{EPW} is the volume of all the rooms witch are thermally isolated from the exterior. To determine the correction factor of the energy saving qualities of the self-regulating inlets $r_{nat.sup}$, the inlets are divided in 5 different classes: P0 (not self-regulating) up to P4 (good self-regulating), see TABLE 3.

TABLE 4 presents the calculated $\dot{V}_{in/exfil,heat} + \dot{V}_{dedic}$. According to the EPR the use of good selfregulating inlets (P4) should be able to decrease the infiltration and ventilation airflow with 11 to 14 % depending of the air-tightness of the building.

SIMULATION RESULTS

In the different test house models we have implemented theoretical self-regulating inlets of each class. These inlet models react as follow: from 0 up to the upper pressure difference limit for each inlet class, the airflow rate through the inlet follows the power law. The upper pressure difference limit is taken at the range of 2 up to 5 Pa. At higher pressure differences the airflow rate remains constant. For example an inlet of class P2 with a nominal airflow rate (at 2 Pa) of 100 m^3/h will follow the power law up to 180 m^3/h (= 1.8 * q_N). This will be at a pressure difference of 6.48 Pa. At higher pressure differences the airflow rate remains constant at 180 m^3/h.

The *total airflow rate* (infiltration and ventilation) is calculated with COMIS for the different classes of inlets and for the different air-tightness values. The absolute results and the results relative to non self-regulating inlets is given in table 5.

TABLE 5

average infiltration and ventilation airflow rate of row house and detached house

air-tightness n50 (1/h)	**Class P0**	**Class P1**		**Class P2**		**Class P3**		**Class P4**		
	V_{P0} (m^3/h)	V_{P1} (m^3/h)	V_{P1}/V_{P0}	V_{P2} (m^3/h)	V_{P2}/V_{P0}	V_{P3} (m^3/h)	V_{P3}/V_{P0}	V_{P4} (m^3/h)	V_{P4}/V_{P0}	
5.3	345	345	*99.9%*	345	*99.9%*	345	*99.7%*	343	*99.3%*	**ROW HOUSE**
3	282	281	*99.9%*	281	*99.9%*	281	*99.7%*	279	*99.1%*	
1	224	224	*99.9%*	224	*99.9%*	223	*99.5%*	221	*98.6%*	
0.6	212	212	*99.9%*	212	*99.9%*	211	*99.5%*	208	*98.4%*	
5.3	370	367	*99.2%*	367	*99.2%*	365	*98.5%*	359	*97.2%*	**DETACHED HOUSE**
3	303	299	*98.9%*	299	*98.9%*	296	*98.0%*	291	*96.1%*	
1	239	235	*98.4%*	235	*98.4%*	232	*97.0%*	226	*94.6%*	
0.6	225	221	*98.2%*	221	*98.2%*	218	*96.8%*	212	*94.2%*	

The main total airflow rate decreases almost 1 % for the row house and 3 to 6 % for the detached house by using the best self-regulating inlets. Comparing with the results of EPR, the gains are in these two cases a bit overestimated in the EPR.

To have an idea of the *energy loss* by ventilation we approximate the ventilation heat loss (or the enthalpy) for a whole heating season with the following formula:

$$E = \sum_{i=1}^{hoursofheatingseason} 3600 \rho c_p Q_i \left(T_{\text{int}(i)} - T_{ext(i)}\right) \qquad (J) \quad (eqn.\ 4)$$

The total air infiltration and ventilation rate at hour i Q (m^3/s) will have to be heated from outside temperature $T_{ext(i)}$ (K) to the indoor temperature $T_{int(i)}$ (K). When we neglect the moisture, the sensible heat (enthalpy) can be calculated when we know the air density ρ (kg/m^3) and the specific heat of dry air c_p (J/kg.K). By placing self-regulating inlets, the energy demand is reduced with about 1% in the row house and 2.3 to 4.8 % in the detached house. The absolute impact of placing self-regulating inlets is greater in air-tight dwellings but nevertheless the energy impact of increasing the air-tightness of a house is much greater than the impact of placing self-regulating inlets.

TABLE 6

energy impact of ventilation and air infiltration

air-tightness n50 (1/h)	ROW HOUSE				DETACHED HOUSE			
	Class P0	**Class P4**	**ΔE**	**ΔE**	**Class P0**	**Class P4**	**ΔE**	**ΔE**
	E_{P0} (kWh)	E_{P4} (kWh)	$E_{P0}-E_{P4}$ (kWh)	E_{P4}/E_{P0}	E_{P0} (kWh)	E_{P4} (kWh)	$E_{P0}-E_{P4}$ (kWh)	E_{P4}/E_{P0}
5.3	6240	*6197*	*42*	*0.7%*	6684	*6528*	*156*	*2.3%*
3	5144	*5100*	*44*	*0.9%*	5537	*5358*	*179*	*3.2%*
1	4135	*4078*	*57*	*1.4%*	4434	*4238*	*196*	*4.4%*
0.6	3921	*3859*	*62*	*1.6%*	4194	*3994*	*200*	*4.8%*

The impact of self-regulating inlets on the *indoor air quality* is evaluated with the European Standard EN 13779. Although the scope of this Standard is not the naturally ventilated residential buildings, the mentioned classification of the indoor air quality (IDA classification) is useful to compare the different situations. To evaluate the indoor air quality, the percentage of time with at least a moderate indoor air quality (IDA 3 or better) is calculated. To have at least IDA 3 the CO2-concentration in the room must be lower than 1000 ppm above the outdoor concentration level.

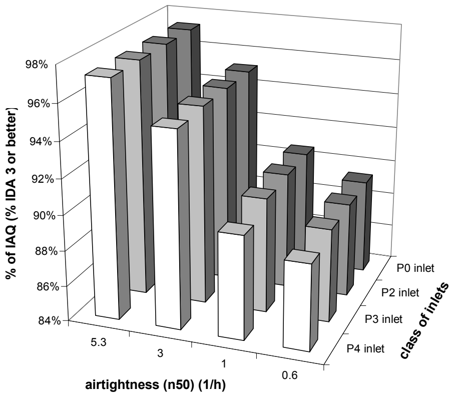


Figure 2: time % of IDA 3 or better for the row house

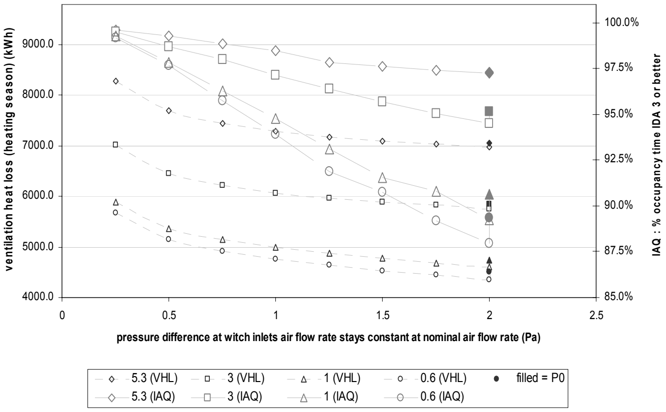


Figure 3: ventilation heat loss (VHL) and Indoor Air Quality (IAQ) with varying self-regulating startpoints (0.25 Pa -> 2 Pa)

Figure 2 shows that the use of self-regulating inlets on the indoor air quality is almost nihil (< 0.8 %). The influence of self-regulating inlets on the indoor air quality takes place at moments that the indoor air quality is already good (the low CO_2-concentrations become a bit higher).

When the *pressure difference starting point for self-regulating* is situated between 0 en 2 Pa we observe some quiet remarkable phenomena (figure 3). The lower the pressure difference starting point the higher the airflow rates, the better the IAQ, but also the higher the ventilation heat loss. The use of '1,75Pa'-inlet gives the *same* ventilation heat loss than non self-regulating inlets (P0). The '0,25Pa-inlet' will have 18 % (n_{50} = 5,3 h^{-1}) to 28 % (n_{50} = 0,6 h^{-1}) *more* ventilation heat loss than with non self-regulating inlets.

In reality the self-regulating starting point is more a range of pressure differences in witch the inlet evaluate to an almost constant airflow. To evaluate the effect of the self-regulating inlet on the ventilation heat loss the complete airflow rate path must be known, certainly in the range from 0 to 2 Pa. At this moment this information is rarely available for the available inlets. A second important problem is the different design regulations of ventilation. Installing a good Dutch inlet (with a design nominal airflow rate at *1 Pa*) in a building designed with the Belgium Ventilation Standard gives more or less a similar effect as the ideal '1Pa'-inlet from our previous simulation. This means 6 % more ventilation heat loss than with normal non self-regulating inlets.

CONCLUSION

Self-regulating inlets can have a positive impact on the ventilation heat loss, but the influence predicted in the EPR occurs to be overestimated in the tests. A expert choice of self-regulating inlets and a good ventilation system design is primordial for a good performance.

REFERENCES

Belgian Building Research Institute (BBRI) and Wenk Sint-Lukas Gent. (1998). *SENVIVV: Studie van de Energieaspecten van Nieuwbouwwoningen in Vlaanderen: Isolatie, Ventilatie, Verwarming. Eindverslag.* Project 930.256/WTCB, Brussels.

BIN. (1991). *Ventilatievoorzieningen in woongebouwen*, Belgian Institute for Standardisation, NBN D 50-001, Brussels.

CEN. (2004), *Ventilation for non-residential buildings –Performance requirements for ventilation and room-conditioning systems*, EN 13779, European Committee for Standardization (CEN), Brussels

De Gids W.F. (1997), Controlled air flow inlets. *Air Infiltration and Ventilation Centre, Proceedings of "Ventilation and Cooling", 18th Annual Conference*, Athens, Greece, 23-26 September 1997, **Volume 1**, pp 245-256.

Liddament, M.W. (1996), *A Guide to Energy Efficiënt Ventilation,* Air Infiltration and Ventilation Centre, Coventry, Great Britain.

Maeyens, J. & Janssens, A. (2003). Air exchange rates, energy losses and indoor air quality duet o the application of the Belgian ventilation standard. *Proceedings of the 2^{nd} International conference on research in building physics,* Belgian, Leuven, 14-18 September.

Maeyens, J. & Janssens, A. (2003a). Impact of residential natural ventilation and air-tightness techniques on the energy loss and indoor air quality. *proceedings of the 24th AIVC conference & BETEC conference - Ventilation, Humidity control and energy*, pp 289-294.