ON THE IMPACT OF URBAN ENVIRONMENT ON THE PERFORMANCE OF NATURAL AND HYBRID VENTILATION SYSTEMS

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ABSTRACT

The impact of the urban environment on natural and hybrid ventilation was investigated through experimental and computational procedures in the framework of RESHYVENT European Project. An experimental campaign was organized in two urban street canyons in Athens, during summer 2002, consisting of field and indoor experiments. The experiments aimed at the investigation of the impact of the various urban features on the efficiency of different ventilation systems. Natural, mechanical and hybrid ventilation experiments were carried out in three building apartments under different ambient conditions. A comparison analysis, in terms of air exchange rates and air-exchange efficiency, was performed between the studied ventilation systems. Besides, computational calculations of air flow characteristics were carried out for advanced RESHYVENT hybrid ventilation systems considering a great number of simulation scenarios. The most important constraints of the urban environment on the performance of hybrid ventilation systems are highlighted.

KEYWORDS

Urban environment, hybrid ventilation, field experiments, ventilation experiments, computational procedures.

INTRODUCTION

The potential of natural ventilation systems can be seriously reduced in the urban environment because of its ambient characteristics and mainly due to low wind speeds, high ambient temperatures and increased external pollutant and noise levels. Hybrid ventilation is known to exploit the benefits of both natural and mechanical ventilation modes, to optimize the performance of ventilation, both from the thermal comfort and the indoor air quality point of view (Heiselberg, 2002). It is particularly important in urban canyons where the potential of natural ventilation is reduced due to attenuation of wind speeds (Santamouris, 2001). Thus, it is important to investigate the performance of hybrid ventilation systems under specific urban conditions in order to improve our knowledge and to attain optimum performance of these systems.

An urban measurement campaign was organized in two street canyons very near to the centre of Athens during summer period. Air and surface temperatures, wind speeds, wind directions and outdoor air characteristics (TVOC's, CO_2, CO and NO_x) were measured inside and outside the street canyons together with ventilation and air quality measurements inside the buildings. Infrared thermographies were taken on an hourly basis together with surface temperatures on street level and on the opposite building walls. Ventilation experiments were performed consisting of natural, mechanical and hybrid ventilation. The experiments were implemented on a 24-hour basis, for a number of five consecutive days for each canyon. The results obtained from experimental procedures were analysed in order to evaluate the impact of the urban parameters on the performance of hybrid ventilation. Also the air exchange rates and air-exchange efficiency were estimated in the three building apartments. A comparative study of the performance of different ventilation systems in urban canyons was performed. In order to complete the work on the parameters that influence hybrid ventilation in urban environment, computational calculations of air flow characteristics were implemented using the multizone airflow and thermal model COMIS/TRNSYS. A detailed sensitivity analysis was made, considering a great number of simulation scenarios.

The aim of this study is to summarize the work performed within RESHYVENT project in order to investigate the impact of the urban environment, as well as, to identify the most important limitations on the performance of natural and hybrid ventilation systems.

EXPERIMENTAL RESEARCH OF NATURAL AND HYBRID VENTILATION IN URBAN CANYONS

The total experimental campaign was based on field and indoor experiments aiming at the investigation of the impact of the various urban features on the applied ventilation system efficiency.

Site Description and Field Measurements

The field measurements were performed every 30secs for a number of 5 consecutive days, during June to September 2002 and they are illustrated in Figure 1.

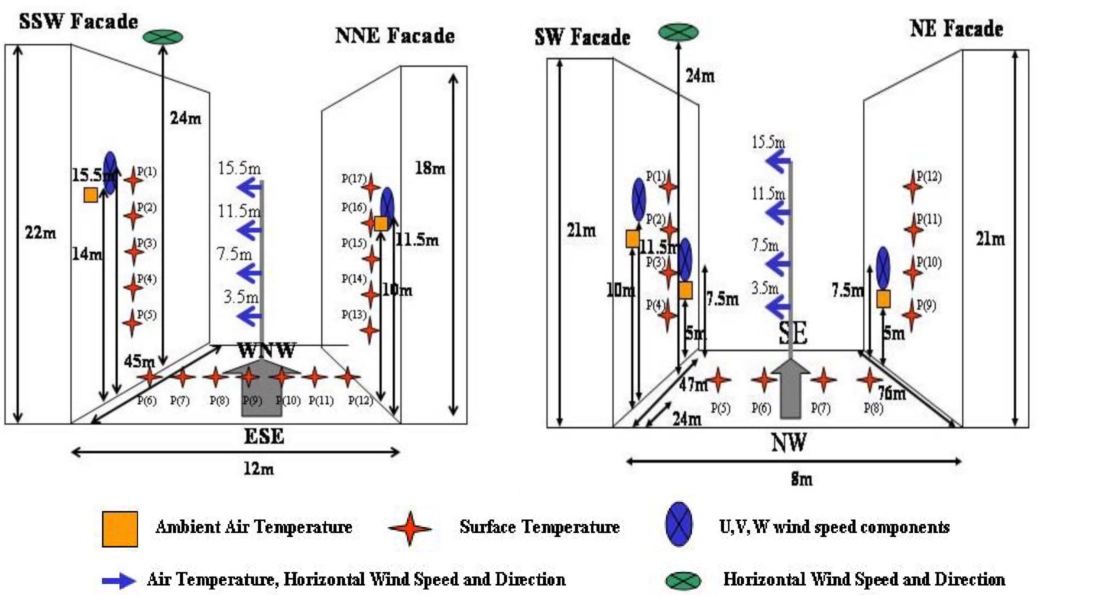

Figure 1: A schematic representation of the field measurements performed inside and outside the two urban street canyons (left is Ragavi and right is Ag. Fanouriou canyon)

The two studied canyons are different, in terms of geometrical characteristics and orientation (Table 1). Namely, Ragavi street is an almost regular and asymmetric street canyon, whereas Ag. Fanouriou is a deep and symmetric canyon. Both canyons are typical with regard to the surrounding urban scale, however they presented a different microclimate, as it was investigated from the analysis of measured parameters (Niachou et al, 2005c).

TABLE 1
Characteristics of studied street canyon and building apartments

Canyon	Orientation from North	H/W	L/H	Measured Period	Apartment	Area (m^2)	Volume (m^3)
Ragavi	100	1.7	2.3	19/07-23/07/02	A_1	65	112
Ag. Fanouriou	137	2.6	3.6	28/08/-2/09/02	A_2	78	130
				11/09-15/09/02	A_3	50	120

Ventilation Experiments

A total number of 114 ventilation experiments were conducted consisting of 3 infiltration, 30 natural, 34 mechanical and 47 hybrid ventilation experiments. Each experiment consisted of two parts. At first the tracer gas was injected inside the rooms and afterwards the tracer decay concentration was measured. Internal fans were used to homogenize to the extend that it was possible the internal concentrations. In A_2 and A_3 experiments two tracer gases (N_2O, SF_6) were injected during the first stage in two different zones.

Natural ventilation experiments were performed with single-sided and cross ventilation configurations. In case of single-sided ventilation, openings were considered either, from the canyon or, the rear canyon facade. Cross ventilation experiments were studied with two or more openings placed at the front and back canyon side. Mechanical ventilation was tested experimentally with one or two fans operating in inlet or extract modes. All possible configurations were studied with the fans placed on both building external walls.

Hybrid ventilation experiments were focused on fan-assisted natural ventilation, where supply and extract fans were used to enhance pressure differences by mechanical fan assistance. The fans were installed to openings adjacent to the canyon and rear façades operating in inlet or extract modes together with natural ventilation through one or two openings.

EVALUATION OF THE EXPERIMENTAL RESULTS IN URBAN CANYONS

Field Measurements

In order to understand the impact of the urban environment on the potential of natural and hybrid ventilation, a detailed analysis of air and surface temperature distribution, as well as, of the observed airflow characteristics inside the two studied street canyons was performed. The observed differentiations of wind and temperature distribution have been discussed in order to get a better insight of the urban canyon microenvironment. The latter has been shown to have a direct impact on the ventilation performance in urban buildings (Niachou et al, 2005a, 2005b).

Ventilation Measurements

The investigation focused on air-exchange rates and air-exchange efficiency in the three urban building apartments. A comparative study of the performance of different ventilation systems in urban canyons has been performed (Niachou et al, 2005a, 2005b), as shown in Figure 2. Besides a comparison was made between single and multi-zone methodologies. The multi-zone approach, in spite of its better theoretical basis, has been found more sensitive to the accuracy of the measured concentrations, especially when a single tracer is used. Moreover, a methodology to determine the ventilation efficiency in two tracer gas experiments is proposed (Niachou et al, 2005b).

Natural cross ventilation has been shown to lead to higher ACH values than single-sided natural ventilation under different ambient conditions. Hybrid ventilation has been shown to be associated with rather lower ACH than natural cross-ventilation, but slightly higher ACH under single-sided ventilation or calm conditions. This, of course, does not mean that hybrid ventilation may not be of use during winter times, or during those few days during the summer that natural ventilation is not an effective means of cooling, either due to low winds or due to high ambient temperatures.

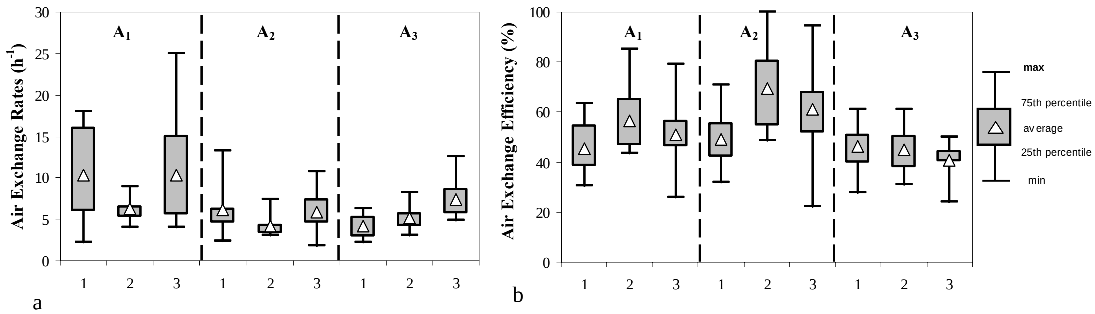

Figure 2: Boxplots of estimated air-exchange rates and air-exchange efficiency values (%) based on multi-zone method (h^{-1}) for natural (1), mechanical (2) and hybrid (3) ventilation experiments under different ambient conditions

Nevertheless, there is more to evaluating hybrid ventilation than comparing the mean values of the air exchange rates, which have a relatively high spread for natural ventilation. Despite the small number experiments performed under calm conditions (wind speed lower than 0.2m/s), it was confirmed that hybrid ventilation has an advantage over natural under windless conditions (Figure 3). It should also be stated that apart from the comparison of estimated air exchange rates, there is a qualitative difference between natural and hybrid ventilation, in terms of air-exchange efficiency. Higher air-exchange efficiency values have been estimated in hybrid ventilation experiments in comparison with single-sided ventilation. In most cases, there is also an improvement relative to natural cross ventilation.

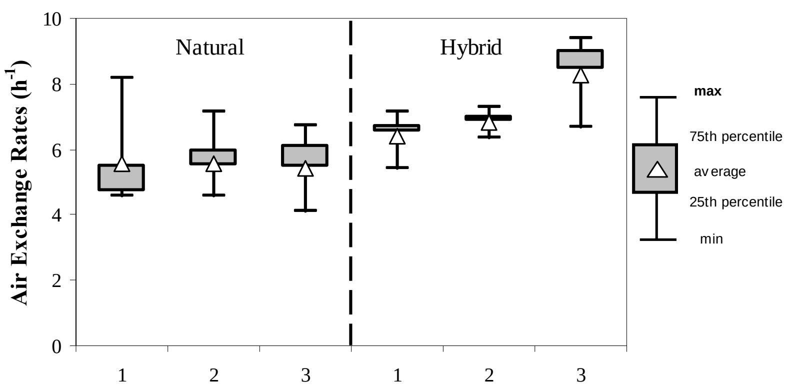

Figure 3: Boxplots of estimated air exchange rates (h^{-1}) for natural (single-sided) and hybrid ventilation experiments at A_3 apartment, under calm conditions based on the single-zone (1,2) and multi-zone (3) methodologies

COMPUTATIONAL CALCULATIONS OF AIRFLOW CHARACTERISTICS IN URBAN CANYONS

In order to complete the work on the parameters that influence hybrid ventilation in urban environment, computational calculations of airflow characteristics were performed, using the multizone airflow and thermal model COMIS/TRNSYS. The reference building is a single-family house, namely an apartment, located inside an urban street canyon. Advanced hybrid ventilation systems have been studied, based on RESHYVENT concept and on RESHYVENT consortiums. Five different canyon configurations have been studied, having an aspect ratio (H/W) equal to 1, 1.5, 2, 2.5 and 3. The rear canyon facades were studied either with local or with no local obstructions. The undisturbed wind speed data has been translated into canyon data based on the developed research methodology within URBVENT European Project. The Cp-values for the two external building facades and for the five canyon geometries were estimated by "CP-generator" by TNO.

A detailed sensitivity analysis has been performed considering all the following parameters:

- Canyon Geometry
- Canyon Layout
- Outdoor Urban Air Characteristics
- Indoor Pollutant Emissions
- Building Leakage
- Demand Control

A set of simulations under steady state and dynamic conditions have been performed. The dynamic simulations were performed on an hourly basis within a year period for different climates. A full data basis with all simulation scenarios and results are given in final report of WP10 of RESHYVENT project (Niachou and Santamouris, 2005). These airflow characteristics helped to get a better insight of the impact of the urban environment on the ventilation effectiveness.

Description of Hybrid Ventilation systems

The two hybrid ventilation systems were studied consisting of demand control, a low-pressure system supported by wind and buoyancy and balancing supply and exhaust.

Pilot RESHYVENT Ventilation System

The first studied hybrid ventilation system (Figure 4) is a pilot ventilation system, based on RESHYVENT concept. It consists of two inlet/extract fans attached on the external building walls (canyon and rear canyon facades), a balancing supply and exhaust system (with a corresponding performance of 795m^3/h at 0 Pa pressure difference) and a low pressure system supported by wind and buoyancy.

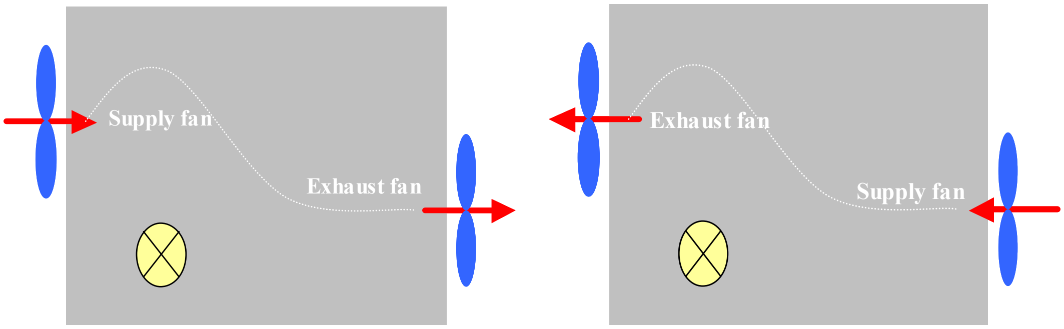

Figure 4: A representation of the pilot hybrid ventilation system with the two inlet/extract fans installed at the two external building walls. An inverse operation of the fans is considered on the right photo

RESHYVENT Hybrid Ventilation System for Moderate Climates

The second studied ventilation system is one of the four RESHYVENT ventilation systems which was developed for moderate climates and employs natural air supply and natural or mechanical air exhaust duct system. Heating and cooling were also specified for the apartment (zone). The heating set point was 16°C and the cooling set point was 26°C.

The system consists of self-regulating air inlets, DC fan, motorized damper, flow meter, central control unit, CO_2 sensors and ductwork. The roof outlet is considered 1m above the building roof in all canyon geometries. The demand control of the ventilation system is based on monitoring of CO_2 in rooms. There is a CO_2 sensor and a self-regulating air inlet in each room. The self-regulating inlets are usually positioned above windows. These inlets are able to maintain a constant flow rate for the pressure difference across the facade higher than 1 Pa. The exhaust fan is used when the air exhaust through the duct is lower than the demanded flow. The efficiency of the hybrid ventilation system in the different canyon geometries was also investigated with pressure-dependent grilles in order to better realize the canyon effect. When the CO_2 concentration is below a threshold value (etc. 1200 ppm) then ventilation system ventilates only at the minimum level (10dm^3 s^{-1}). When the concentration of CO_2 in a room increases to 1200 ppm, then the inlet in this room opens. The inlet opens to a certain target flow rate, which depends on the nominal flow rate of the inlet and the gradient of increase of the CO_2 concentration. The airflow rate in the exhaust increases to a value which is the sum of the basic ventilation flow rate and the target flow rates of the opened inlets. The ventilation system first tries to achieve the exhaust flow rate by adjusting the motorized damper in the vertical exhaust duct (stack). If natural driving forces are not sufficient then the fan is switched on and its speed adjusted to match the demanded flow rate. The RESHYVENT ventilation system was examined either with natural or hybrid exhaust modes. In the natural ventilation exhaust mode, the exhaust airflow rate from the duct was affected by the natural driving forces. The total demanded flow rates (dm^3/s) was based on occupancy and activity schedule within the 24-hour period (Table 3). In case of the hybrid ventilation system, the exhaust fan had to meet the total demanded airflow rate.

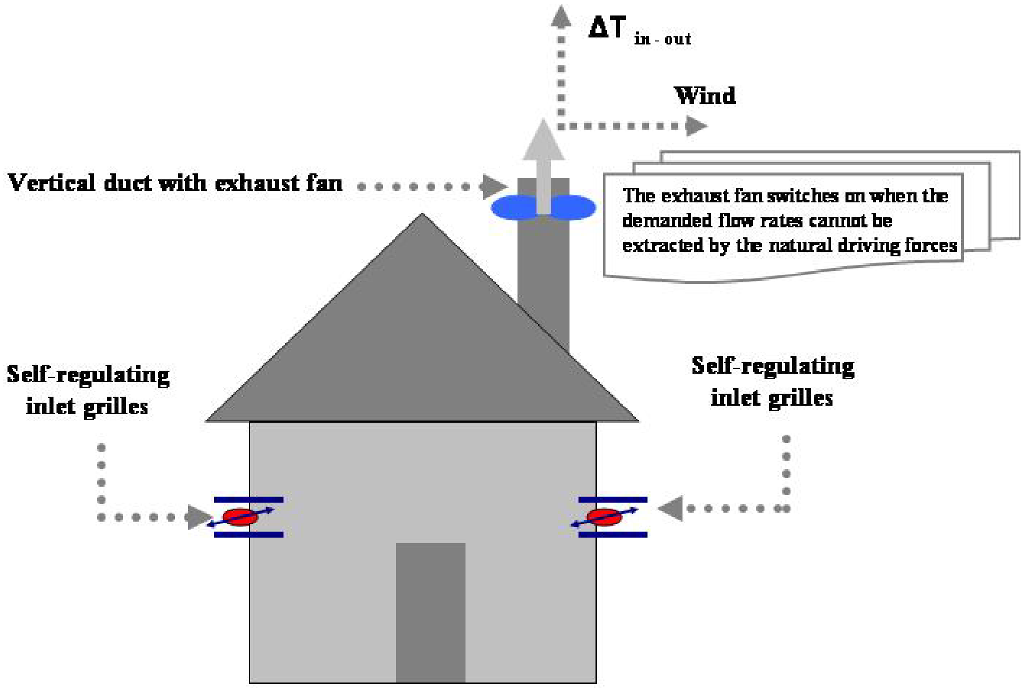

Figure 5: Representation of the RESHYVENT hybrid ventilation system for moderate climates

The inlet grilles were considered fully open between 0Pa and 0.5 Pa. Above 0.5 Pa the self-regulating inlet grilles started to control and there was no longer a standard relation between pressure and airflow. The airflow admission (dm^3/s) in relation with the pressure difference for self-regulating and pressure-dependent air inlets given in Tables 4-5.

TABLE 3
Demanded exhaust flow (dm^3/s)

Time	Demanded flow (dm^3/s)
0-6h	28
6-8h	42
8-17h	21
17-19h	42
19-22h	28
22-23h	42
23-24h	28

TABLE 4
Characteristics of self-regulating inlets

ΔP (Pa)	Flow rate (dm^3/s)
0	0
0.1	8.2
0.2	11.6
0.3	14.2
0.4	16.4
0.5	18.4
0.6	19.0
0.7	21.7
0.8	22.5
0.9	24.0
1	26
50	26

TABLE 5
Characteristics of pressure-dependent inlets

ΔP (Pa)	Flow rate (dm^3/s)
0	0
0.1	8.2
0.2	11.6
0.3	14.2
0.4	16.4
0.5	18.4
0.6	19.0
0.7	21.7
0.8	22.5
0.9	24.0
1	26
2	36.7
5	58.0
10	82.1
50	183.6

COMPUTATIONAL RESULTS

A detailed analysis of the efficiency of the pilot and RESHYVENT ventilation systems has been performed in different urban situations. The main concluding results regarding the performance of these systems are discussed in the following paragraphs.

Concerning the efficiency of the pilot RESHYVENT hybrid ventilation system, based on the RESHYVENT concept, the most important results are:

- The combined effect of wind and temperature difference resulted in greater airflow rates inside the reference building. However, a better performance was observed when wind direction was towards the building walls without local obstructions around it, rather than, when the wind blows towards the shielded building walls. The absolute minimum total ventilation rates were observed, either for windless conditions, or for parallel to the canyon axis flow.

- The impact of the outdoor air characteristics showed that when the ambient TVOC's concentration was increased, then greater ventilation supply and exhaust rates were required in order to sustain the indoor TVOC's concentration below the desirable levels. The better IAQ levels were related with strong natural driving forces (wind and temperature difference) and better outdoor air characteristics.

- A comparison analysis was performed considering that the inlet/extract fans would operate in a reverse mode. Namely, the supply fan is considered at the canyon (shielded) façade and the inlet fan at the rear canyon (unshielded) wall (Figure 5). The two hybrid ventilation systems were found to have a different performance under variable outdoor conditions. However, for each studied system the better performance, in terms of air change rates, was observed for winds towards the mechanical supply fan. Nevertheless, better indoor air quality is obviously expected when the mechanical supply fan is attached on the unshielded building walls, due to increased pollutant concentrations originating mainly from traffic sources, especially when air circulation is reduced inside the canyon.

The efficiency of RESHYVENT ventilation system for moderate climates will be discussed mainly with pressure-dependent inlet grilles in order to realize better the canyon effect. Both natural and hybrid ventilation exhaust systems were studied.

- From the study of hybrid ventilation system in the five canyon geometries, it was estimated that RESHYVENT ventilation system would operate more hours in natural exhaust ventilation mode, when there were available natural driving forces. The performance of the ventilation system with the natural duct exhaust system in different canyon geometries showed that wind effect is dominant driving force in canyons with lower aspect ratios (regular or avenue canyons). Stack effect is maximum in deeper canyons (H/W greater than 2), when the average height of buildings is increased. Under the combined wind and stack effect, then the air exhaustion through the duct depends on the dominating natural driving force.

- From the estimated pressure differences across canyon facades with the natural exhaust ventilation system, it was found that the majority of pressure differences range between 0Pa-1Pa for all canyon geometries. The smaller the aspect ratio of canyon is, the maximum % of values between 0Pa-1Pa becomes. Thus, the range between 0Pa-1Pa becomes of high interest for pressure-dependent or self-regulated air inlets when installed at canyons facades and the ventilation exhaust system operates in natural mode.

- The study of two different canyon configurations, with and without surrounding obstacles at the rear building walls, showed that wind effect is reduced a lot near shielded facades. Higher exhaust flow rates were estimated with the natural exhaust system in canyons without local obstructions. Besides, the hours of operation of the exhaust fan and thus the fan energy are increased in canyons with local obstructions around the buildings, as a result of the reduced wind effect.

- The effect of different outdoor air characteristics on the efficiency of the hybrid ventilation system has been shown through TVOC's, seeing that its concentration in the urban environment can be very variable. A better IAQ was observed (with regard to TVOC's), when the control of the inlet grilles was based on TVOC's rather than when was based on CO_2. The control strategy of the inlet devices is very crucial, since it is possible with appropriate control to improve the effectiveness of the hybrid ventilation system, so as to meet indoor IAQ, without increasing the demanded flow rates of the system. Thus, the energy cost for heating or cooling will be reduced when IAQ is achieved with the minimum required flows.

- A parametric study has been performed considering two indoor TVOC's emissions. Namely, an average TVOC's emission equal to $1.1 mgh^{-1}m^{-2}$ (emission factor for 30 vinyl floorings reported by Gustafsson et al, 1993) and a high emission of $2.2 mgh^{-1}m^{-2}$. It was resulted that when high indoor pollutant emissions are expected in urban buildings, then it is very important to consider effective control strategies in order ensure the required IAQ levels with the minimum demanded flow rates. First of all, it important to reduce source emissions inside the building and then to increase ventilation rates, thus to avoid increased energy costs.

- The impact of the building leakage on the efficiency of the IC2 ventilation system was studied considering different leakage classes (0.6, 2.5 and $5h^{-1}$@50Pa). It has been found that when the building leakage is increased, then the introduced airflow through the inlet grilles is reduced, as a result of the increased infiltration rates.

- Finally, from the sensitivity analysis with different control strategies for the opening of inlet grilles, it was resulted that it is very important to apply effective control strategies for the operation of inlet grilles. When appropriate control is applied, it is possible to achieve the best thermal comfort and indoor air quality with the minimum demanded flow rates and thus with the minimum energy cost. Passive cooling or combined control strategies with passive cooling and CO_2 or TVOC's were found very effective.

CONCLUSIONS

Natural and hybrid ventilation in urban areas is highly affected by a number of urban parameters. Effective design of hybrid ventilation in urban buildings requires a good understanding of the urban climate characteristics. The most important parameters (canyon geometry and layout, wind and temperature distribution inside canyons, pollutant concentrations, external noise, solar/daylight access, humidity and wind pressure on building facades) have been identified and analyzed in the framework of RESHYVENT Project. The most important limitations and constraints of the impact of the urban environment on the performance of natural and hybrid ventilation have been identified through a number of experimental and computational procedures.

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