Air Distribution in Rooms, (ROOMVENT 2000)
Editor: H.B. Awbi

ENERGY IMPACT OF VENTILATION RATES

Vítor Leal[1], Eduardo Maldonado[1] , Christophe Delmotte[2], A. Blomsterberg[3], K. Pennycook[4], , P. Barles[5], P. Hardegger[6], P. Wouters[2] and W. De Gidds[7].

[1]IDMEC- Institute for Mechanical Engineering – Pólo FEUP
Rua dos Bragas, 4050-123 Porto, Portugal
[2]BBRI -Belgian Building Research Institute, Belgium
[3]J&W Consulting Engineers, Sweden
[4]BSRIA, UK
[5]ALDES, France
[6]Basler & Hofman, Switzerland
[7]TNO-Bouw, Netherlands

ABSTRACT

As heat exchanges through building envelopes and undesirable internal gains have been reduced in the last years due to energy conservation efforts, the importance of the energy needed to heat, cool and move outdoor air for ventilation has increased in relative terms. This study, developed within the European project TIP-VENT (JOULE) aims to study the impact of ventilation air flow rates upon the energy needs of typical buildings.

Five real buildings were selected as case-studies: An hotel, an auditorium, an office building, a single-family residence and an apartment building. They were all simulated in a mild, a moderate and a cold climate. Several sensitivity studies were performed, among them: (1) impact of air flow rates stated by standards and regulations; (2) impact of building air tightness; (3) impact of ventilation control strategies, including variable ventilation, free-cooling and heat recovery.

Conclusions clearly show that the different air flow rates demanded by different regulations & standards can have a large impact upon energy consumption. Opportunities for energy savings are also identified, namely in terms of the use of rational control strategies and active systems.

KEYWORDS

Ventilation, Air Flow, Energy Demand, Regulations, Standards, Cooling, Heating, Control Strategies, Air Tightness, Free-cooling, Heat-recovery.

INTRODUCTION

The buildings sector represents more than 40 % of the total energy consumption in the European Union (Energy in Europe, 1996). Although the energy efficiency of equipment is increasing, the number of new systems and appliances is also increasing, e.g., the demand for HVAC systems is fast increasing in many countries, especially in Southern Europe. So, energy consumption in the building sector still has a tendency to increase. Taking into account the EU energy policy and the Kyoto agreements, it is very important to identify energy saving opportunities in the buildings sector. After the effort to increase insulation in the past decades, it is clear that energy use due to air change is now the area with more potential for further savings. Orme (1998) estimated that, for the non-industrial building stock of the then 13 AIVC countries, the total annual energy needs for heating due to air change amounts to 48% of delivered space heating energy.

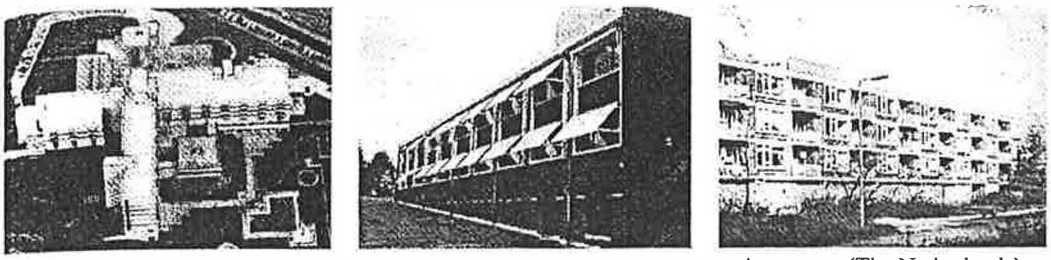
Regulations directly or indirectly concerning ventilation are now in force in most countries. These try to take in account both human health and energy consumption considerations. As air flow rates required to satisfy health requirements are not yet technically clear, as the recent discussion in Europe over proposed CEN-PrEnv 1752 well demonstrates, air flow rates stated by different regulations can be significantly different. Moreover, many regulations do not usually stimulate energy-efficient solutions. For example, some regulations state minimum but not maximum air flow rates. It is over this background that project Tip-Vent aims to analyse ventilation in buildings. It brings together and studies the cross-impacts of fields that have many times been considered one-by-one at a time: Indoor air quality, regulations and standards, maintenance of HVAC systems, energy consumption, and the creation of a positive environment for the development of innovative and smart systems. This work reports on the part of this project that aimed to analyse the impact of ventilation air flow rates upon energy consumption.

METHODS

The study consisted mainly of performing a set of sensitivity studies through computer simulation. A set of representative buildings was chosen to be taken as case-studies. These were a hotel, a university auditorium, an office building, a semi-detached dwelling and an apartment. Some can be seen in figure 1.

Following the choice of the case-studies, it was decided to establish their energy requirements in a mild, a moderate and a cold climate. Based on the analysis of temperature and solar radiation histograms, it was decided to consider Lisbon (Portugal) as a mild climate, Uccle (Belgium) as a moderate climate and Stockholm (Sweden) as a cold climate. Each building was, thus, studied in each of these locations. The main construction characteristics of the buildings were changed when "moving" a building from one country to another, in order to adapt it to the local use and construction practices and regulations. Table 1 shows the average U-value of exterior walls and the heating and cooling set-points for the hotel and the university auditorium at the real location (Portugal) and at the two other virtual locations, Belgium and Sweden. Other characteristics taken into account were U-values from other envelope components, air-tightness and internal gains. For all of these, experts in each country provided typical values. This procedure was repeated for all the studied buildings (Leal et al, 1999).

The sensitivity studies focussed on the following items related to air flow rates: requirements stated by regulations and standards, control strategies and use of efficient active systems, namely heat recovery and mechanical free-cooling. Table 2 shows how the criteria for setting outdoor air-flow rates differ in some European countries, and thus raises the question of their impact upon energy demand. Most of the simulations were performed with a well-validated, widely used software, the European reference program, ESP-r (ESRU, 1997), and results validated with available data from each building at its original location. For some particular sensitivity studies where ESP-r is not particularly efficient, Visual DOE (Eley Associates, 1996) and Enervent4 (TNO Bouw, 1998) have also been used.



Hotel (Portugal) — Office building (Belgium) — Apartment (The Netherlands)

Figure 1: Some case-study buildings at their original locations

TABLE 1
EXTERIOR WALLS U-VALUE AND HEATING AND COOLING SET-POINTS AT EACH REFERENCE LOCATION

BUILDING	COUNTRY					
	Belgium		Portugal		Sweden	
	U-value ($W/m^2.K$)	Set-points (heat.–cool.)	U-value ($W/m^2.K$)	Set-points (heat.–cool.)	U-value ($W/m^2.K$)	Set-points (heat.–cool.)
Hotel	0.51	20°C - 25°C	0.51 – 0.63	21°C – 24°C	0.26 – 0.29	20°C – 26°C
Auditorium	0.57	20°C - 25°C	0.97	20°C - 25°C	0.26	20°C - 25°C

TABLE 2
CRITERIA FOR DEFINING VENTILATION AIR FLOW RATES IN DIFFERENT COUNTRIES FOR THE HOTEL

Belgium	Portugal	Sweden	France	UK	Switzerland	Netherlands
Bedroom : 3.6 $m^3/h.m^2$ (min. 25 m^3/h, max. 36 m^3/h per person) Bathroom : 3.6 $m^3/h.m^2$ (min : 50 m^3/h) (max: 75 m^3/h)	*35 m^3/hr per person*	*Minimum 0.35 l/sm^2 and minimum 15 l/s in guest rooms, 7 l/s.person*	*25 m^3/h per person*	*with no smoking: 8 l/s/person with some smoking: 16 l/s/person with heavy smoking: 24 l/s/person with very heavy smoking: 32 l/s/person*	*Smoking not allowed: 12-15 m^3/h.person (0.15 % CO2) 25-30 m^3/h.person (0.10 % CO2) Smoking allowed: 30-70 m^3/h.person*	*Bedroom : 3.6 $m^3/h.m^2$ (min. 25 m^3/h, max. 36 m^3/h per person) Bathroom : 3.6 $m^3/h.m^2$ (min : 50 m^3/h) (max: 75 m^3/h)*

RESULTS

Impact of Regulations

The main reason for having ventilation requirements is human health and building conservation. However, clear and objective criteria based on health considerations to state air flow rates are still not available. Under these circumstances, each country defines air flow rates based on their own accepted criteria and, perhaps, taking into account some energy considerations. Assuming that the outdoor air quality is uniform throughout Europe, it makes sense to ask why the ventilation rates stated by different regulations and standards are so different and, most of all, to study the impact of choosing an air flow rate instead of another. This study investigated what would happen if the mechanical ventilation air flow rates for some buildings in a particular location were changed to those mandated by other countries' regulations. Figure 2 shows the heating and cooling energy demand for a hotel located in Portugal when applying the air-flow rates required by different regulations and standards. It shows that the difference between the lowest and the highest heating demand is 90 %. If the hotel were located in Belgium or in Sweden, this maximum difference would still be 70% and 82% respectively.

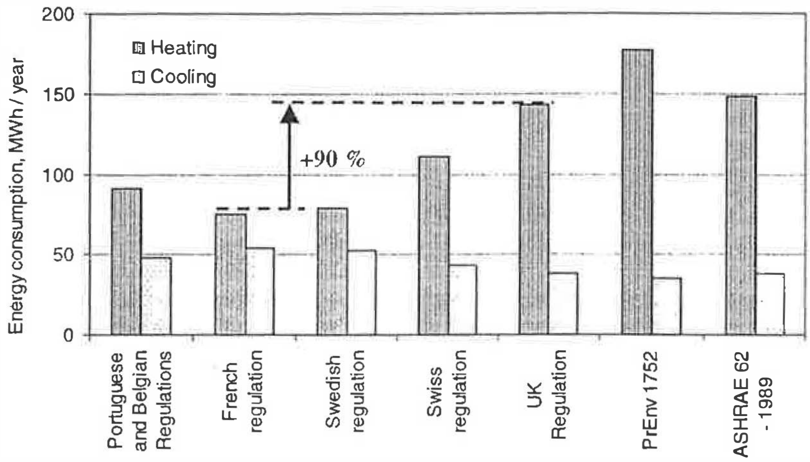


Figure 2: Energy demand of the hotel in Portugal applying air flow rates stated by different regulations or standards[1]

For the auditorium, the air flow rates from regulations and standards that require the most energy for heating are the Portuguese, the Swiss, and the ASHRAE standards. Those requiring the least consumption are the French and the Swedish regulations. The difference between the two groups would be 128%, 81% and 62%, depending on whether the building were located in Portugal, Belgium or Sweden, respectively. Differences in cooling energy demand would be smaller, although still important (the maximum difference would be 41%). As the cooling demand is, however, much smaller than the heating demand (schools are closed for most of the Summer), the difference in cooling demands is not so relevant as it is for heating. In the dwelling, only heating was considered as AC is very unusual even in Southern Europe. The difference in energy consumption between the regulations requiring the most and the least consumption would be 152%, 79% and 193% (excluding Pr. Env 1752, which was not approved as a standard but was still considered in the present study for the sake of completeness).

Impact of Control Strategies

For the non-residential buildings, several control strategies were considered, including modulating the air flow rates to the real occupancy of the spaces (e.g., CO_2 control). For the Hotel, it was observed that if air flow rates were proportional to occupation, instead of fixed amounts independent of occupation, the savings potential in heating energy consumption would be 38% in Portugal, 33% in Belgium and 37% in Sweden. Proportional strategies would, however, slightly increase the cooling energy consumption. This could however be avoided by applying constant air flow in Summer or, better yet, by adopting mechanical free-cooling as the most energy-saving strategy. The Auditorium has an occupation that is very variable during the day. Thus, it was very sensitive to changes in the control strategy. In the case of the real location of the building in Portugal, a simple two-speed fan could reduce the heating energy consumption by 66% relatively to a

[1] In the UK regulation, the air flow rate depends on whether smoking is allowed or not. In the hotel, smoking was considered allowed, but not allowed in the school auditorium.

constant flow rate fan, provided someone manually selected the correct fan speed every hour. If an ideal proportional control were implemented (CO_2 control is assumed as a suitable approximation), the reduction could be of about 77%. The difference between the constant flow and the proportional control if the building were located in Sweden would be of about 67%.

Impact of air tightness

Although the scenario throughout Europe is not uniform, the most common situation in the case of residential buildings, i.e., the dwelling and the apartment, is that they are naturally ventilated. In these buildings, the air tightness plays a very important role. It was observed that the typical infiltration levels of the dwelling range from 0.1 to 0.6 air changes per hour (or even more), at average meteorological conditions, depending on the country. Taking as an approximation that there was only air change due to infiltration, figure 3 shows the results for the heating energy demand of the apartment in the three reference climates. It was found that, for this range of values, consumption has a nearly linear relation with the leakage level. The difference in heating energy demand between the limits of the usual range (0.1 and 0.6 ach^{-1}) would be of 77%, 132% and 166% for virtual locations of the building in Portugal, Belgium and Sweden respectively. Of course, the colder the climate, the tighter requirements are mandated by local regulations. So, this range cannot be fully extrapolated for every possible combination, as some lack credibility.

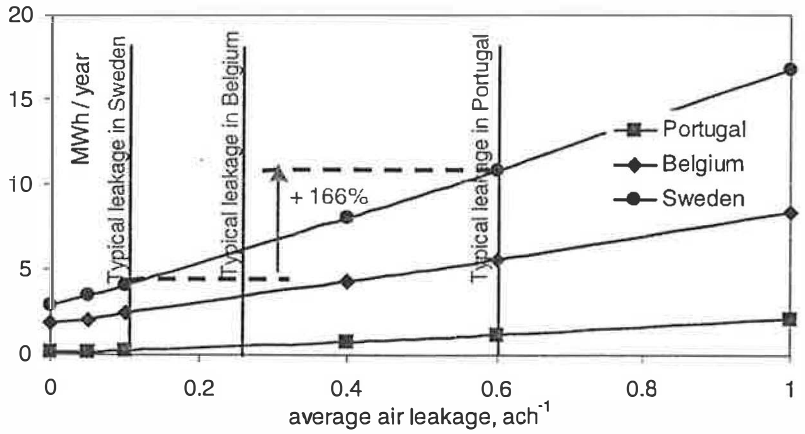


Figure 3: Heating energy demand in the apartment, with natural ventilation, for different air tightness levels.

Impact of active systems

Heat recovery and mechanical free-cooling received a particular attention in this study. Regarding heat recovery, taking a simple 50% efficiency, results showed a saving potential in heating energy demand of up to 40% in the hotel (In Portugal), 50% in the auditorium (In Belgium) and 20% in the dwelling (in Stockholm). All these buildings have mechanical ventilation systems that centralise exhaust. They also pressurise the building, in practice eliminating infiltration. Concerning free-cooling, all studies showed that increased air flow rates in Summer, at times when the outside air temperature (or enthalpy) is lower than inside, result in considerably smaller energy demand.

Importance of Fan-Power Consumption

It was confirmed that the fan energy consumption can be generally small if fans are properly selected, especially in residential buildings (usually below 10% of the total HVAC energy consumption). In some service buildings with high recirculation rates, however, fan consumption can exceed 20% of total needs. There is, nevertheless, a large dependence on the particular system design in each building. This point is especially important because fans consume the most expensive form of energy: electricity.

CONCLUSIONS

Air flow rates mandated by standards and regulations can have a very large impact upon the energy consumption in a building. If air flow rates mandated by regulations and standards from different countries are applied to a certain building at a certain location, differences of nearly 100 % in cooling and heating energy can be found. As minimum air flow rates should be established based on health criteria, these results call for a critical evaluation of the existing standards and regulations toward a certain degree of uniformity.

The use of control procedures that allow adjusting air flow rates to the real and time-dependent occupancy can have an extremely important impact on energy consumption. This is especially applicable for service buildings with a highly variable occupation pattern during the day. The energy saving potential for this technique can be significantly larger than the savings potential for heat recovery. This is thus an area with great potential for development. Regulations and standards should clearly make a reference to this issue. In general, heating energy consumption is proportional to air flow rates, but cooling consumption increases if ventilation rates are smaller. In summer, the optimum ventilation pattern is low ventilation rates when the outdoor temperature is higher and large ventilation rates otherwise, i.e., free-cooling.

For naturally ventilated buildings, which constitute a majority of the residential sector in Europe, the average air tightness levels can be very different from country to country. Countries with less stringent requirements can have a major savings potential if they tackle this issue seriously.

Energy consumption due to fans can be usually small in the total HVAC energy consumption but, in some particular cases, it can easily exceed 15% of total consumption. It is an expensive form of energy, and should be reduced through a careful selection of components and careful design.

REFERENCES

Eley, C. and Kennedy J (1996). Visual DOE Program Documentation (version 2.0), San Francisco, USA.

Energy Systems Research Unit (1997). *The ESP-r System for Building Energy Simulation - User Guide Version Series*, University of Strathclyde, Glasgow, Scotland.

European Commission, DGXVII, *Energy in Europe* (1996), special edition.

Leal. V., Maldonado E. M. and Delmotte C. (1999). *The impact of ventilation air flow rates upon energy consumption in buildings*, Tip-vent task 1 final draft report, EU contract JOE3-CT 97-0080. (Web site: www.tip-vent.com).

Orme, Malcolm (1998). *Energy Impact of Ventilation – Estimates for the Service and Residential Sectors*, Air Infiltration and Ventilation Center, Coventry, United Kingdom.

TNO Bouw (1998). *Enervent 4 Manual* (developed in the framework of the ECBCS IEA Annex 27), Delft The Netherlands.