2012 International Conference on Power and Energy Systems
Lecture Notes in Information Technology, Vol.13

Impact of Controlled Ventilation Systems on Energy Consumption in Mediterranean School Buildings

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Keywords: Energy Efficiency, Thermal Comfort, Energy Consumption, school buildings

Abstract. Current standards for indoor air quality (IAQ) in non-residential buildings demand high air renewal rates with different filtration stages and constant flow. Currently, new school buildings must incorporate mechanical ventilation systems which modify traditional heating installations in order to comply with the requirements for indoor air quality and energy efficiency. This study analyses the technical and energy outcomes involved in a school building when changing from a traditional central heating system with radiators, to an HV system which fulfils the current regulatory framework.

1. Introduction

The introduction of new European ventilation standards (UNE-EN 13779:2008 [1]) for non-residential buildings, has involved a very significant increase in the outside air rates used for the ventilation of buildings, and in the filtration requirements. The case of school buildings is of special significance due to the sensitivity of the occupants to the degradation of indoor air quality, which has been linked to air related disorders among occupants [2], and the high occupation density and large annual operation time. This has obliged a change from traditional heating systems to new Mixed or All-Air type systems which can fulfil the requirements. Annual energy consumption is expected to increase as higher levels of IAQ are obtained in school buildings, whilst attempting to address the energy efficiency-thermal comfort-indoor air quality dilemma [3,4,5].

The aim of this study is to assess the energy impact, in a standard representative centre, when evolving from a traditional heating system without controlled ventilation (based only on natural infiltration and manual operation of the openings, to a more complex Heating and Ventilation system, analysing the expected increases in the consumption of the building and identifying the most suitable system in terms of energy efficiency.

2. Methodology

2.1 School Building Case study

The study was carried out on an existing school building which represents the base model of school construction in the Mediterranean area. The model was analysed using energy simulations, obtaining the behaviour of the heating system and associated energy consumptions of this initial model, and other models with HVAC systems [6] developed to comply with the requirements for air quality and heating in the building.

The energy simulation models were carried out using the DOE 2.2 engine through the CALENER-GT interface, the official Spanish certification software, obtaining the initial and final energy consumption and associated CO_2 emissions of the building, enabling precise data to be obtained on annual, monthly, and hourly consumption.

The study object was a 5 year old, three story State school building (Fig. 1) and isolated from other buildings. It was largely representative of the typology and constructive definition found in the regional area, and was built under the Spanish enactment of Directive 2002/91/EC [7]. Table 1 shows the thermal envelope.

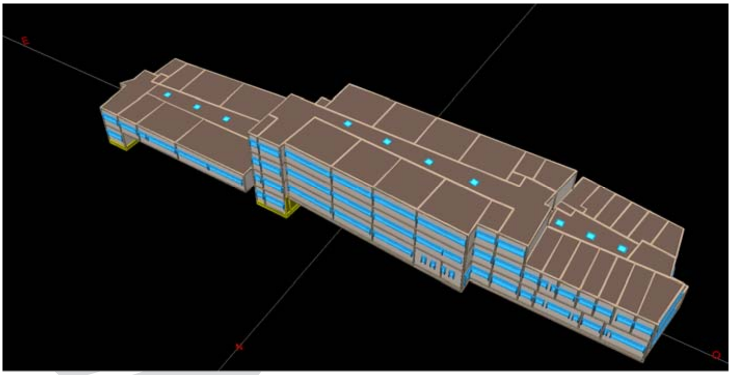


Figure 1. Case study simulations

Table 1. Characterization of the thermal envelope

Building elements		U (W/m^2K)
Facades	Double brick masonry walls, 3cm plastic insulation	0.65
Openings	6+12+6 double glazing, aluminium frame	3.4
Roofs	Concrete framework, grave cover, 6cm plastic insulation	0.41
Internal walls	Light brick masonry walls, no insulation	-

Initially, conditions of the operational values for occupancy, lighting, heating, ventilation and air-tightness were established according to the official timetable. The occupancy schedule considered, varied, depending on whether it was a weekday or weekend. The building was considered to be unoccupied from 1 July to 31 August.

The heating system works from 20 November to 31 March (taking into account Christmas holidays), from 8:00 am to 12:00 pm (taking into account a reduced service to the administration area from 16:00 to 18:00h). The ventilation system must be running the whole time the school is open due to the presence of occupants and the need for IAQ control (8:00 to 15:00 h. and reduced occupancy from 16:00 to 18:00h). In compliance with national regulations, a set temperature of 21°C was considered during the heating period (no cooling system was envisaged).

Despite the Class I category considered as a design objective, the real behaviour without mechanical ventilation shows a poor quality indoor environment, with CO_2 levels of more than 1,000 ppm above the outside air level in most of the classes, which equates to an IAQ level IDA4 in Standard EN-ISO 7730[8] .

In the evolution models, where the supply of outdoor air is controlled, the study considered a supply rate of 12.5 l/s per occupant (Class I/IDA2 indoor air quality as a design objective), which must ensure a CO_2 concentration below 600 ppm above the outdoor air level, as per EN-ISO 15251[9].

Table 2. Climate values in Huelva. Period: 1971-2000

Average monthly	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Day temperature (°C)	11,4	12,7	14,6	16	18,8	22,2	25,4	25,5	23,5	19,4	15,3	12,6
Maximum day temperature (°C)	16,3	17,6	20,3	21,4	24,1	27,8	31,6	31,8	29,3	24,7	20,2	17
Minimum day temperature (°C)	6,6	7,7	9	10,7	13,4	16,6	19,2	19,3	17,7	14,2	10,4	8,1
Hours of sunshine	170	170	223	246	303	339	372	347	277	211	173	148

2.2 Systems Analysed

The analysis of the original system of the building allowed the energy consumption baseline to be established. It is a traditional heating system, with radiators and a central diesel boiler (H-RO), and lacks ventilation control. In this case it may be considered that indoor ventilation is provided by the continuous infiltration through the thermal envelope and the voluntary opening of windows by the user. Field observations indicate an approximate value of one indoor air volume renewal per hour; in this case, the outdoor air is not subjected to any filtration process, with no guarantee of any outdoor air cleaning. There is no pre-heating, which leads to significant thermal gradients inside the classroom (vertical and horizontal).

Alternative systems are proposed [10] which provide treated and controlled outdoor air, all of them ensuring a minimum flow of outdoor air, a filtration process and pre-heating, and when possible, the use of heat recovery. The systems considered are as follows:

- Central Heating with distributed radiators and Neutral Air Mechanical Ventilation(HV:R+NMV): radiators solve the local heating loads, Air Handling Units are provided to supply fresh air at indoor conditions, this system provides heat recovery capacity with high energy efficiency and uses a reduced number of fans. Easier moisture control if required.
- Central Heating with distributed radiators and Passive Mechanical Ventilation (HV:R+PMV): radiators solve the local heating loads and the ventilation load, Air Handling Units supply fresh air at external conditions with no heating treatment. Filter and fan systems increase in number
- Central All-Air System (HV-AIS): Central boiler distributes hot water to the Air Handling Units distributed though the building according to the configuration of the thermal areas of the All-Air constant flow system. The AHU´s provide thermal and ventilation. If the flow of the outdoor air supply exceeds the thermal needs, the VAV does not function.
- Central All-Air System (HV-AISPT): Central boiler distributes hot water to the Air Handling Units with local post-treatment of the air, adapting it to a multi-zone system. The AHU´s provide thermal treatment and ventilation. The flow of the outdoor supply remains fixed and the thermal load of the classrooms is adjusted through the water post-heating sets, which allows individual thermal control of each room.
- Central Air-Water System with neutral outdoor air (HV-AWSN): A major part the features of this system are common to those described above for HV:R+NMV installation, fan-coil units are used instead of radiators, assuming the local heating loads, the Air Handling Units supply fresh air at indoor conditions.

Except for the first system, those proposed allow the evolution to air conditioning systems (HVAC), which may be considered as a future step to provide all year round indoor environmental control.

In order to obtain a more similar comparison scenario for the different systems, the thermal generation is common to al, a conventional diesel water boiler with a 93% performance, adjusting the thermal output to the individual power requirement.

3. Discussion and Results

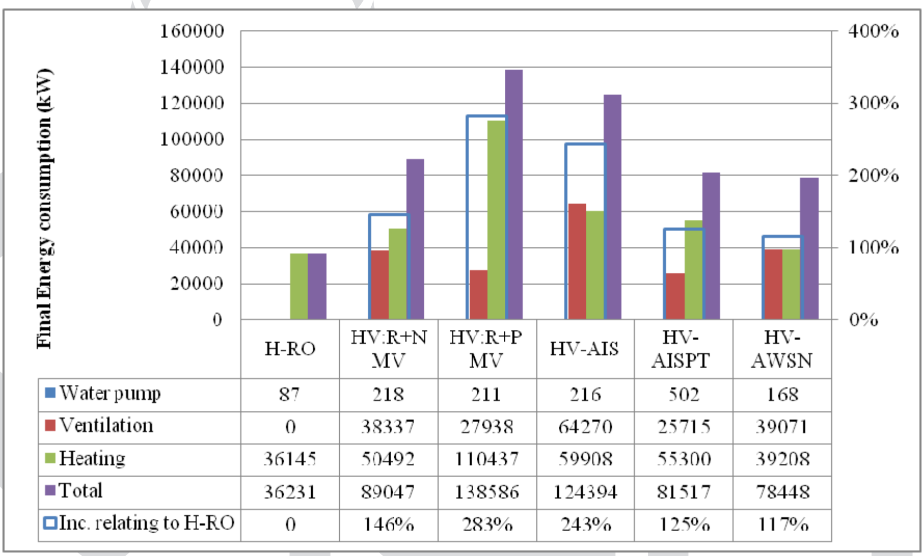
As different energy sources are present in the models, the annual energy demand was converted to primary energy which allowed the carbon dioxide emission units to be calculated.

Table 3. Coefficients for energy inputs.

Coefficients for energy inputs	Final Energy		Emissions of CO2	
	Electricity	Gasoil	Electricity	Gasoil
Primary Energy	2,603	1,085	1,689	0,311

Decision-making for the intervention strategy was carried out guided by the energy assessment of the building, both for its original condition and for the alternatives, with a comparative analysis being established to measure the predicted energy consumption. As expected there was a substantial increase in annual energy consumption and a rise in the associated CO_2 emissions.

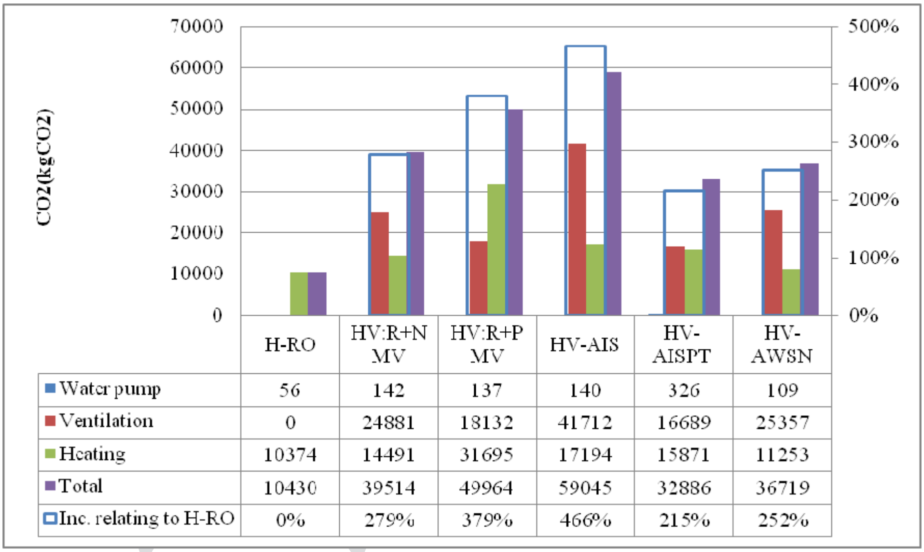
Those systems that meet the current requirements for indoor air quality, increase the final annual energy consumption by between 2.16 to 3.82 times; the post-heating or Fan Coil solutions being those which consume a smaller amount of both final and primary energy in the B4 climate zone, but nevertheless is double that of the initial system H: OR.



	H-RO	HV:R+N MV	HV:R+P MV	HV-AIS	HV-AISPT	HV-AWSN
Water pump	87	218	211	216	502	168
Ventilation	0	38337	27938	64270	25715	39071
Heating	36145	50492	110437	59908	55300	39208
Total	36231	89047	138586	124394	81517	78448
Inc. relating to H-RO	0	146%	283%	243%	125%	117%

Figure 2. Energy consumption for different systems

The most remarkable aspect is the significant increase in energy consumption associated with air transport in the building (mainly due to the operation of the fans and the load losses in the filters), especially in the HV-AIS system, assuming an increase in CO_2 emissions of an order of three to five and a half times the initial level. This badly affects the environmental impact of the operation of the building , and involves an important increase in the operating budget of the building, due to higher cost of electricity versus diesel fuel.



	H-RO	HV:R+N MV	HV:R+P MV	HV-AIS	HV-AISPT	HV-AWSN
Water pump	56	142	137	140	326	109
Ventilation	0	24881	18132	41712	16689	25357
Heating	10374	14491	31695	17194	15871	11253
Total	10430	39514	49964	59045	32886	36719
Inc. relating to H-RO	0%	279%	379%	466%	215%	252%

Figure 3. CO_2 emissions for different systems

4. Conclusions

The main conclusion of this study is that the traditional design criteria of the heating system should be modified to meet the requirements of indoor air quality associated with school use, without resorting to all year round air conditioning. All the systems with post heating units or the mixed type systems are appropriate, providing controlled air ventilation and heating capacity. In the mixed systems, the fan coil type is the most appropriate, but the simplified version that incorporates AHU´s to the traditional radiators may be considered as the simplest solution that allows retrofitting existing facilities without such an excessive consumption in comparison with other hypotheses.

Special care must be taken during the installation design process to control energy efficiency aspects, in order to minimize high consumption, but not to the detriment of the indoor air quality.

References

[1] EN 13779:2008. Ventilation for non-residential buildings. Performance requirements for ventilation and room-conditioning systems. Bruxelles: CEN, 2008.

[2] C.W. Bayer,. S.A Crow,. and J. Fischer, Causes of Indoor Air Quality Problems in Schools: Summary of Scientific Research, Columbia, MO, SEMCO, Inc.2000

[3] R. Becker, I. Goldberger, M. Paciuk, Improving energy performance of school buildings while ensuring indoor air quality ventilation, Building and Environment, vol. 42, pp. 3261-3276, 2007.

[4] Eley Associates, Architectural Energy Corporation, & Accounting Office, M. Improving Indoor Enviromental Quality and Energy Performance of California K-12 Schools1-1-17, 2003.

[5] P. Wargocki and D. P. Wyon. Effects of HVAC on Student Performance. Effects of HVAC on Student Performance, ASHRAE Journal 7, 2006.

[6] J. Jalas, K. Karjalainen and P. Kimar, Indoor Air and Energy Economy in school buildings. Proceedings of Healthy Buildings 2000, vol. 4, 273

[7] Directive 2002/91/EC of the European Parliament and of the Council of 16 December 2002 on the energy performance of buildings.

[8] ISO 7730:2005 Ergonomics of the thermal environment -- Analytical determination and interpretation of thermal comfort using calculation of the PMV and PPD indices and local thermal comfort criteria.

[9] EN 15251:2007 Indoor environmental input parameters for design and assessment of energy performance of buildings addressing indoor air quality, thermal environment, lighting and acoustics.

[10] W. Grondzik and R. Furst, HVAC Components and Systems, Vital Sings Curriculum Materials Project. http://arch.ced.berkeley.edu/vitalsigns/res/downloads/rp/hvac/hvac-sml_opt.pdf