Natural ventilation systems in Mediterranean schools. A prototype experience in Andalusia as an alternative to mechanical ventilation

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ABSTRACT

In high density occupation rooms, it is necessary to control indoor air quality (IAQ) combined with other comfort parameters. An adequate IAQ in classrooms enhances children learning and academic results are improved.

In the last decade, international technical regulations have increased air-tightness requirement in buildings in order to reduce heat losses. Following this trend, current Spanish regulations are based on mechanical ventilation systems to guarantee IAQ in no residential buildings. However, its use in schools presents several problems due to operational costs and maintenance needs. To solve these issues, Andalusian government is developing a research work to design alternative systems. In this way, natural ventilation systems already in use in UK school buildings, are tested in Andalusian schools, under the conditions of the Mediterranean mild climate and regional scholar schedule, with different operating conditions from those already tested in northern regions.

In this paper is presented an experimental Natural Ventilation System to guarantee IAQ conditions. It is designed combining cross ventilation and stack effect strategies in each classroom, calculated with computational simulations and compared with a mechanical ventilation system under current Spanish regulations. Main conclusion derived from simulations is the feasibility of using natural ventilation systems to guarantee Indoor Air Quality in classrooms and enhance the energy efficiency of the buildings of Andalusian schools. Based on this, a standard Natural Ventilation System model is proposed to be used for design criteria in new buildings to be constructed in coming years in Andalusia.

Previous simulations show that these natural ventilation systems are an alternative to comply with Spanish technical regulations. In addition, using these systems is possible to reduce investment costs between 8-10% and to avoid running problems during the use of the buildings, in addition to savings due to energy consumptions and CO_2 emissions. Thus, this kind of systems could be used as passive actions to design Zero Energy Buildings.

This study will be extended with an experimental campaign in a new building located in the province of Seville, designed with both Natural and Mechanical Ventilation Systems and now under construction, is going to be used as a Test Building. It will be in use from September 2017 and a measure campaign is going to be developed during the whole scholar year, to analyse both natural and mechanical ventilation systems, comparing their operation, consumptions and users perception.

KEYWORDS

Natural Ventilation Systems, Mediterranean climate, schools, prototype, technical regulations

1 INTRODUCTION

Directive 2002/91/EU about efficiency energy in buildings, (Europeo, Consejo, and Uni 2003) imposes energy savings in buildings by reducing consumptions. This requirement was developed in further Directives as 2010/31/UE (Comisión Europea 2010) defining nearly zero energy buildings (NZEBs). This subject has a high research activity as it is shown in (Deng, Wang, and Dai 2018), (Desideri et al. 2014),(Zhu 2014),(Pikas et al. 2015) (Attia and Carlucci 2015). Associated to climate, Krawczyk (Krawczyk 2014) shows the high dependence of demand with location. Regarding HVAC (heating, ventilation and air conditioning) systems Chenari et al evaluated their greater effect on energy usage in buildings (Chenari, Dias Carrilho, and Gameiro da Silva 2016). In addition these HVAC systems accounts for 60–70% of total energy use in non-industrial buildings where infiltration and ventilation suppose between 30–50% of this energy consumption (Khan, Su, and Riffat 2008). Attia and Carlucci (Attia and Carlucci 2015), put the focus on space cooling, heating and ventilation operation to reduce energy demand.

Most of the strategies developed for energy savings in buildings operation use to combine different strategies as: increase buildings air-tightness (Inive / International Network for Information on Ventilation and Energy Performance n.d.), improve HVAC systems as its size (Sun et al. 2014) or HVAC loads and control based on real occupancy (Yang, Ghahramani, and Becerik-Gerber 2016). Besides, in high airtight buildings, heat gains are only dissipated by ventilation (Flourentzou, Pantet, and Ritz 2017), and additional systems or strategies are required in order to guarantee IAQ and reduce condensation problems and moistures. In addition, in classrooms, as high density occupation spaces, it is necessary to control indoor air quality (IAQ) in combination with other comfort parameters to enhance children learning and improve academic results. IAQ in schools has been studied recently in several locations: Greece (Barrett et al. 2015), (Kalimeri et al. 2016), Serbia (Jovanovi et al. 2014) , USA (Air et al. 2007) , The Netherlands (Classroom ventilation and indoor air quality — results from the FRESH intervention study 2016), (Toftum et al. 2015), Denmark (Assessment of ventilation and indoor air pollutants in nursery and elementary schools in France 2016), France (Indoor air quality in Portuguese schools : levels and sources of pollutants 2016; Pegas et al. 2011; Severo et al. 2016), Portugal (Almeida and De Freitas 2014). In some recent studies is analysed the Southern European climate, exposing the evidence of inadequate IAQ in schools and its negative effects on health (Rufo et al. 2016), (Chatzidiakou, Mumovic, and Summerfield 2017). So, in new high air-tight school buildings with high density occupation spaces, ventilation is an especially relevant design key for both end users health and energy consumption.

The use of Mechanical Ventilation Systems has been widely extended to achieve IAQ in last two decades, integrating sometimes heat recovery solutions to reduce energy consumptions (Wang et al. 2014). Following this trend “Standard Passivhaus” (Passivhaus Institut n.d.) is having an intense development in Europe, as a model of Zero Energy Building design. Being an appropriate solution for cold climate regions, however in mild climate zones, the primary energy savings linked to heat recovery can be smaller than the electricity required for running the required mechanical ventilation system depending on the building application and occupation pattern. In addition, as showed by Oropeza and Østergaard (Oropeza-Perez and Østergaard 2014), a dwelling considered as a passive house focused on heating savings presented overheating problems during warmer session. Furthermore, mechanical systems operation in schools presents several problems due to operational costs and maintenance needs which leads to the fact that they are not being used regularly. This is described for Almeida et al in Portugal (Almeida and De Freitas 2014), and the situation is similar to most

of the mild climate region of Spain. It makes necessary to search for alternative solutions for the specific conditions of mild climate schools.
At local level, in Spain, the current HVAC regulations (Ministerio de Industria 2013) develop a detailed technical framework for MVS design and implementation to ensure IAQ in no residential buildings. Although regulation is open to alternative systems to the mechanical ones, the real situation is that the technical framework is not developed yet, indirectly favouring MVS system installation. This situation is similar in other countries as Swiss, as it is exposed in (Flourentzou and Pantet 2014).
Due to the problems derived from the inclusion of these MVS in school buildings built up in the last decade in Andalusia, regional government is developing a research work to design ventilation systems alternative to the mechanical ones. On this purpose, NVS which are already in use in UK school buildings, have been tested in Andalusian schools, under the conditions of the Mediterranean mild climate and the regional scholar schedule. The goal is to verify their adequateness to provide high indoor air quality and comfort conditions.
In this way, a design program for new buildings, has been developed in 2017. Within this program, NVS is under installation in a set of new school buildings in order to prove and validate its operation. Its main objective is to assess the NVS performance, previously modelled and tested at local scale, to a wider range. It will generate the required new knowledge about its application to schools under these conditions and it should give support to the future development of regional technical regulations. In addition, under the ClimAct project, in development since June of 2016 to December of 2019 in the framework of the program Interreg-Sudoe Program of European Union, Natural Ventilation Systems in Andalusian school buildings are going to be analysed, among other strategies, as a way to accomplish to a transition to a low carbon economy in schools in Mediterranean zone.
Within this framework, this paper presents the Natural Ventilation System model designed to guarantee IAQ conditions in classrooms, comparing results with the Mechanical Ventilation System operation. The model is designed to be included in each classroom and it is based on a cross ventilation strategy in combination with stack effect, in order to improve the air movement even in days with reduced indoor/ outdoor temperature difference and without wind conditions. Its performance was evaluated with computational simulations and compared with the Mechanical Ventilation System installed under current Spanish regulations in terms of final and primary energy and CO_2 emissions savings. Considering the results obtained, a standard model was proposed to be used in the classrooms of new buildings which will be constructed in Andalusia in coming years.
Main conclusion of simulations is the possibility of using natural ventilation systems in Andalusian schools to guarantee Indoor Air Quality and comfort conditions in classrooms. These systems are shown as an alternative to comply with Spanish technical regulations. At the same time with these systems is possible to reduce investment costs between 8-10% and to avoid running problems during the use of the buildings, in addition to savings due to energy consumptions and CO_2 emissions. Thus, the use of this kind of systems could be used as passive actions to design Zero Energy Buildings.
A new building located in the province of Seville, designed with both Natural and Mechanical Ventilation Systems and now under construction, is going to be used as a Test Building. It will start its operation on September 2017and it will be used along the next year for tests campaigns. Consumptions and Indoor Environment Quality (IEQ) using both natural and mechanical systems will be compared. Expected results are the improvement of the IEQ, with less energy consumption, as well as the enhancement of the indoor thermal conditions in spring and autumn by reducing indoor overheating using the Ventilative Cooling effect.
This experimental action is included in the “Energy Strategy of Andalucía 2020” (Agencia Andaluza de la energía 2016) of the Andalusian Energy Agency.

This paper is structured in 4 sections. Following this introduction in the second section the Mediterranean school buildings framework is exposed. In the third one the design methodology is presented. and in the fourth the main conclusions are summarized.

2 MEDITERRANEAN SCHOOL BUILDINGS FRAMEWORK

2.1 Mediterranean climate. Temperatures during year

The results presented in this paper are focused on a building located in Seville, sub-climatic zone B4 in Andalusia (where there are five sub-climatic zones). This mild climate zone, presents soft thermal conditions. Hourly mean temperature evolution for the months within the scholar schedule is presented in Figure 1:

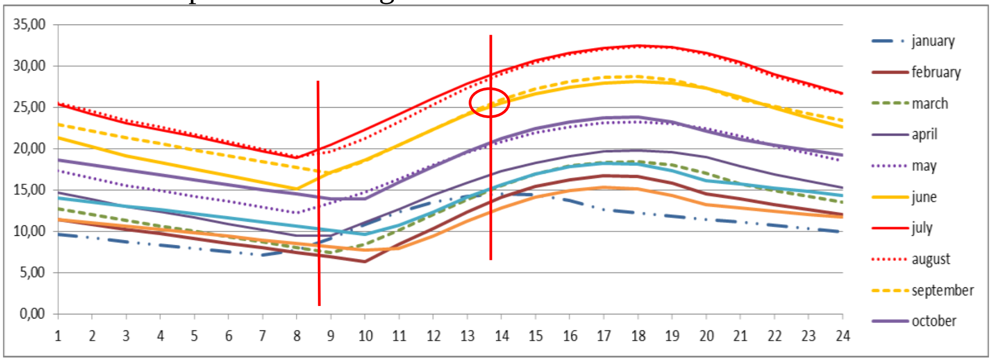

Figure 1. Hourly mean temperature evolution for the months within the scholar schedule for B4 zone in Andalusia. Data obtained from Spanish Ministry published data *.met

In Figure 1, mild climate conditions are shown with the distribution of outdoor temperatures along the scholar session in a representative day of each month .Maximum temperatures from September to June into the school time, are below 30 ºC and around 26ºC in the last hour of the daily sessions, at 14:00. Furthermore, in winter season there are no days with temperatures under 5ºC (mean temperatures of each month).

2.2 School buildings characteristics

There are more than 80,000 schools in the Mediterranean region (Promoting renovation of schools in a Mediterranean climate up to nearly Zero-energy buildings | ZEMedS n.d.). Being a big energy consumers, this sector consumes 4% of the energy in the commercial sector in Spain (Krawczyk 2014). Only in Andalusia there are more than 4500 public schools. There are relevant international R&D projects. (Home n.d.), (DOWNLOAD AREA | RENEW SCHOOL n.d.), (Erhorn-kluttig and Erhorn 2014), (Check and improve the energy performance of schools and disseminate best practices - Intelligent Energy Europe - European Commission n.d.), (Promoting renovation of schools in a Mediterranean climate up to nearly Zero-energy buildings | ZEMedS n.d.), (Teenergy Schools | High energy efficiency schools in Mediterranean Area n.d.) and an intense R&D activity in school buildings. Among other publications is relevant interesting CIBSE’s School Design Group (CIBSE - School Design Group n.d.) publication TM57:2015 Integrated School Design (CIBSETM57 2015), with specific recommendations for school buildings. The school building segment is unique in the building domain since it has specific typologies, users and usage patterns, energy infrastructures, energy uses and functions, Veryschool Project (VERYSCHOOL.EU - Valuable Energy for a smart school n.d.). Main characteristics can be resumed in the next:

a) Schools usually operate around 175 days in the year (half of days in a year). In Mediterranean zone there are the summer school holidays which last 2 months and a half as well as Christmas and Easter holidays. The number of school days is similar in other countries too, even being shorter the summer break.

b) School buildings design is mainly based in a rational space organization. Classrooms have wide dimensioned windows in order to allow natural illumination of the space, are usually grouped and there is a corridor to access them, as well as there are top-hung windows to corridor to be used for both cross ventilation and illumination.

Fig. 2. Typical school building windows. a) left façade windows, b) right corridor windows

c) School operation is usually organized with a break between lessons and a main break to go out to the courtyard and take a snack. In addition, there are several internal displacements and changes of class into the school building, so that classrooms are spaces with non-permanent occupation.

d) Mediterranean schools present reduced heating requirements, due to the mild weather and internal gains. However, ventilation is necessary along the whole school year. Heating vs ventilation requirements are represented in the next Figure 3

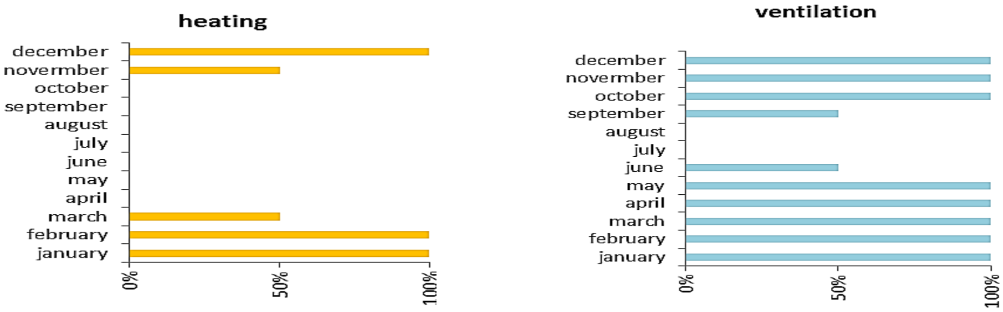

Fig. 3. Mild climate school heating and ventilation patterns.. a) Left. Heating profile estimation in terms of heating days percentage by month. b) right. Ventilation profile estimation in terms of percentage of ventilation days per month

2.3 Andalusian schools

With a high number of schools in Andalusia, built along long periods there are clear differences among them regarding their construction period. In older schools, the absence of regulations and construction standards resulted in less airtightness in buildings constructed in twentieth century. Ventilation was controlled opening doors and windows (Almeida, Ramos, and Freitas 2016), (Romana, Ianniello, and Igor 2013) as way to control contaminant levels and comfort conditions in classrooms (Stabile et al. 2016).

However in 21st century new schools construction criteria changed. In next figure a Mechanical Ventilation System installed in an Andalusian school under actual technical regulation (Ministerio de Industria 2013) is shown. It supposes a relevant capital cost, ducts integration in buildings, need of additional oversized electricity facilities which includes transformers, and maintenance of the whole set of direct and indirect installations.

Fig. 4. Mechanical Ventilation system in an Andalusian school. Roof tops

Nevertheless, these Mechanical Systems don't offer the indoor quality expected and estimated under calculations due to different usage patterns and maintenance issues associated both to operational and maintenance costs to be paid by end user. In addition, due to the high internal heat gains in classrooms, due to metabolic activity, the heating period is shorter than other spaces like residential buildings. Therefore, some valuable solutions in other applications, as could be heat recovery, would be cost efficient only in very cold regions (Erhorn-kluttig and Erhorn 2014). Besides, from the point of view of health, additional problems can appear with MVS as the Sick Building Syndrome (SBS), being a risk for airborne infectious diseases as presented by Pereira et al (Luiz et al. 2015).
Accordingly, regarding to the issues derived from the design of MVS as equipment, the associated capital, operational and maintenance costs and the low benefit derived from them under the real operation of the schools, more sustainable and environmental friendly solutions are required. In this framework is developed this work of analysis and promotion of Natural Ventilation Systems in Andalusian schools.

3 METHODOLOGY

The methodology followed in this study presents the next steps:

1) Study of International experiences in natural ventilation systems: with specific focus on the well stablished BB101 (Bb101 2006) in UK. The study was focused on the adaptation requirements of proven natural ventilation strategies for school buildings in northern countries to Andalusian schools.
2) Analysis of the forgotten Natural Ventilation examples in Andalusian schools of the early 20th century: Although similar devices based on these principles were used in Andalusian schools 30-40 years ago, the evolution of technical design and regulatory framework in buildings as well as end user changes of habits among other things have displaced them. In Figure 5 are shown an example taken from an old school.

Fig.5 left) Cross ventilation in an Andalusian school. Right) Natural Ventilation system in an Andalusian school built in 1985

3) A hypothesis is stated in Andalusia, proposing a system based in stack effect and cross ventilation, which is based in ancient examples and following BB101 recommendations.
4) Model building thermal simulation and CFD calculation: Using Designbuilder (DesignBuilder Software Ltd - Home n.d.), 10 options were calculated for the same theoretical building model (5 with NVS and 5 with MVS comparing pairs of options in each sub-climatic Andalusian zone) in order to calculated the energy savings that could be obtained using NVS instead of mechanical ones. CFD option was used to prove the effectiveness in the air flow through the classrooms. Ten options were calculated in the same building model (5 with NVS and 5 with MVS comparing pairs of options in each sub-climatic Andalusian zone) in order to obtain energy savings using a natural system for ventilation instead of a mechanical one. CFD option was used to prove the effectiveness in the air flow through the classrooms.
5) Standard Natural Ventilation System: Analysing results obtained, a standard solution was defined, in order to be used in new buildings design, simplifying the design process with no additional calculations.

3.1 Natural Ventilation System standard model

In Figure 6 the ventilation standard model proposed is shown. From left to right plants and roof are represented. This simple system is applicable for each classroom and it is composed by automatic intake windows in the facade and two stacks in the opposite wall connected with the roof for extraction.

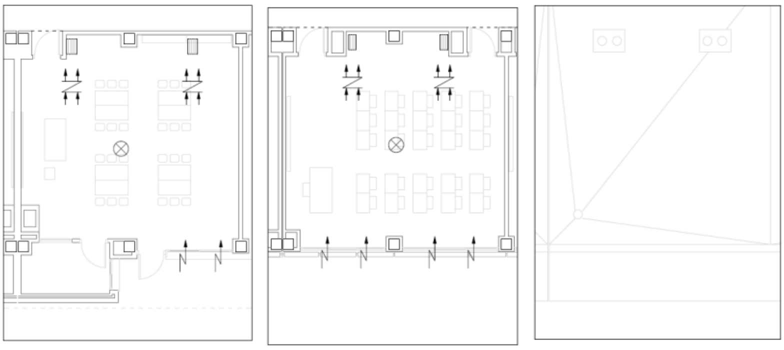

Figure 6. Standard classroom NVS model plants. Left) ground floor, middle) first floor plant and right) roof

The automatic windows operation is controlled by a CO_2 level sensor disposed in the middle of the classroom roof, in order to avoid be damaged by the pupils. System outlets are connected from the classroom with the building roof using a dynamic aerator. In Figure 7 a section and an axonometric view are represented:

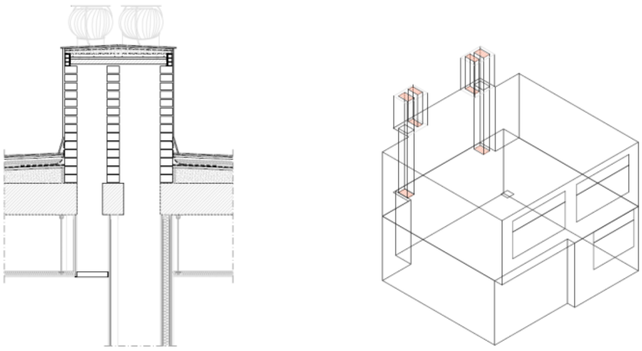

Figure 7. Standard classroom NVS details: left) section and right) axonometric view

3.2 Test Building description

The theoretical solution previously calculated is implemented in the design of a new school building, which is now under construction and it is being used as a prototype model, in order to test this standard solution. The school is located in "Mairena del Aljarafe", in a suburban area 8 km from the city center of Seville with an adequate and no contaminated outdoor air quality.

Figure 8 Location. Google maps image

The building is a pre-school and primary school level (from 3.-12 years old). There are 27 classrooms for 25 pupils and the teacher (675 children). Lessons are developed from 9:00 to 14:00 hours. The canteen operates from 14:00 to 16:00. In the afternoon there are extra-scholar activities for some children (not all of them), which are mainly sports and only from October to May. Building characteristics are shown in the next Figures and Tables.
Main characteristics of construction and materials are presented in Table 1:

Table 1: Characteristics and materials

Element	**Material**
Structure	Concrete
Roof	Slab concrete with insulation
Walls	Insulated cavity wall
Windows	Aluminium with thermal break / double glass 4/10/6. Brise-soleil sun blinds
Lighting	Fluorescent with electronic ballast T-5
Heating	Water radiators with natural gas boiler
Cooling	No cooling system
Ventilation	Natural Ventilation System
	Mechanical ventilation System

The building is developed in ground floor and first floor with a surface around 4,300 m^2.

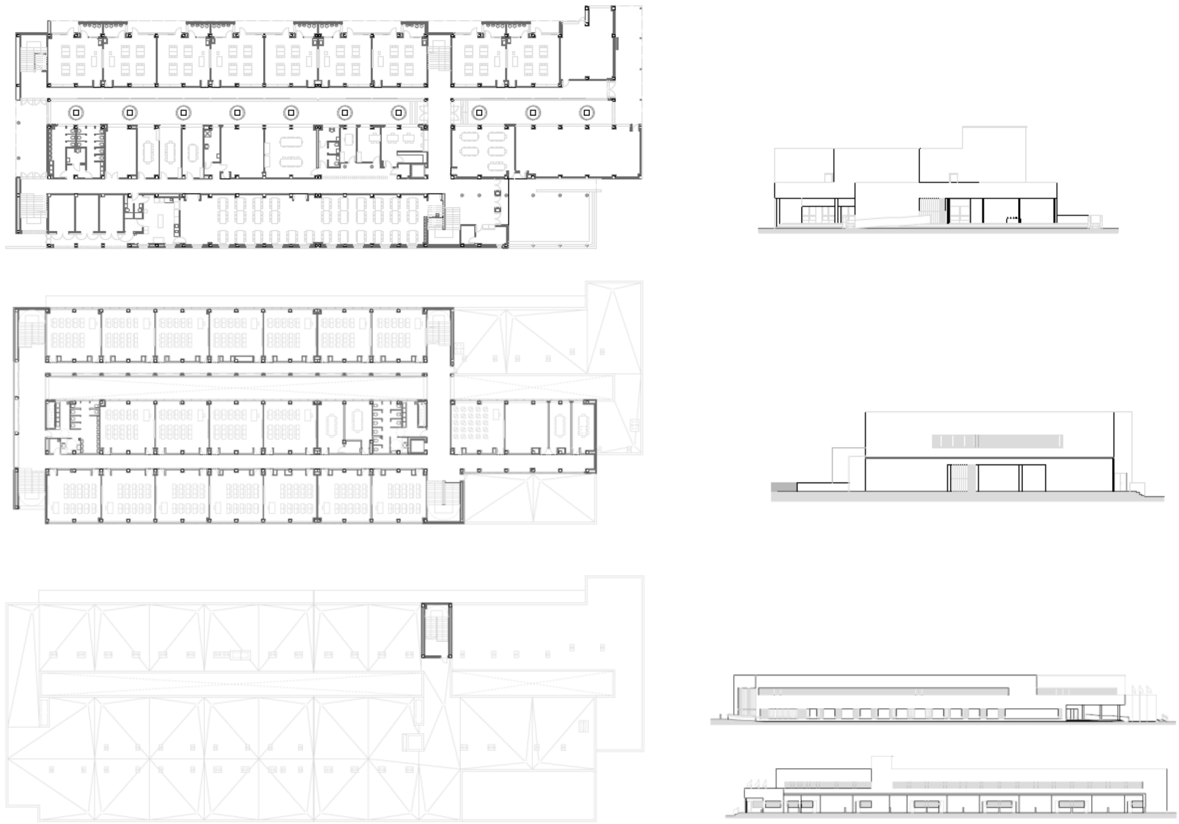

Figure 8 Project plants and fronts (APAE*)

The building is under construction and it is expected to be finished to the next scholar year and in operation since mid-September of 2017. Next images show the current construction works.

Figure Construction works images (APAE*)

Considering project data, installed thermal power is 250.2 kW and installed electric power 294.5 kW, mainly due to the requirements of the mechanical ventilation system operation. Project data investment costs are 230,105 € for the MVS considering the electric transformer needed for the operation of this facility and 59,000 € for the NVS with a total investment cost of 4,464,839.49 €. NVS supposes in this case a 5.54% of the new building total cost.

3.3 Expected results

Project data presents a MVS with 6 machines (500 W; 2x1500 W and 3x11000 W).
Considering 178 school days and the MVS operating an average of 4 hours per day, electric savings expected in terms of final energy is around 25.988 kWh per year.
Even considering the energy use increase for heating, savings expected in terms of primary energy and CO_2 emissions could be around 52,770 kWh per year and 35.3 tons of CO_2 per year. Besides, maintenance costs and indoor comfort will be improved in addition to these.

4 CONCLUSIONS

The increase of the air-tightness in the buildings, thought to reduce energy savings is resulting in more ventilation requirements. Consequently, in 21th century´s near zero energy buildings defined by European Directives, ventilation will be an essential design key.
Besides, in high density occupation rooms, as classrooms in schools, ventilation requirements are much more important than in other kind of buildings, so that if systems which use energy in their operation are designed to ventilate schools, these will have a high energy impact. In addition, in Mediterranean climate schools, ventilation is needed much more time than heating due to mild climate and internal gains.
Ventilation systems based in natural strategies offer the opportunity of ventilate with no energy consumption as well as to reduce the indoor overheating in autumn and spring seasons in mild climate locations. In addition more than 5.4% of initial investment cost can be saved, as well as electric power and maintenance costs due the operation of a mechanical system. Besides, these systems offer a healthier indoor environment in locations with an adequate outdoor air quality, thanks to they don't need filters and ducts which can suppose a source of contaminants if an adequate maintenance program is not followed.
A standard system model in classrooms has been included in a test building in which a measure program will be developed. This building is under construction and it will be operating next scholar year. With regard to project data, energy and CO_2 savings around 52,770 kWh and 35.3 tons of CO_2 in terms of final energy consumption and CO_2 emissions should be possible per year.

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6 REFERENCES

Agencia Andaluza de la energía. 2016. "ESTRATEGIA ENERGÉTICA DE ANDALUCÍA 2020." : https://www.agenciaandaluzadelaenergia.es/es/estra.

Air, Indoor, The Authors Journal, Blackwell Munksgaard, and Indoor Air. 2007. "Indoor Air Quality in Michigan Schools." : 109–21.

Almeida, Ricardo M S F, and Vasco Peixoto De Freitas. 2014. "Indoor Environmental Quality of Classrooms in Southern European Climate." *Energy and Buildings* 81: 127–40.

Almeida, Ricardo M S F, Nuno M M Ramos, and Vasco P De Freitas. 2016. "Thermal Comfort Models and Pupils ' Perception in Free-Running School Buildings of a Mild Climate Country." *Energy & Buildings* 111: 64–75.

"Assessment of Ventilation and Indoor Air Pollutants in Nursery and Elementary Schools in France." 2016. : 350–65.

Attia, Shady, and Salvatore Carlucci. 2015. "Impact of Different Thermal Comfort Models on Zero Energy Residential Buildings in Hot Climate." *Energy and Buildings* 102: 117–28.

Barrett, Peter, Fay Davies, Yufan Zhang, and Lucinda Barrett. 2015. "The Impact of Classroom Design on Pupils' Learning: Final Results Ofaholistic, Multi-Level Analysis." *Building and Environment* 89: 118–33.

Bb101. 2006. Department for Edcuation *Building Bulletin 101 Ventilation of School Buildings*.

Chatzidiakou, Lia, Dejan Mumovic, and Alex James Summerfield. 2017. "What Do We Know about Indoor Air Quality in School Classrooms ? A Critical Review of the Literature." 8975(February).

"Check and Improve the Energy Performance of Schools and Disseminate Best Practices - Intelligent Energy Europe - European Commission." https://ec.europa.eu/energy/intelligent/projects/en/projects/check-it-out (March 23, 2017).

Chenari, Behrang, João Dias Carrilho, and Manuel Gameiro da Silva. 2016. "Towards Sustainable, Energy-Efficient and Healthy Ventilation Strategies in Buildings: A Review." *Renewable and Sustainable Energy Reviews* 59: 1426–47.

"CIBSE - School Design Group." http://www.cibse.org/networks/groups/school-design (March 22, 2017).

CIBSETM57. 2015. *Integrated School Design*.

"Classroom Ventilation and Indoor Air Quality — Results from the FRESH Intervention Study." 2016. : 538–45.

Comisión Europea. 2010. "Directiva 2010/31/UE Relativa a La Eficiencia Energética de Los Edificios." *Boletin Oficial* L135: 13–35.

Deng, S, R Z Wang, and Y J Dai. 2018. "How to Evaluate Performance of Net Zero Energy Building E A Literature Research." *Energy* 71(2014): 1–16.

Desideri, Umberto et al. 2014. "Design of a Multipurpose ' Zero Energy Consumption ' Building according to European Directive 2010 / 31 / EU : Life Cycle Assessment." *Energy & Buildings* 80: 585–97.

"DesignBuilder Software Ltd - Home." https://www.designbuilder.co.uk/ (April 16, 2017).

"DOWNLOAD AREA | RENEW SCHOOL." https://www.renew-school.eu/en/links/download-area/ (March 23, 2017).

Erhorn-kluttig, Heike, and Hans Erhorn. 2014. "School of the Future – Towards Zero Emission with High Performance Indoor Environment." *Energy Procedia* 48: 1468–73.

Europeo, E L Parlamento, E L Consejo, and D E L a Uni. 2003. "DIRECTIVA 2002/91/CE Relativa a La Eficiencia Energética de Los Edificios (DEEE)." *Directiva* 2002: 65–71.

Flourentzou, Flourentzos, and Samuel Pantet. 2014. "THEORETICAL AND REAL

VENTILATION HEAT LOSSES AND ENERGY PE FRORMANCE IN LOW ENERGY BUILDINGS." (Mopec).
Flourentzou, Flourentzos, Samuel Pantet, and Katia Ritz. 2017. "Design and Performance of Controlled Natural Ventilation in School Gymnasiums." *International Journal of Ventilation* 0(0): 1–12.
"Home." http://www.school-of-the-future.eu/ (March 23, 2017).
"Indoor Air Quality in Portuguese Schools : Levels and Sources of Pollutants." 2016. : 526–37.
"Inive / International Network for Information on Ventilation and Energy Performance." http://www.inive.org.
Jovanovi, Marina, Biljana Vu, Valentina Turanjanin, and Marija Zivkovi. 2014. "Investigation of Indoor and Outdoor Air Quality of the Classrooms at a School in Serbia." 77: 42–48.
Kalimeri, Krystallia K et al. 2016. "Indoor Air Quality Investigation of the School Environment and Estimated Health Risks : Two-Season Measurements in Primary Schools in Kozani , Greece." *Atmospheric Pollution Research* 7(6): 1128–42.
Khan, Naghman, Yuehong Su, and Saffa B Riffat. 2008. "A Review on Wind Driven Ventilation Techniques." 40: 1586–1604.
Krawczyk, Dorota Anna. 2014. "Theoretical and Real Effect of the School's Thermal Modernization - A Case Study." *Energy and Buildings* 81: 30–37.
Luiz, Marcelo et al. 2015. "RISK ASSESSMENT FOR AIRBORNE INFECTIOUS DISEASES BETWEEN NATURAL VENTILATION AND A SPLIT-SYSTEM AIR CONDITIONER IN A UNIVERSITY CLASSROOM." : 1–5.
Ministerio de Industria, Energía Y Turismo. 2013. "Reglamento de Instalaciones Térmicas En Los Edificios." : 137.
Oropeza-Perez, Ivan, and Poul Alberg Østergaard. 2014. "Potential of Natural Ventilation in Temperate Countries - A Case Study of Denmark." *Applied Energy*.
"Passivhaus Institut." http://www.passiv.de/en/02_informations/02_passive-house-requirements/02_passive-house-requirements.htm (March 23, 2017).
Pegas, P N et al. 2011. "Indoor Air Quality in Elementary Schools of Lisbon in Spring." : 455–68.
Pikas, Ergo, Martin Thalfeldt, Jarek Kurnitski, and Roode Liias. 2015. "Extra Cost Analyses of Two Apartment Buildings for Achieving Nearly Zero and Low Energy Buildings." *Energy* 84: 623–33.
"Promoting Renovation of Schools in a Mediterranean Climate up to Nearly Zero-Energy Buildings | ZEMedS." http://www.zemeds.eu/ (May 2, 2016a).
———. http://www.zemeds.eu/ (March 23, 2017b).
Romana, Francesca, Elvira Ianniello, and Boris Igor. 2013. "PMV E PPD and Acceptability in Naturally Ventilated Schools." *Building and Environment* 67: 129–37.
Rufo, João Cavaleiro et al. 2016. "Indoor Air Quality and Atopic Sensitization in Primary Schools: A Follow-up Study." *Porto Biomedical Journal* 1(4): 142–46.
Severo, Milton et al. 2016. "Source Apportionment of CO 2 , PM 10 and VOCs Levels and Health Risk Assessment in Naturally Ventilated Primary Schools in Porto , Portugal ^ S Paci E." 96: 198–205.
Stabile, Luca et al. 2016. "Effect of Natural Ventilation and Manual Airing on Indoor Air Quality in Naturally Ventilated Italian Classrooms." *Building and Environment* 98: 180–89.
Sun, Yuming, Li Gu, C F Jeff Wu, and Godfried Augenbroe. 2014. "Exploring HVAC System Sizing under Uncertainty." 81: 243–52.
"Teenergy Schools | High Energy Efficiency Schools in Mediterranean Area." http://teenergy.commpla.com/ (March 23, 2017).

Toftum, Jørn et al. 2015. "Association between Classroom Ventilation Mode and Learning Outcome in Danish Schools." *Building and Environment* 92: 494–503.
"VERYSCHOOL.EU - Valuable Energy for a Smart School." http://www.veryschool.eu/ (May 2, 2016).
Wang, Yang et al. 2014. "Indoor Air Environment and Night Cooling Energy Efficiency of a Southern German Passive Public School Building Operated by the Heat Recovery Air Conditioning Unit." *Energy and Buildings* 81: 9–17.
Yang, Zheng, Ali Ghahramani, and Burcin Becerik-Gerber. 2016. "Building Occupancy Diversity and HVAC (Heating, Ventilation, and Air Conditioning) System Energy Efficiency." *Energy* 109: 641–49.
Zhu, Zishang. 2014. "Assessment of the Technical Potential for Multifunction Building Zero-Carbon Renovation with EnergyPlus." (November 2012): 178–88.