Smart energy management of combined ventilation systems in a nZEB

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Abstract: The high energy consumption, attached to a high energy demand in buildings, has led the development of several research projects with the target of reducing the energy consumption in the buildings. As a result of this high consumption, the increased CO_2 emissions that have been generated in recent years, have reached alarming levels, which is why it is necessary to reduce the environmental impact which we are contributing to our planet through the use of energy.
The European Directive on Building Performance (EPBD 2018/844/EU), recently updated, requires new buildings to be close to the Zero Energy Buildings (nZEBs), increasing the use of renewable energies on-site, and also highlight how to get to improve the cost-effective renovation of existing buildings with the introduction of building control and automation systems (smart systems), as well as the energy savings and increase the efficiency of energy systems, by reducing CO_2 emissions. The use of new renewable energy technologies integrated in buildings, with the aim of reducing the consumption of the facilities that all nZEB buildings must have, such as the ventilation system used as an Indoor Air Quality (IAQ) control technique.

In this study, the energy management of the enthalpy ventilation control system is analysed, where dynamic monitoring is going on in the building controlled through Supervisory Control And Data Acquisition (SCADA), in combination with different ventilation systems as free-cooling, heat recovery and geothermal energy of an Earth Air Heat eXchanger (EAHX), all of them as strategies implemented in a real nZEB building (LUCIA) located on the campus at the University of Valladolid, with the goal of improving energy efficiency in ventilation. In order to get this aims, monitoring data of several energy parameters (temperature, air velocity, air flow rate, enthalpy, etc.) are measurements, they allow us to perform a control of the combined ventilation systems to achieve a high IAQ and analyze an optimization of the energy efficiency of the all systems and to study of energy recovery and savings of carbon emissions that directly affect the reduction of the impact of climate change.

The results achieved are the energy efficiency of the building in ventilation and optimum system operation in cooling and heating mode. In addition, by controlling the ventilation, the IAQ of the nZEB building is improved.

Keywords: nZEB; Smart Energy Management; HVAC System; EAHX; Enthalpy Control; IAQ

1 Introduction

The high energy consumption, combined with the high energy demand of buildings, has led to various research projects aimed at reducing energy consumption in buildings.
As a consequence of this high consumption, the increase in CO_2 emissions over the last few years has reached critical limits and, therefore, it is necessary to reduce the environmental impact of the use of the energy to which we are subjecting the Earth[1].
With the implementation of the new European standards, the concept of near Zero Energy Buildings (nZEB) is introduced. The construction of near Zero Energy Buildings or the rehabilitation of buildings towards the nZEB, involves the use of new technologies and the use of renewable energy in order to compliance with the regulatory framework and, therefore, achieve this commitment to increase energy efficiency by reducing consumption[2–5].

Analysing the information supplied by the European Union, the construction sector is the most responsible for primary energy consumption, around 40%, with CO_2 emissions quite roughly 36%. For this reason, the EU has established contingency regulations to lessen the effects of these high values and thus contribute to the reduction of GreenHouse Gases (GHG)[6–8].
On this concept, the European Commission of Energy, through the Directive on the Energy Performance of Buildings EPBD 2010/31/UE [9], adopted the decision to reduce the energy demand of buildings through passive design strategies, as well as the reduction of energy consumption through the implementation of efficient energy systems, increasing the energy contribution produced by renewable energy generation systems, in addition to certification and verification of the different facilities and systems that are part of each building. This directive refers to buildings, all existing and new, being close to near Zero Energy Buildings by the end of 2020. On the other hand, for all those public or government buildings this period is reduced to the

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end of 2018. This directive has recently been updated to the EPBD 2018/844/EU directive [10], with the target of defining the cost-effective renovation of existing buildings through the introduction of building management systems and automation, as well as an improvement in energy savings, together with an increase in the efficiency of energy facilities. All of this, in order to obtain a significant reduction in carbon emissions[11]. The use of new renewable energy technologies integrated in buildings, with the objective of reducing the consumption of the facilities which every building in the nZEB concept is required to be fitted with, such as the ventilation system used as an Indoor Air Quality Control (IAQ) technique [10,12].

2 Case Study. LUCIA nZEB

The smart building management system studied is designed as one of the high energy efficiency systems integrated in the LUCIA building, nZEB building that belongs to the University of Valladolid, with a total area of 7500 m^2 for the development of research projects through laboratories and spin-off areas [13].(Fig. 1)

Figure 1. LUCIA nZEB

This building presumes to be the second best rated building in the whole world, and the first in the European continent according to LEED PLATINO certification. (Leadership in Energy and Environmental Design), in addition to the four-leaf rating on the GREEN tool (GBC Spain)[14,15].
This international recognition is based on its high level of energy savings, the use of materials with very low environmental impact, low water consumption and high efficiency in the management of waste generated by the building, in construction, demolition and in the working hours of the building.

LUCIA building is at the top of energy technologies, with several systems providing high efficiency, allowing it to be used as a model for achieving targets using only renewable sources. It can be said that the building has an almost zero CO_2 balance. The target of the building with its bioclimatic design, increased insulation, passive ventilation and other strategies, is validated with a reduction of energy demand by more than 50% compared to a standard building of similar features. In addition, it is important to highlight the possibility of supplying surplus energy to adjacent buildings, enabling the savings of these buildings that profit from this energy supplied.
The building is completely monitored by the energy meters of the chiller, the Central Heat Power (CHP), the boiler, the absorption unit and the hot water of the sanitary systems always through the ModBus protocol [16]; the consumption of heating, ventilation and air conditioning energy is also monitored through pulse counters. There are almost 100 electrical grid analysers distributed throughout the building to measure the active energy, reactive energy, phase voltage, frequency of each area. Thus, it is feasible to control the energy consumption and comfort thresholds of each zone.[13]
The LUCIA building also incorporates passive measures, such as south-facing, improved solar collection in winter and sun shading in summer, as well as natural ventilation with geothermal recovery, Thermal insulation of walls with a thermal transmittance of 0.157 W/m^2K, besides a high thermal inertia reducing the impact of external temperature changes on the comfort parameters in LUCIA nZEB, and double glazing windows stuffed by argon. The zigzag façade is shown as the chief construction feature of the LUCIA nZEB, generating automatic shade and a natural eaves due to the forged concrete in the upper part of each window and the glazed surface in its different orientations, east and west.
Also, LUCIA building has a green roof aiming to reduce the effect of urban thermal insulation on the surface of the building.

An important concept in building design has been the great importance of natural lighting, both for direct and diffuse radiation, through the use of special devices, such as natural light tubes with reflective material and translucent photovoltaic facades. Artificial lighting is controlled by the use of high-efficiency lights together with the control of the intensity of the lux level and the occupation at each instant in each area.
The artificial lighting of the building is provided by T5 electronic ballasts with Digital Addressable Lighting Interface (DALI) [17], and is designed according to lighting standards. The objective is to offer a total of 9.7 W/m^2 to the different laboratories and a minimum of 3.8 W/m^2 for the corridors of the building. LED downlights and DALI fluorescent lamps are used in transit areas.
Central heating and electricity systems, high-efficiency ventilation and air-conditioning systems, as well as a back-up absorption cooling system and geothermal systems have been installed in the facilities.

Energy generation is carried out by a Central Heat Power (CHP) system powered by a biomass boiler (Nominal Power 329kW, Efficiency 0.88, 100-125 kg/h) and generating a thermal energy production of 200-220 kWh, where 100-110 kWh are supplied at 90 ºC and the remaining 100-110 kWh at 450 ºC. Electricity is supplied through four rectified engines to work with lean gas, plus one that is in stand-by used only for maintenance operations, each with 112 kW of power (generating a total of 100-130 kWh), to which photovoltaic panels are added for the complete production of electricity using different technologies [13].

The air-conditioning system has an constant external flow system of 100% (15,000 m^3/h), that feeds the heating and cooling combined with the ventilation system. The heat is controlled by tube fancoil systems spread around the complete building. An absorption cycle (Nominal Power 176 kW, EER 0.7) with its cooling tower to remove the waste heat generated and a Chiller, being a conventional air cooling system, (Nominal Power 232.7 kW, EER 3.3) supply the cooling[18].
A geothermal heat recovery system is associated with the climatization system. A system Earth Air Heat eXchanger (EAHX) is formed by 52 tubes (Diameter 0.2 m, Area 0.031 m^2, Length 16 m) supplying a total heat exchange length of 832 m, with a mean airflow of 15,000 m^3/h, designed to provide an estimated contribution of 62,000 kWh/year in summer and 50,740 kWh/year in winter reducing emissions by 21,000 kg CO_2 during the working hours of the building per year.
In addition, this building represents a successful experimental unit for the testing and analysis of new energy efficiency measures or changes in the working parameters of existing operations, in order to induce a radical shift in the design and development of future buildings which are carbon neutral

3 Analysis and Results.

The control and management system of the building is developed by an advanced integrated system called Desigo™ (Siemens) in established SCADA technology (Supervisory Control and Data Acquisition software) [19].
Desigo™ system has been designed to ensure optimum management of all facilities, including electricity, HVAC, intrusion control, fires, alarms, etc. A predictive control of the whole building is generated, which enables the foresight of the different error-warnings that may arise.
The main feature of the system is the ability to carry out an integrated management of the energy processing of the building, ensuring that the energy supplied at all times is as low-intensity as possible. The Desigo™ development is implemented due to the integral monitoring of all sensors, hardware, measurement and regulation of building equipment. It also manages the registrations and storage of all the data acquired within the time periods previously required by the user. Each consumption parameter is regularly accounted for and recorded by the central building control, and monitoring system is going on, which saves the data and generates regular reports for consumption analyses.

The climate control model of the LUCIA building is carried out by controlling the constant air flow, or by the set temperature. Choosing one or the other only depends on the season of the year. The set points are established at 40-60% humidity, with a temperature of 21ºC in winter and 26ºC in summer.[20]
It is also possible to operate free-cooling in the main Air Handling Unit (AHU) while the system is generating fresh air in summer, thus increasing the efficiency of the systems. This is achieved by means of a geothermal ventilation system through buried pipes and a night ventilation system, in the aim of cooling the building naturally.

The ventilation system of the building presents four working modes, the air through buried pipes, Earth Air Heat eXchanger (EAHX), without through buried pipes (EAHX) and additionally there is the possibility of working with or without free cooling.

There is also the possibility of adding the heat recovery option, moreover, the capacity to use free-cooling in the UTA when cold is demanded in the building, and the ambient temperature is lower than that of the building, reducing energy consumption and increasing the thermal efficiency of the systems through the aerothermal exchanger (EAHX). Additionally, free cooling can be provided by night ventilation of the building. Therefore, there is the possibility of air conditioning the building with or without the EAHX exchanger, and with or without free-cooling.

To sum up, the different modes of operation could be: with buried pipes and heat recovery, without buried pipes and heat recovery, or just free-cooling, where neither the air passes through buried pipes nor the heat recovery systems are working. (Fig. 2)

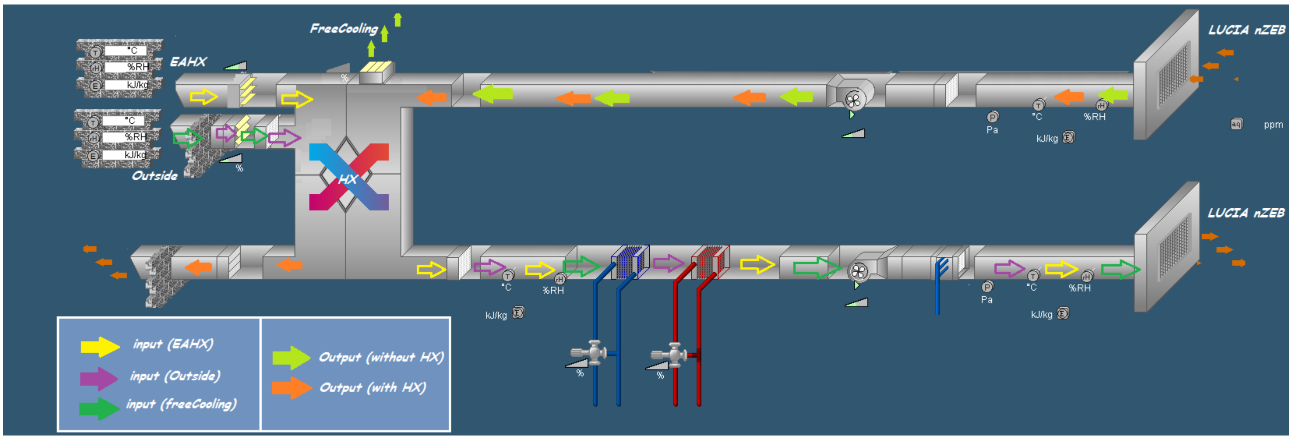

Figure 2: The modes of operation

The sensors have been installed supplying the temperatures and humidity of the two air inlet dampers to the data Acquisitor, where they are shown in the SCADA and we can analyze the incoming data. The management system manages this data in order to provide an optimized feedback applied to the Air Handling Unit (AHU), and to utilize the supply of the best energy parameters.
Figure 3 shows the saved dynamic temperature and humidity monitoring data at the input. Due to the dynamic monitoring of these energy parameters it is possible to confirm that the EAHX system works better in periods between summer and winter temperatures, all this in coherence with the weather data of the system geolocation to study.
In the study, the figures show how the temperature at those dates of the period remains constant providing an advantage over the intake air from outside at certain times for its operation.
Maintaining a stable ground temperature is one of the first characteristics that facilitate this smart HVAC control. Therefore, this EAHX technology will work better as long as its annual ground temperature is more stable. Figure *3e* shows how on October 20th the air temperature by the EAHX system remains constant due to the ground temperature gradient, to the detriment of the external temperature, which drops significantly about 10ºC.
Figure *3f* shows how on December 17th the EAHX system air temperature remains constant at 14ºC, in an interval between 4-10ºC above the external air temperature, which promotes the use of the EAHX system due to the heating demands requested by the building on this day.

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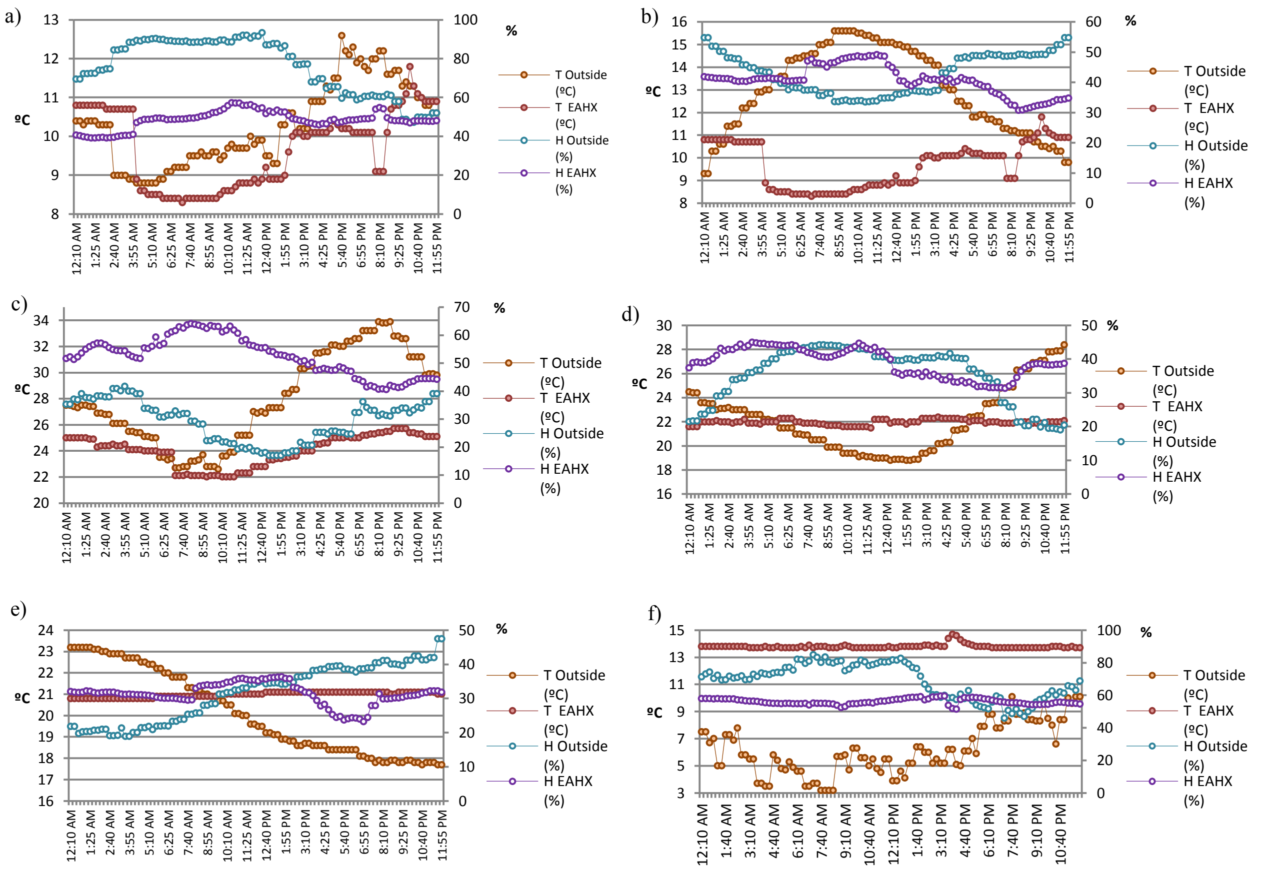

Figure 3. Temperature and Humidity on: a) February 10th b) April 3rd c) June 20th d) August 17th e) October 20th f) December 17th.

The smart building control system will design the most cost-effective strategy to reduce energy consumption by measuring the enthalpic differences of the respective air inlet dampers.

This ensures perfect operation and high energy and economic efficiency of the whole energy systems of the building. (Fig. 4)

The air inlet in the Air Handling Unit is supervised by the SCADA via enthalpy control, seeking the best prerequisites for achieving the comfort parameters indoors at the lowest cost in terms of energy and economy. According to the climate data, it will be opted for obtaining the inlet air through EAHX or directly from the outside air damper. The seasons determine the climatic parameters outside, hence there are months in which more external air will be used than air through the buried pipes at EAHX.

Figure 4 shows the dynamic monitoring of enthalpies for the subsequent smart management of the Air Handling Unit. This enthalpy control encourages the choice of the optimum air quality at the AHU inlet. The smart HVAC system according to demand by the building, heat or cooling, select the best choice. Figure *4b* shows how on April 3rd, due to the demand for heating required by the building, 75% of the time, the air supplied to the AHU is provided by the EAHX system due to the best energetic properties, with the exception of the period between 13.00 to 20.00, when the AHU is supplied with air from outside directly as a result of its best characteristics. However, Figure *4f* shows how on December 17th, being a period of high demand for heating, better air properties are obtained by introducing almost 92% of the EAHX air flow to the AHU. The enthalpic control of the HVAC system enables the choice of the best systems to achieve the parameters set for comfort, temperature and humidity.

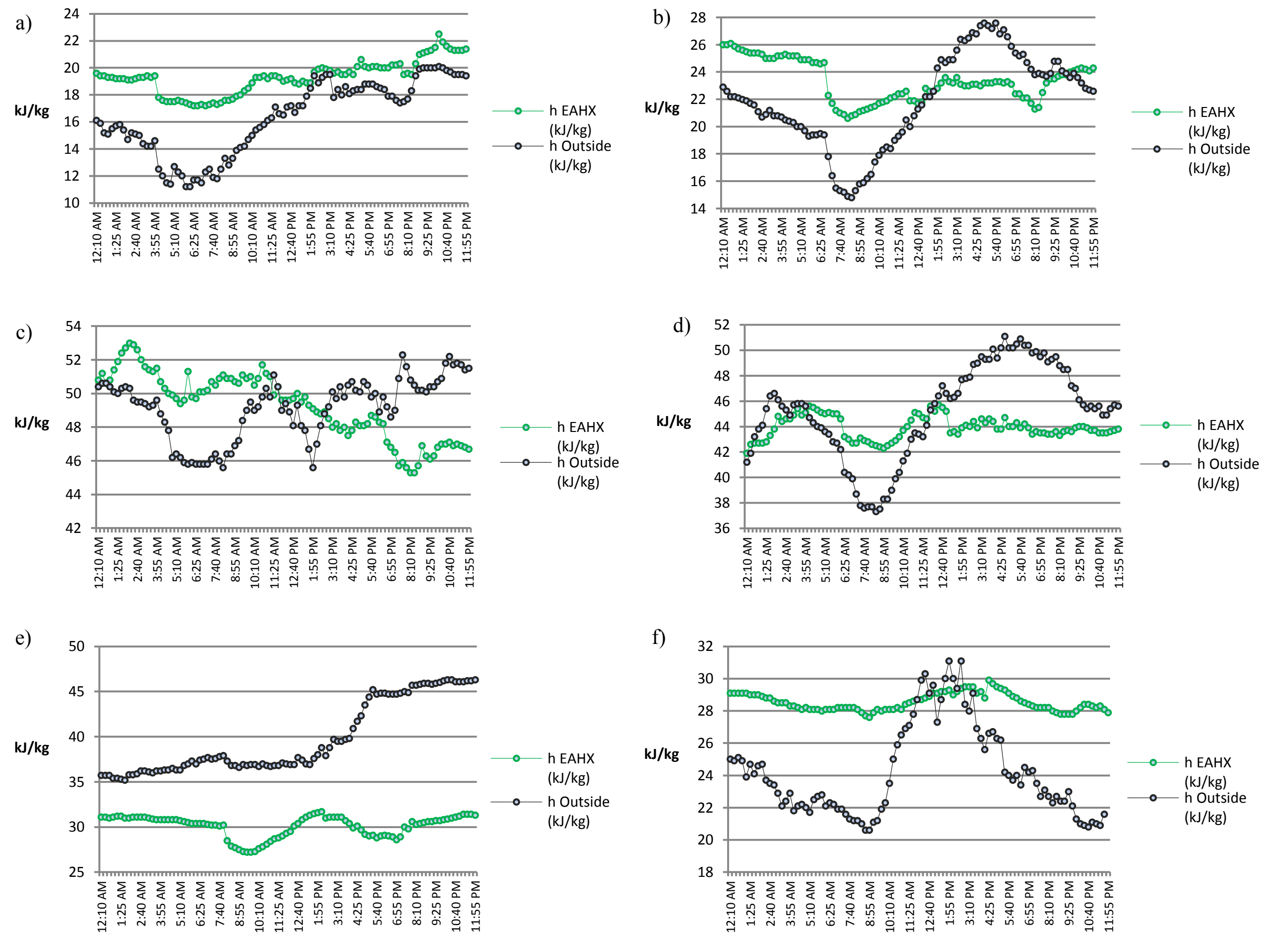

Figure 4. Entalpies EAHX and outside on: a) February 10th b) April 3rd c) June 20th d) August 17th e) October 20th f) December 17th

The use of the heat recovery unit within the air handling unit depends on the setpoint parameters established by the building directly. If, due to economic and energy saving conditions due to enthalpy control, it is considered necessary, it will come into service, providing a better efficiency of the system and a better use of energy, generating meaningful savings and improving air quality, being controlled by a sensor in the return flow to the AHU. The sensor is programmed with 700 ppm as the safety threshold, from which the supply flow would increase to reduce indoor air pollution and increase the IAQ.

In accordance with the previously mentioned European directives, reference is made to the importance of the reduction of CO_2 emissions in the generation of energy associated with buildings. Conversion factors for biomass and conventional fuels determined for Spain are used to quantify the CO_2 emissions saved related to the EAHX. The following conversion factors have been used for the valuation of CO_2 emissions: Electricity 0.357 kg CO_2/kWh; Diesel 0.311 kg CO_2/kWh; LPG 0.254 kg CO_2/kWh and natural gas 0.252 kg CO_2/kWh. All in accordance with the factors defined by Spanish standards[21].

Savings in carbon emissions through the use of the EAHX are from 95 tons CO_2/year if it was supplied by natural gas, 114 tons CO_2/year by Liquefied Petroleum Gas (LPG), or 134 tons CO_2/year by diesel, all according to the European regulation of emissions.
Other important sections of this paper focus on the economic savings generated on the LUCIA nZEB by the EAHX.
The economic analysis has been carried out following the Spanish fuel price policy in 2017. The EAHX generates economic savings of around 19,000 € more than if biomass were used to obtain the kWh saved by the EAHX, in this nZEB.

Focusing on traditional fuels, the comparison is in the range from 24,000 € for Natural Gas to 28,000 € that would be saved in generation respectively by the use of a fossil fuel such as Diesel. Moreover, without the EAHX, the building would require an additional sum of 1500 €/month due to extra biomass consumption.

4 Conclusions

This research paper emphasizes the importance of high efficiency and quality of ventilation in the IAQ indicators, in order to achieve the previously mentioned European Standard.

The smart management of the HVAC system by using a combination of 3 systems of high technological innovation to achieve better ventilation and higher IAQ, through the control and regulation of the different energy parameters that adjust the HVAC of the building. This control is made up by the dynamic monitoring of energy parameters which, by means of the scada implemented in the building, carries out the analysis of the optimum energy consumption of the complete HVAC system, being one of the highest in the whole building.

The use of EAHX system produces significant CO_2 savings around 100 tons CO_2/year in comparison to the use of traditional fossil fuels and significant economic savings, 24000€/year in the energy consumption of the building.

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