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IAQ Improvement by Smart Ventilation Combined with Geothermal Renewable Energy at nZEB †

Javier M. Rey-Hernández [1,2], Ana Tejero-González [2,3], Eloy Velasco-Gómez [2,3], Julio F. San José-Alonso [2,3], Francisco J. Rey-Martínez [2,3,*] and Paula M. Esquivias [3]

1 Higher Polytechnic School, European University Miguel de Cervantes, 47012 Valladolid, Spain; jrey@uemc.es
2 Institute for Advanced Production Technologies (ITAP), 47011 Valladolid, Spain; anatej@eii.uva.es (A.T.-G.); eloy@eii.uva.es (E.V.-G.); julsan@eii.uva.es (J.F.S.J.-A.); paula.esquivias@uva.es (P.M.E.)
3 Energy and Fluid Mechanics Department, University of Valladolid, 47002 Valladolid, Spain
* Correspondence: rey@eii.uva.es; Tel.: +34-983-00-1000
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Abstract: The building sector has the responsibility of being a generator of high carbon emissions, due to inefficient energy consumption in the last decades. For the European Union (EU) and the building sector, this pollution has generated a great impact and concern, establishing objectives in sustainability and energy efficiency in the short term. The EU, committed to energy sustainability, has established several guidelines, aiming at reducing carbon emissions. For this reason, European directives have been published to increase energy efficiency and sustainability in buildings, with EPBD 2018/844/EU being the most up-to-date regulation. This directive mainly focuses on reducing carbon emissions and increasing the efficiency of energy systems in buildings, but it also refers to the importance of establishing indoor air quality indices and smart management of ventilation systems. Before this directive was published, many of the implemented ventilation strategies did not consider the indoor air quality (IAQ) in their scope of established comfort parameters. Therefore, this study analyses the performance of the ventilation system, controlled smartly to cover the demand and the established IAQ rates via CO_2 ppm, through renewable geothermal energy systems. This study has been carried out at the LUCIA building, a near Zero Energy Building (nZEB), which belongs to the University of Valladolid, Spain. This building stands out for being one of the most sustainable buildings in the world, according to LEED certification, ranking as the most sustainable building in the northern hemisphere. This building to study is equipped with cutting-edge energy systems, with zero carbon emissions. Several parameters have been analysed (air speed, enthalpy, air flow, temperature, humidity, kWh, climate data, etc.) enabling an energy optimisation of the combined systems. All the monitoring data obtained by the smart management have been analysed, providing favourable outcomes, due to the establishment of IAQ levels, according to the EPBD 2018/844/EU. After this study, the smart management of ventilation combined with removable geothermal energy can be exported as a strategy to reach the established IAQ levels through zero carbon systems.

Keywords: indoor air quality (IAQ); smart management; near zero energy buildings (nZEB); smart ventilation; carbon emissions

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1. Introduction

Due to high energy consumption in the buildings sector, carbon emissions have increased in recent decades, reaching very high levels. Thus, reducing the environmental impact caused by energy use, via decarbonization and greater efficiency, becomes a main target.

In response to this scenario, the European Union (EU) has established regulations to reduce the energy demand of buildings. Within the directives published by the EU, in particular the Energy Performance of Buildings Directive (EPBD) 2010/31/EU, we highlight: the passive strategies concerning the design of the building envelope; the reduction of energy consumption by the implementation of highly efficient energy systems; a stronger supply of renewable energy sources to the demand of the building; and the implementation of inspections and certification of the energy facilities, which belong to the building. According to this regulation published by the EU, it is regulatory as in all old and new buildings, to aim to comply with the concept of a zero energy building, at the latest, by the end of 2020. For government and public buildings, this period has been minimized by two years.

The Earth-to-Air Heat eXchangers (EAHX) are highly efficient renewable energy systems which comply perfectly with European Union directives. Therefore, they are a viable alternative to achieve the objectives set within the regulations, due to the heat exchange with the soil located under and around the building [1,2].

The temperature of the soil, regardless of the composition, varies. These fluctuations grow at a slower speed than in air, thereby causing thermal storage in the soil. This thermal storage is used as a source of renewable energy [3,4]. The use of thermal energy due to the flow of air passing through the earth–air heat exchanger, in order to heat or cool the air supplied to the HVAC (Heating, Ventilation and Air Conditioning) system, is used to achieve the established levels of indoor air quality (IAQ) of the building under study, being much more efficient, and achieving a reduction in energy consumption in the building demand [5,6]. The thermal inertia in the soil, which facilitates the heat exchange between the soil and the air flow, reaches its maximum in the months with extreme outdoor temperatures, facilitating better values in the thermal recovery of the air supply to the ventilation system [7].

2. Case Study

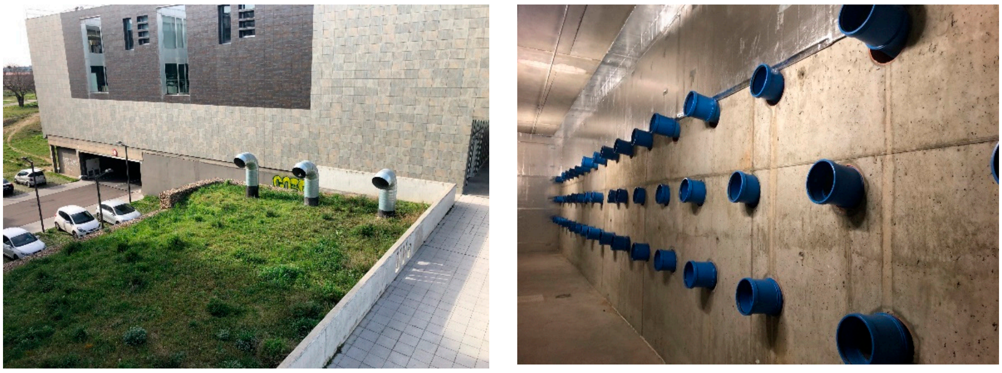
The case study is carried out in the facilities of the LUCIA Zero Energy Building (ZEB) at the University of Valladolid, Spain. It is a 7500 m^2 ZEB building, used as laboratory/research facility by the University's departments. Within the facilities, the EAHX is included as a system powered by renewable energy sources, which allows it to reach the established IAQ levels with a lower energy consumption.

The building where the EAHX system is integrated is one of the best recognized as a ZEB building by the LEED certification, due to its high efficiency renewable energy technologies. Consequently, this building has zero carbon emissions. The studied building is built within the PassivHaus concept, with an important insulation to avoid thermal losses, the implementation of passive ventilation and other types of passive strategies that allow the reduction of the energy demand of the building in a total of 50% compared to a standard building. The energy generation power allows it to supply energy to nearby buildings, providing energy savings in nearby buildings.

The HVAC system installed in the case study building consists of an air handling unit, providing heating, cooling and ventilation to each area of the building. The HVAC system is distributed throughout the building, using 4-pipe fan coils, to provide heating and cooling. There is also the possibility to provide night ventilation by free-cooling, and with the possibility to use, or not, the air treatment unit recovery system, and the geothermal recovery system.

The EAHX system in the study has a total of 52 pipes, each one 200 mm in diameter. This is a total of 0.031 m^2 of surface per pipe. Taking into account the 16 m length per pipe, providing a total cross section for all the pipes of 1.63 m^2, and 832 m exchange length over the total number of pipes. A constant air flow of 15,000 m^3/h flows through the heat exchanger. This EAHX supplies a total of 62,000 kWh/year in the spring and summer period, and 50,740 kWh/year in the autumn and winter period. Carbon emissions are reduced by 21 tons by this heat recovery [8] (Figure 1).

The ground where the pipes are buried, in which the air flows through the EAHX, has enough space for thermal energy recovery, and therefore contributes to increasing energy efficiency.



(**a**) (**b**)

Figure 1. Earth-to-air heat exchanger at the LUCIA building: (**a**) outside; (**b**) inside.

3. Analysis and Results

The system where the study is being carried out, in LUCIA ZEB, has integrated several sensors with the aim of measuring the greatest number of energy parameters possible such as: temperature, humidity, enthalpy, indoor air quality (IAQ) in ppm, and energy consumption by fans. All these parameters are monitored, through a SCADA system within the BMS, importing data with a frequency between 1 and 5 min. The acquired data is used to analyse its performance, integrating improvements and analysing errors.

The ventilation system has 700 ppm as a set parameter, to keep constant the IAQ levels. If this parameter is disturbed by pollution in any area and its air quality index is threatened, an overpressure is supplied by the ventilation system, in order to bring the situation back on track.

Table 1 shows the energy recovered by the geothermal system during one year by area, and its operating hours. To analyse this system, combining months from April to September, it reaches a recovery of 65920.3 kWh. In the remaining 6 months, it reaches a recovery of 36,094 kWh. With these values, it is possible to determine the importance of the EAHX in the months of high cooling demand. The geothermal recovery reached a total of 102 MW in its 2209 h of operation, bearing in mind that EAHX worked 35% of the building's operating hours. It is the BMS system which chooses when the conditions are optimal to work the HVAC system with the EAHX recovery. The system was designed to work 39% of the hours of operation of the building.

Table 1. EAHX monthly energy savings.

	Jan	**Feb**	**Mar**	**Apr**	**May**	**Jun**	**Jul**	**Aug**	**Sep**	**Oct**	**Nov**	**Dec**
Heat Recovery/area (kWh/m^2)	0.2	0.51	0.38	0.18	2.91	2.71	1.53	0.52	1.12	1.41	1.07	1.06
Working time (h)	152.25	162	206.5	148.75	212.25	247	203.5	99	188.25	220	217.25	152.25

The next figure shows the heat recovery by the EAHX, keeping the IAQ levels stabilized in 700 ppm CO_2. The peak of heat recovery is in May and June due to the thermal inertia of the ground. This balanced thermal inertia facilitates the heat exchange between the air flow and the soil (Figure 2).

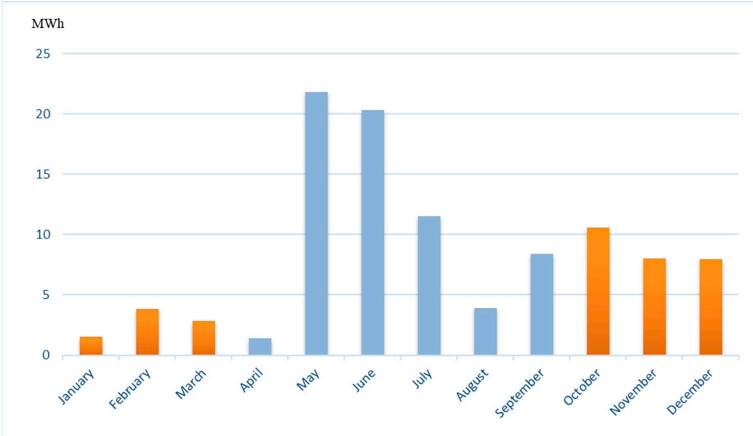


Figure 2. Heat recovered in MWh by the EAHX system.

4. Conclusions

The LUCIA building due to the smart ventilation with its EAHX, supports stable IAQ levels in 700 ppm of CO_2, around the different areas of the building, and manages to recover a high amount of thermal energy. During the year of study, it recovered 362,000 kWh, reducing the carbon emissions associated by the renewable geothermal system.

This recovered thermal energy helps to reduce the environmental impact of the building, without reducing the previously established air quality indices.

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Conflicts of Interest: The authors declare no conflict of interest.

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