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Assessing the performance of a renewable District Heating System to achieve nearly zero-energy status in renovated university campuses: A case study for Spain

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ABSTRACT

This paper presents the implementation of a biomass-fuelled District Heating System (DHS), as a part of a deep energy renovation exercise to achieve a climate-resilient campus with minimum carbon dioxide emissions. The case study is carried out for the University of Valladolid, an average-sized university in Spain, with a continental weather climate.

Prior to renovation, the different building blocks had a wide-ranging level of fossil fuel consumption for space heating and domestic hot water ranging between 60 and 430 kWh/m^2·year. The application of this centralised heating system allows to achieve the minimum threshold for near zero-energy buildings (nZEB) of 100–120 kWh/m^2, in accordance with the Spanish Standards. These values correspond to the maximum European indicators for offices in continental weather conditions. Results of this comprehensive study show that 15 out of the 19 buildings reached the nZEB target, due to the proposed strategy. The overall carbon dioxide emissions have dropped by 92.69% as compared to the original fossil-fuel powered boiler, thus bringing carbon dioxide emissions down to 1.57 kgCO$_2$/m^2·y.

Therefore, it is shown that deep energy renovation strategies through renewable energy DHS have the potential of achieving nZEB for universities in continental weather conditions.

1. Introduction

In the past few years, the European Union has encouraged a strong drive towards environmental responsibility and social commitment favouring climate change mitigation [1,2]. This commitment is expressed through legislative measures that support the "Energy Efficiency First" principles and stronger deployment of renewable energy systems, especially in the deep renovation of existing buildings with specific emphasis on public authority buildings at the rate of at least 3% of total floor area per year [1]. These regulations aim to effectively and efficiently achieve the decarbonization targets of the European Union [3].

The building sector is the main contributor to the total energy use in the European Union (40%) and accounts for 36% of the associated Carbon emissions [4–6]. Consequently, in 2010 new initiatives to minimise this impact were presented, including the EPBD 2010/31/EU, which actively promoted the reduction of the energy demand in the building sector [7]. One of the requisites was that Member States produce cost-optimal studies to provide cost-effective energy efficiency packages. Those should be implemented with the minimum energy performance requirements, in a bid to push new and renovated buildings closer to near zero-energy status [8].

The EPBD (EU) 2018/844 went further and requested that a

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Nomenclature

BMS	Building Management System
BPIE	Buildings Performance Institute Europe
CHP	Combined Heat and Power
CTE	Spanish building code regulations (Código Técnico de la Edificación)
DHS	District Heating System
DHW	Domestic Hot Water
EEM	Energy Efficiency Measures
EI	Energy Efficiency Specific Indicator
EI_p	Total Primary Energy Consumption Indicator
EI_{p_nr}	Non-Renewable Primary Energy Indicator
EI_{pr}	Renewable Primary Energy Indicator
EPBD	Energy Performance of Buildings Directive
EU	European Union
KPIs	Key Performance Indicators
MS	Member States
NG	Natural Gas
nZEB	nearly Zero-Energy Buildings
PEF	Primary Energy Factor
RET	Renewable Energy and other Technologies
SCADA	Supervisory Control and Data Acquisition
UVa	University of Valladolid

minimum share of renewable thermal energy contribution has to be achieved every year by all Member States (MS) [1]. This Directive includes also other more ambitious requirements such as devising a long-term renovation plan by March 2020 that specifically targets the worst performing buildings [9]. Among the different strategies, smart control of buildings via building energy systems, energy storage, cleaner heating and cooling systems and demand response capacity have drawn the most attention. Due to this implementation, the energy performance rating of buildings is no longer only focused on the primary energy indicators but will have to be combined with other markers such as the carbon footprint and smart readiness indicator, as well as indoor comfort and air quality assessment levels.

Nevertheless, the definition for nZEBs is still valid [10,11], whereby buildings have to reduce their energy consumption through cost-effective improvements to the building envelope and the building energy systems and complement the low energy demand by renewable generation of energy, on-site or nearby [12,13]. Therefore, solutions that cost very little such as passive measures are given priority, followed by the interventions to the building envelope and building energy systems, with the eventual solution based on the integration of renewable energy systems [14,15].

The BPIE reports that only 2.5% of buildings in Europe fulfils the criteria of the Energy Class A (most efficient buildings), while 75% are classified as "energy inefficient" [9,16]. University campuses are usually in low energy categories [17], thus their modernisation is among the current EU nZEB targets [18]. Pakere, Cerezo-Narvaez, and Teres-Zubiaga et al. identify and analyse possible energy efficiency strategies needed, in order to achieve a Carbon Neutral European Union in the shortest possible time [19–21].

Biomass is considered one of the most abundant renewable energy resources in the EU. Aste. et al. studied a new nearly zero-energy district, located in Milan, Italy, where District Heating (DH) was fuelled by biomass. A solution based on the combination of a low-energy building design and high-efficiency technical systems have been studied, which resulted in a significant reduction of energy end-uses [22–24].

In another case study, in Denmark, Kristensen et al. investigated a DH efficiency of building typologies based on heating consumption data of more than 40,000 buildings, to provide a building typology relationship, from the data recorded by the Danish Government system [25]. Braimakis et al. [26] studied the performance of Combined Heat and Power (CHP) plants to cover the heat demand of industrial processes while producing district heating and cooling to meet decarbonization goals. Quirosa et al. conducted a model for the sustainability of biomass DHS, optimizing their implementation and sustainability [27]. Braimakis et al. conducted the techno-economic evaluation of biomass combustion for CHP generation coupled to a DHS and investigated the profitability of the plant depending on operating parameters [28].

Hilma et al. analysed the prospects of local biomass resources as substitutes for fossil fuel imports, with the aim of providing renewability in DHS. The study shows that the alternative energy sources may act complementary to each other, providing better joint performance [29]. Wang et al. stressed that the energy efficiency of the cases is determined by energy drivers, standards, policies, technology, and its ratio, determine the energy performance of the cases [30]. To achieve zero energy is a process, rather than the end goal [31–34]. That is why many projects need further alternations throughout the lifetime [35–38].

Over the last years, EU has allocated significant funds in improving the energy efficiency of the building sector, increasing the use of renewable energy and the number of nZEB. De Luca et al. [39] presented a study analysing the energy and economic aspects related to renewable energy to reduce the environmental impact of the existing buildings. The minimum share of Renewable Energies established by the Italian regulations was considered in this investigation.

Ferrara et al. [40] conducted a novel, more efficient design optimisation approach based on deep residual learning technique to make the process of finding optimal design solutions more efficient. The design of renewable energy systems for nZEB is a complex challenge.The analysis of demand response control allows the optimization of renewable energy systems to nZEB buildings. Huang et al. [41] proposed a nZEB control method that allows full collaboration between nZEBs and takes into account the uncertainty in demand prediction by optimizing each energy system.

Seljom et al. analysed the impact on long-term investment decisions of renovation to ZEBs concept [42]. ZEBs reduce investments in the electricity and heating sector. Rabani et al. studied the retrofitting of buildings to achieve nZEB status, and proposed a methodology to automate the procedure of finding the best combination of implemented measures to minimize the energy use of the building and achieve the nZEB target, while improving comfort conditions [43]. Li et al. analysed the two ZEB strategies: minimizing the energy needs of buildings (heating and cooling) through EEM (Energy Efficiency Measures), and meeting the remaining energy needs by adopting RET (Renewable Energy and other Technologies) [44]. Patiño-Cambeuro, Srinivasan, and Wilnhammer et al. evaluated several energy retrofit packages, and showed how energy efficiency measures are basis for achieving the objectives [45–48]. In fact, Spain, being one of the most proactive EU member states in decarbonization, has just established a nZEB definition comprising a target number threshold, and a minimum required share of renewable energy sources [8]. All of this is reported in the new Technical Building Code [10], of the Spanish Building legislation, where the basis for the determination of nZEB is regulated.

Recent projects show the efforts made to optimize energy efficiency through the renovation of existing non-residential buildings [48–50] to achieve a high level of decarbonization [14] and a new low-energy building status [15]. University campus buildings are no exception, as in general, they are quite far from the nZEB requirements of the EPBD. Universities, which play a crucial role in modern society, should take the lead in analysing energy efficiency and proposing measures for their own buildings. The aim should be the retrofitting of buildings towards nZEB in the medium term, to comply with the EU Green Deal, which prioritizes energy efficiency, and to achieve a secure energy supply across Europe [51,52]. These actions have an important role in a broader goal for the sustainable development of all university campuses, with the focus on renewable thermal energy systems fulfilling the new requirements.

Some recent studies on the energy assessments and audits of university buildings have been carried out in this area [53–58]. However, none of them includes the combination of a detailed analysis multiple university buildings (19 buildings), combined with a renewable energy powered DHS that uses biomass.

Therefore, the aim of this work is to evaluate the capacity of using renewable energy DHS to achieve nZEB in the chosen sustainable university campuses, facilitating replicability to other university campuses and cities. This analysis contributes towards scientific knowledge in the area of energy retrofits and enables the determination of the current energy indicators at building and campus levels. In addition, it allows to analyse the limits established for non-residential buildings nZEB in Spain and the EU, within the European Green Deal target for decarbonization by 2050. This study focuses on the analysis of non-renewable and renewable primary energy consumption, in order to obtain the Key Performance Indicators (KPIs), and therefore, to show a viable and accessible methodology to achieve the nZEB concept at the European and National regulations, in the rehabilitation of large educational buildings.

This assessment can serve as a pre-retrofit energy baseline to measure savings in future energy renovations of the university. In addition, the methodology will illustrate to what extent actual energy use and actions resulted in reduction of energy costs.

2. Methodology

This paper provides and analyses experimental data obtained from a BMS system, through dynamic energy monitoring of a retrofitted renewable central heating system at the University of Valladolid, to demonstrate the possibility of achieving nZEB levels in renovated university campuses. The methodology applied to carry out this study is shown in Table 1:

In order to define nZEB levels for this paper, the methodology adopted the latest 2019 Spanish building code regulation CTE DB-HE0 [59], which is based on the EU standard (FprEN 15603–1 or its new update, the prEN ISO / DIS 52000–1) [31], as well as the definition for nZEB as appearing in Article 2 of the EPBD 2018/844/EU [1].

According to the Spanish building code regulation CTE DB-HE0, there are several indicators of whether a building is considered anZEB. One of them is to ensure that the non-renewable primary energy consumption is less than 110 kWh/m2·y, in D2 climate zone, Valladolid area, considering a high average internal load, according to the Spanish building standards. This data is also close to the limit value indicated by the EU in a continental climate such as Valladolid. Additionally, the building must attain a primary renewable energy production indicator of at least 50%.

Table 1
Methodology applied to the study.

Step	Development
1	Identification of the Campus buildings, classified in two university sub-campuses (Miguel Delibes and Esgueva Campuses).
2	Data collection of temperature, pressure, hot water flow and energy consumption from the SCADA system in each building.
3	In-depth and detailed energy analysis, carrying out a comparative study between the old systems and the new integration of renewable DHS powered by biomass.
4	Key Performance Indicators (KPIs) assessment in the 19 university buildings, according to European legislation and the Spanish building code regulations (CTE) for ZEB buildings: The non-renewable primary energy, EI_{p_nr}; Renewable primary energy, EI_{pr}; And total primary energy consumption indicators, EI_p.
5	Finally, the impact on the nZEBs in the UVa Campus is compared, by retrofitting a new heating and renewable DHW system.

Therefore, in order to determine the extent to which the UVa Campus will attain the nZEB level with the implementation of the DHS, the total primary energy consumption of each building must be taken into account. In this case, the final energy values, both thermal (heating and DHW) and electrical, must be known. Once the final energy values are recorded, they need to be multiplied by the corresponding Primary Energy Factor (PEF), based on the corresponding fuel used, to obtain the total primary energy consumption of each building.

The assessment includes the collection and study of relevant building data, such as geometric and operational data, the impact of climatic conditions on energy use, as well as the analysis of hourly resolved energy data to identify outliers and possible inefficiencies in the energy systems, both before and after the application of the DHS.

Natural gas, gasoil, and electricity consumption for the 19 building blocks have been collected with the highest timeline resolution available. Regarding natural gas, gasoil, and electricity consumption, the monthly bills of the supplying companies for the last 10 years (from 2008 to 2018) were analysed.

2.1. Case study description

The University of Valladolid (UVa) is a medium-sized Spanish public university, located in Valladolid (Spain). The University was established in 1241, making it the second oldest university in Spain. The University of Valladolid is a member of a network of research institutes, universities, and colleges in Castilla y León, Spanish region. The UVa has two university campuses in the city of Valladolid, spread throughout the North area of the city (Fig. 1 and Fig. 2).

The 19 different building blocks of the University of Valladolid had individual natural gas (NG) or oil heating boilers (gasoil/diesel) for space heating and domestic hot water (DHW) demand (Table 2). In 2018, all buildings were connected to the renewable DHS, which has three boilers of 4.7 MW each. In 2019, in order to cover the demand at the adjacent University Hospital, a fourth boiler of 5 MW was added to the existing facilities, in a previously foreseen space.

The 19.1 MW DHS of the University of Valladolid has more than 12 km of pipelines to provide heating and DHW to 31 public buildings, burning 11 tons of forest waste chips per year. However, for this study, only 19 of the 31 connected buildings are studied, only these belonging to the UVa Campus. (Table 2).

The complex piping system can be simplified into two independent circuits leaving from the DHS. Each of them has three variable flow pumps in parallel to reduce the electrical consumption required to operate the system.

Table 2 shows the 10-year average annual thermal equivalent energy consumption for each building block prior to the implementation of the DHS. On the other hand, the new DHS is managed by a Supervisory Control and Data Acquisition (SCADA) management system. It is based on the dynamic monitoring of different energy parameters of the system and the substations of each building (Fig. 3), such as pressure, water temperature of the DHS, flow rate, energy consumption of the pumps, thermal consumption, electrical consumption of each building on the Campus, and real-time data control of the DHS. This process of dynamic monitoring and real-time control of the entire DHS and the substations of each building is carried out through a large number of sensors and actuators.

Fig. 4 shows SCADA screenshots of: a) the DHS secondary hydraulic circuit b) and the DHS Heat Exchanger per building. Through the SCADA, all the inlet and return temperature data of both the primary circuits (DHS) and the secondary circuits (specific to each Heat Exchanger of the DHS), power, flow rates, accumulated thermal energy, accumulated electrical energy consumption in the pumping systems, among other variables, have been recorded.

The DHS is being fully monitored by more than 500 energy meters

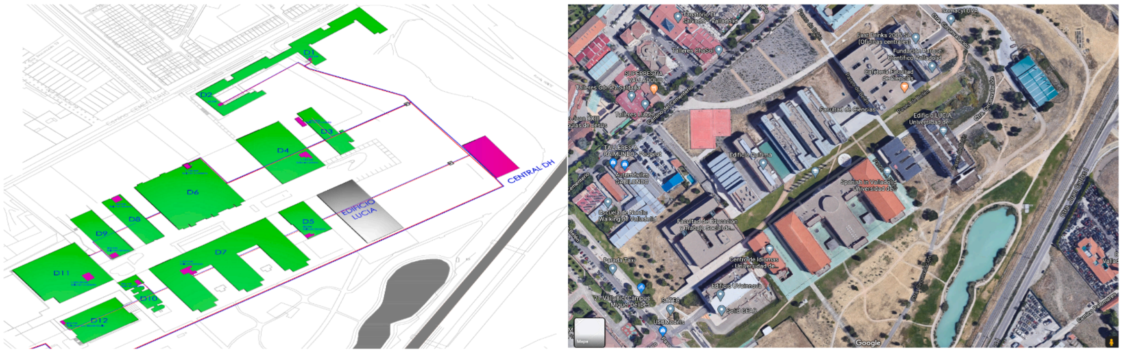

Fig. 1. DHS and buildings of Miguel Delibes Campus (D) at UVa.

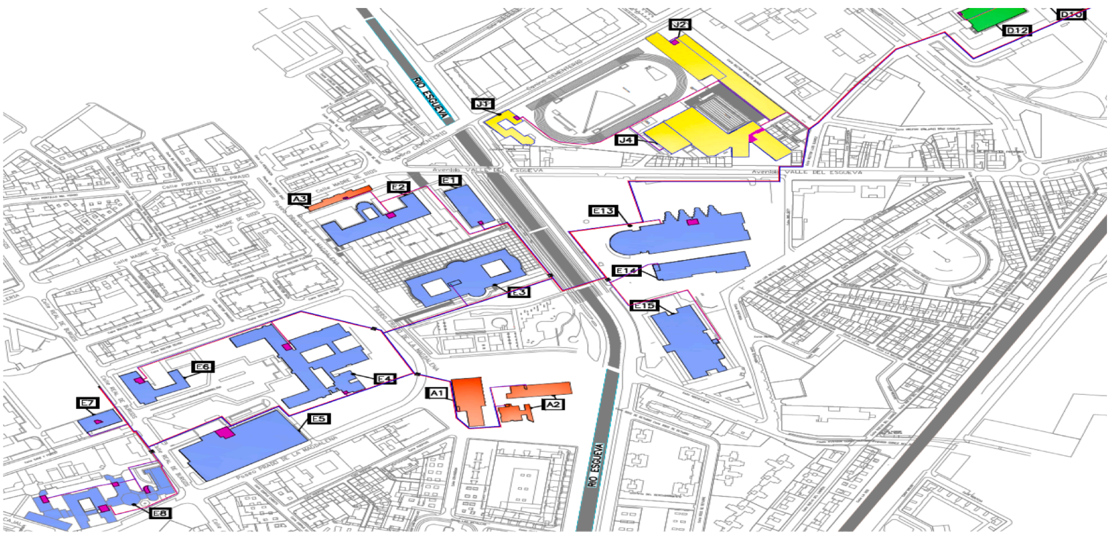

Fig. 2. DHS and buildings of Esgueva Campus (E) at UVa.

Table 2
Summary of data of the selected buildings in the two university campuses, UVa.

Campus	Building	Building Reference	fuel	Area (m^2)	EI final energy ConsumptionNG/ Gasoil ($kWh/m^2 \cdot y$)
Miguel Delibes University Campus (D)	Cardenal Mendoza University Residence. (Apartments)	(D1 & D2)	NG	15,490	100.01
	Miguel Delibes Classroom	(D4)	NG	3,984	254.91
	IOBA. Ophthalmology Research Building	(D5)	NG	3,702	35
	Faculty of Sciences	(D6)	NG	17,220	70
	Faculty of Telecommunications and Computer Engineering	(D7)	NG	27,245	50
	QuiFiMa. Chemistry, Physics and Mathematics Research Building.	(D8)	NG	5,049	105
	University Sports Centre Building	(D9)	NG	1,724	215.05
	Language School	(D10)	NG	4,966	50
	Faculty of Education	(D11)	NG	13,407	55
	R + D Research and Development Building	(D12)	NG	7,033	50.01
Esgueva University campus (E)	Maintenance Service Building	(E1)	Gasoil	1,546	60.01
	University School of Business Administration	(E2)	Gasoil	9,852	50
	Faculty of Philosophy and Letters	(E3)	NG	19,540	63
	Alfonso VII University Residence Building	(E5)	Gasoil	23,864.52	80
	IBGM. Molecular Biology Research Building	(E7)	NG	3,415	80.02
	Faculty of Health Sciences	(E8)	NG	28,987	80
	Faculty of Economics	(E13)	NG	14,876	105
	Esgueva Classroom	(E14)	Gasoil	6,362	65
	Industrial Engineering School. Building 1. "Paseo del Cauce"	(E15)	NG	16,692	100

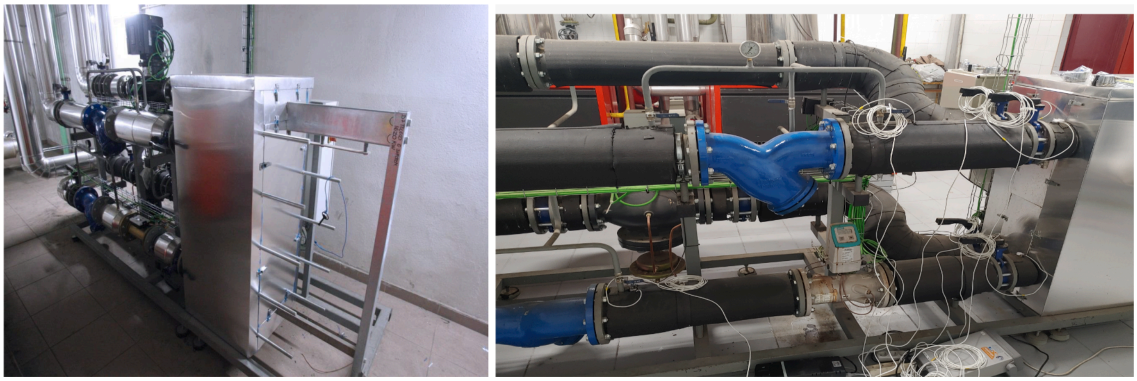

Fig. 3. Heat Exchanger by the DHS in a building of Campus UVa.

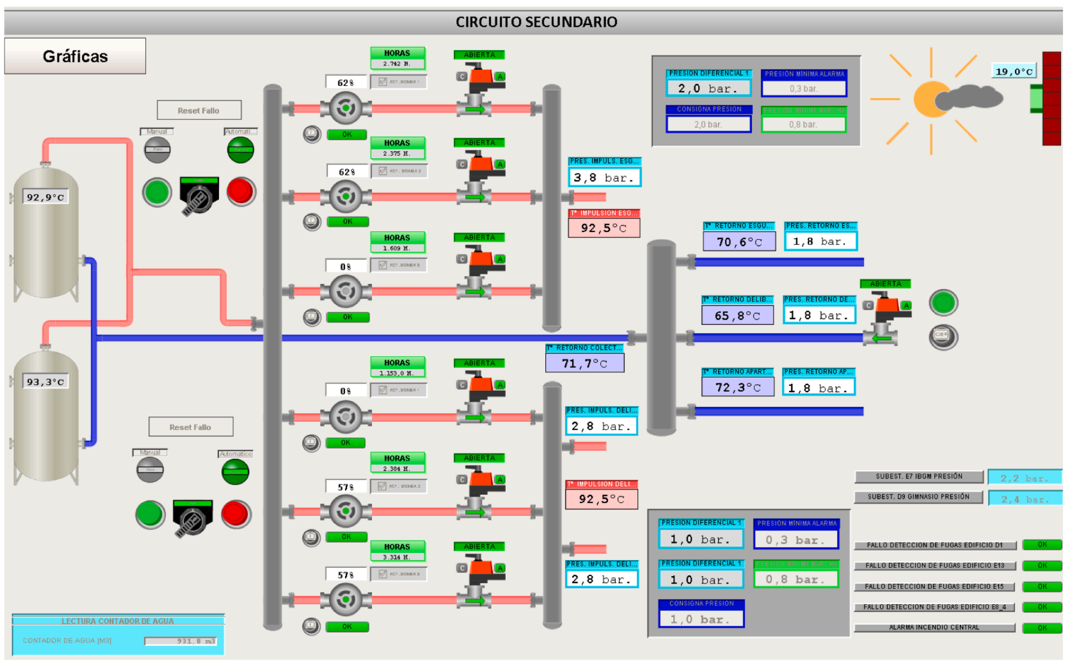

Fig. 4a. SCADA Screenshot. The secondary hydraulic circuit of the DH.

(Temperature, Energy, Power, Humidity, Pressure Loss, Intensity, Voltage, Flow rates, Stored energy, Consumption, Auxiliary equipment, Heat recovery, Network status valves, …), from the boilers, until the substations at the buildings. It is monitored by a correct and reliable communication network. The dynamic monitoring is connected to a BMS management system through a SCADA system, therefore, it is possible to monitor the energy consumption levels of each building.

In order to reduce operating costs, the minimum monitoring and control variables have been selected, applying indirect measurement methods. All sensors are regularly calibrated, achieving an error of less than 1%.

The metering equipment corresponding to each substation of a building is: 1 water flow meter, model 7ME6920-1AA30-1AA0 Siemens with an accuracy of 0.4%; and 4 water temperature sensors, model Pt 100 WIKA 14132823 with a measurement range between −50C to 200C and an accuracy ± 0.15 K.

Furthermore, a combined communications system is used, integrating those already installed. In order to connect the field elements (sensors and actuators) in a large system such as a DHS, it is necessary to use an optimal communications network. Its basic structure consists of the field elements, connected to the input and output modules, all of which are interconnected with the control system.

The interfacing of the system's communication network with the field elements, has been designed to be able to integrate several modes of communication, as follows: Direct communication to the control protocol; Conventional connected through analog/digital input modules; and Field equipment having integrated web servers. The monitoring system is designed to communicate with the most common home automation protocols such as: BACnet IP; Modbus TCP; EIB/KNX IP; and LONworks.

2.2. Data handling methodologies

The data from pertaining to the DHS including heat exchanger data records for each UVa building have been recorded throughout 2019 at 10-minute intervals, so as to have a full picture of its dynamic behaviour and performance.

As an example, Figs. 5 and 6 show the instantaneous water temperatures and thermal power flow in the heat exchanger of the D12 building for two consecutive days. All these data have been checked and verified before being processed to guarantee their reliability.

Fig. 5 shows the temperature monitoring of both circuits during week 47, showing the evolution of temperatures during the heat exchange process in the DHS substations.

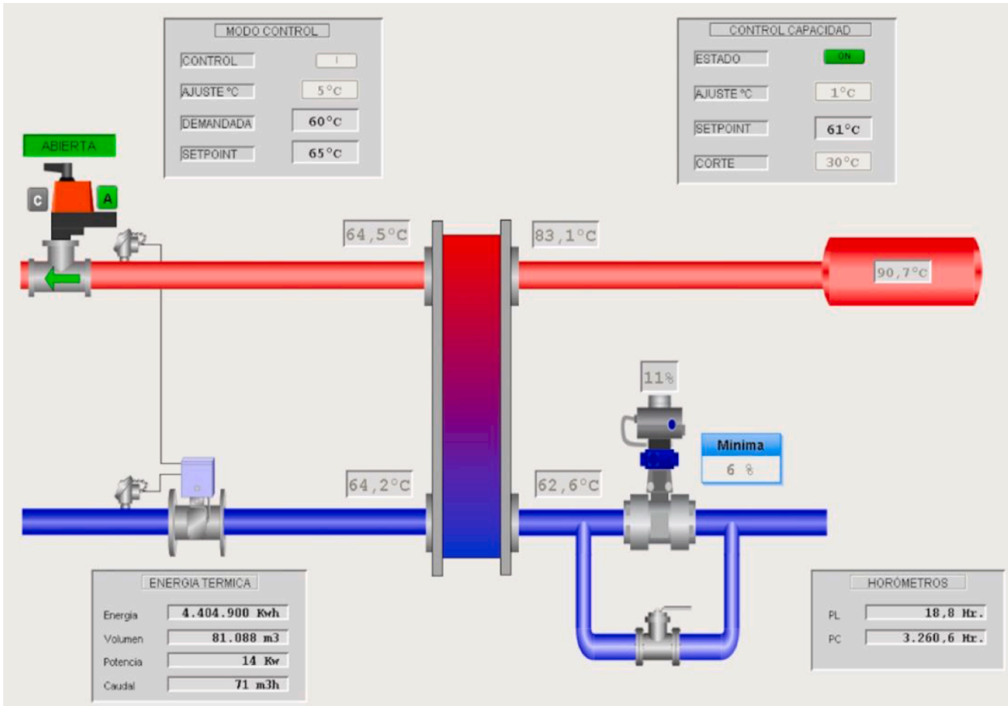

Fig. 4b. SCADA Screenshot. DH Heat Exchanger in each building.

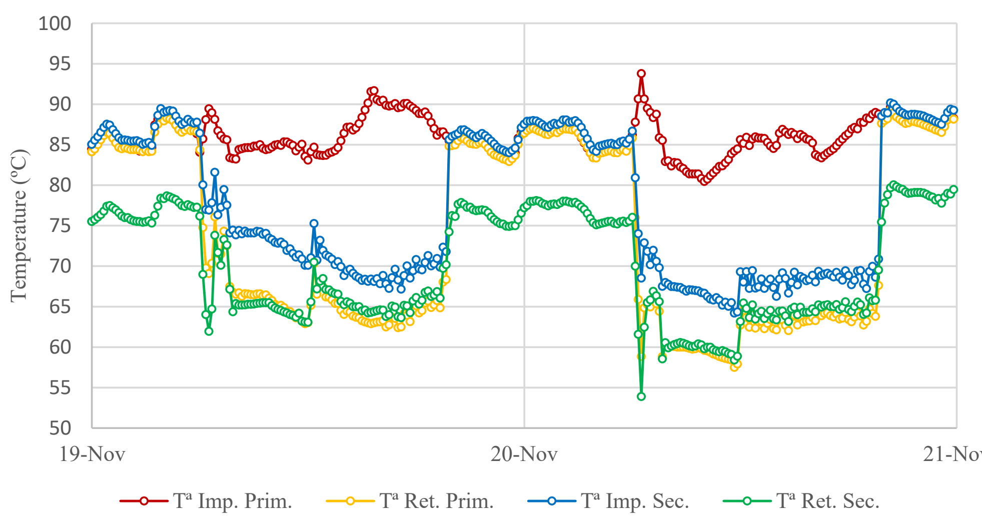

Fig. 5. Temperatures (°C) in the DH heating heat exchanger at D12 building, in 2019.

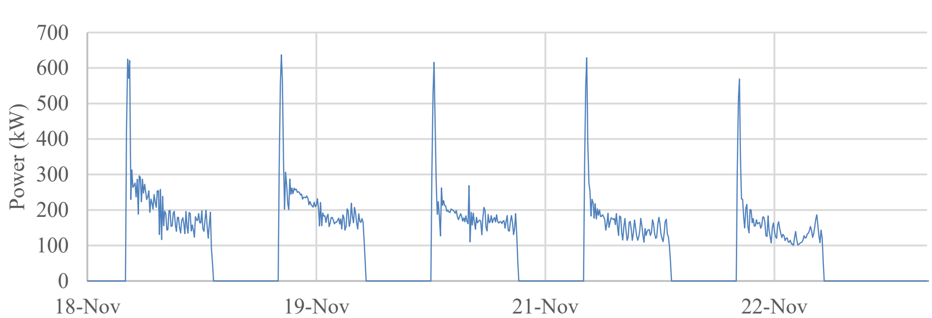

Fig. 6. Thermal power monitoring (kW) at D12 building, in the third week of November 2019.

Where, T^a Imp. Primary is the Supply temperature in the primary circuit

- T^a Ret. Prim. Is the return temperature in the primary circuit
- T^a Imp. Sec. is the supply temperature in the secondary circuit
- T^a Ret. Sec is the return temperature in the secondary circuit

Fig. 6 shows the power demand, which is highest at the beginning of the working day when the biomass DHS ramps up to heat all the buildings after the cold night period. This eventually drops and stabilizes for the rest of the day, with minor variations due to solar gains on sunny days. If the day is colder or cloudier in the afternoon such as on 22 November 2019, then the heating system supplements the extra demand until the end of the day.

The collected data serves to calculate the resulting energy savings by comparing the new energy consumption to that of the old heating systems based on natural gas and gasoil. It should be noted that the results obtained are very different between buildings due to their size and activity. In order to standardize them, the energy efficiency specific indicator (EI) in kWh/m^2 has been introduced, using the floor area per building., as the reference variable.

3. Results and analysis

The thermal energy need of each of the 19 buildings studied was calculated by energy simulation, in order to design the DHS [60]. Table 3 shows the values of thermal energy use, in kWh·y, for each building on both campuses at University of Valladolid. This data provides a detailed overview of the energy consumption patterns in the university's buildings.

Moreover, these values allow for a comprehensive evaluation and comparison of the energy efficiency of each building, enabling informed decision-making regarding resource management and optimization. Analysing this data can help identify consumption patterns, highlight areas that require improved energy efficiency, and facilitate the implementation of conservation and sustainability measures within the university buildings.

Furthermore, these annual records serve as benchmarks for monitoring and assessing progress in reducing thermal energy consumption over time. They provide valuable insights for understanding and managing the thermal energy usage within the University of Valladolid buildings, promoting sustainable practices and environmental responsibility.

Thermal consumption by the DHS in each building, electricity consumption of each building in the campus obtained by the SCADA, and the total amount of both as total final energy consumption are shown in Table 3. Analysing the total final energy consumption can help to identify energy-intensive buildings, evaluate the overall energy efficiency of the campus, and pinpoint areas for potential energy-saving measures. It allows to make optimized decisions and implement the most efficient strategies regarding energy management, resource allocation, and sustainability initiatives.

Fig. 7 show the monthly thermal consumption trend (kWh) of some buildings belonging to the campuses, supplied by the renewable DHS fueled by biomass, during 2019, acquired via Monitoring and Control by SCADA. This data acquisition method, allows for real-time monitoring and control of various parameters related to the DHS. It enables the University to track and analyse the thermal consumption of each building. The system generates a significant amount of data points, encompassing measurements, timestamps, and other relevant information.

By utilizing a renewable energy source such as biomass for the DHS, the University of Valladolid demonstrates a commitment to sustainable practices and reducing its carbon footprint. The monthly thermal consumption trend data provides valuable insights into the energy usage patterns of the buildings, helping to identify potential areas for improvement in energy efficiency and optimize the operation of the heating system.

Analysing the monthly trends can also assist in identifying seasonal variations in thermal energy consumption, which may be useful for planning and optimizing the system's capacity and resources. Additionally, the data acquired through SCADA enables the University to evaluate the performance of the renewable DHS and make informed decisions regarding its maintenance and future developments.

The Energy Index (EI), is an energy quality indicator used to classify buildings according to their energy efficiency, as adopted in the new Spanish regulations CTE DB-HE, December 2019. It is defined as the ratio between the amount of energy consumed by building (kWh) and its useful area (m^2); therefore, the EI value units are $\frac{kWh}{m^2}$.

Regarding the final thermal energy consumption, Fig. 8 shows the Energy Index (EI), which represents the final thermal energy consumed ($kWh \cdot m^2 \cdot y$), in each building using the renewable DHS Fig. 9 shows the Energy Index (EI) of the final electrical energy consumption by the pumps of the DHS, for each building per year. [36].

The total thermal primary energy indicator, renewable and non-renewable, is an energy quality indicator that is similar to the energy intensity indicator. It is defined as the ratio between the amount of energy consumed by a building (kWh) and the useful area of the building (m^2).

In this case, the final energy consumed by the building must be

Table 3
Thermal and electrical energy consumption ($kWh/m^2 \cdot y$) for each building by DHS.

Campus	Building	EI Energy Need	EI Thermal Consumption	EI Electricity	EI Total Consumption
Miguel Delibes University Campus (D)	D1 & D2	81	94.72	1.26	95.98
	D4	202.52	210.63	0.32	210.95
	D5	28.35	31.98	2.20	34.18
	D6	56.70	66.79	0.09	66.88
	D7	40.50	39.03	0.26	39.29
	D8	85.05	86.37	1.18	87.56
	D9	174.19	172.94	0.59	173.52
	D10	40.50	47.04	0.64	47.68
	D11	44.55	44.41	0.04	44.45
	D12	40.51	39.82	0.60	40.42
	E1	45.04	44.27	0.06	44.33
Esgueva University campus (E)	E2	39.50	46.55	0.32	46.87
	E3	51.03	52.34	0.25	52.59
	E5	63.2	62.98	0.92	63.90
	E7	56.71	65.12	1.27	66.39
	E8	64.80	76.12	0.57	76.69
	E13	85.05	97.39	1.12	98.51
	E14	47.40	52.75	0.35	53.10
	E15	72.90	68.83	0.78	69.61

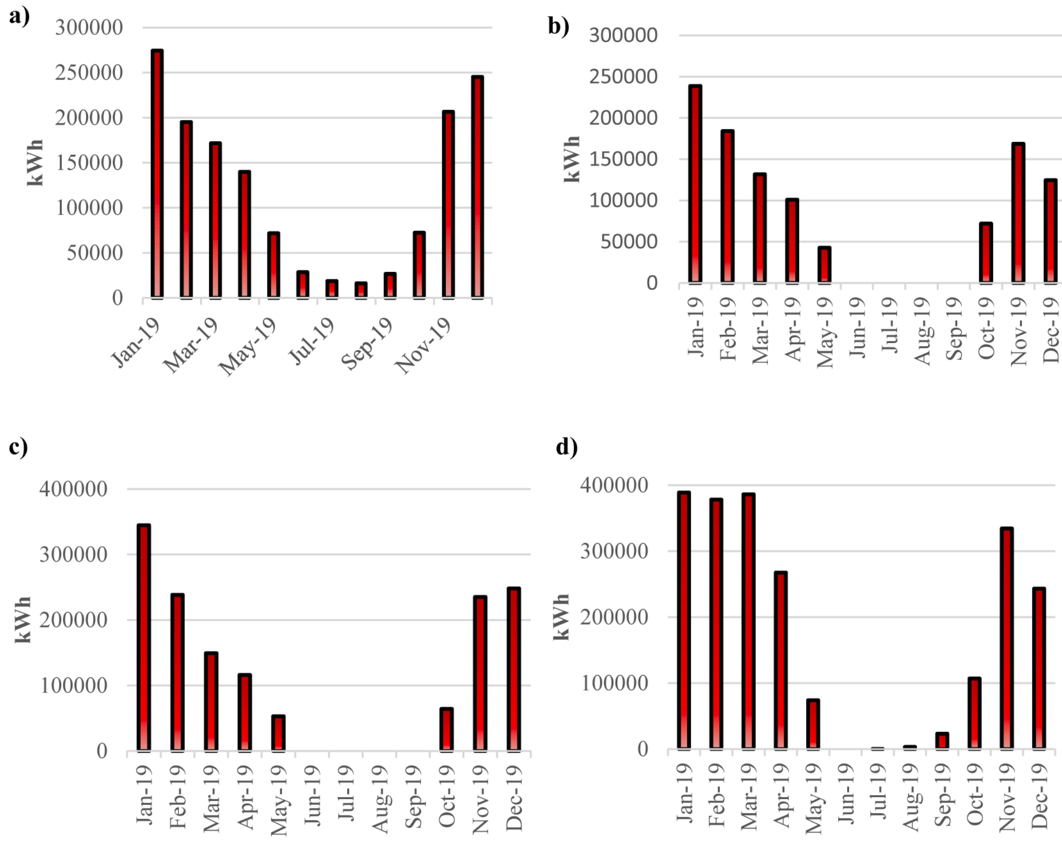

Fig. 7. Building Consumptions **a)** D1 & D2 Building. **b)** D7 Building. **c)** E08 Building. **d)** E13 Building.

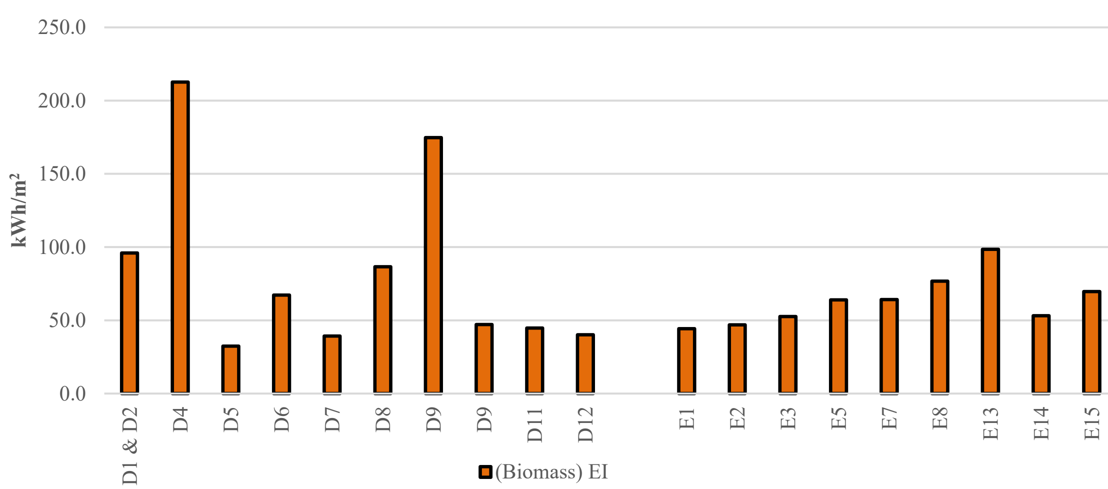

Fig. 8. Energy Index (EI) of biomass fueled DHS.

multiplied by a Primary Energy Factor (PEF), to obtain the primary energy, from the values published by the Spanish government [37]. This PEF accounts for energy losses due to the energy conversion, transportation, and distribution. Primary energy is defined in the Spanish CTE BD-HE0 Standard, as the energy supplied to a building from renewable and non-renewable sources, which has not undergone any conversion or transformation process. That is why, according to Spanish regulations, the value of the primary energy will always be higher than the final energy. Taking into account whether the previous consumption was powered by fossil fuels, and considering the current consumption of thermal energy powered by biomass, as well as the consumption of electrical energy by pumping system, can compare the total consumption of primary energy in each building, in the previous and current instances when the biomass DHS was installed.

The primary energy index is calculated on the basis of the following equations, where f_i and f_j are the thermal and electrical energy factors chosen from the table published by the Spanish government, according to the fuel and energy supplied in the country.

$$EI_p\ (NG\ /\ Gasoil) = Final\ Thermal\ EI * f_i \quad (1)$$

$$EI_p\ (DH) = Final\ Thermal\ EI * f_i + pumping\ electrical\ EI * f_j \quad (2)$$

Fig. 10 shows the total final and primary energy savings indicators, compared to both heating systems. As the primary energy consumed is

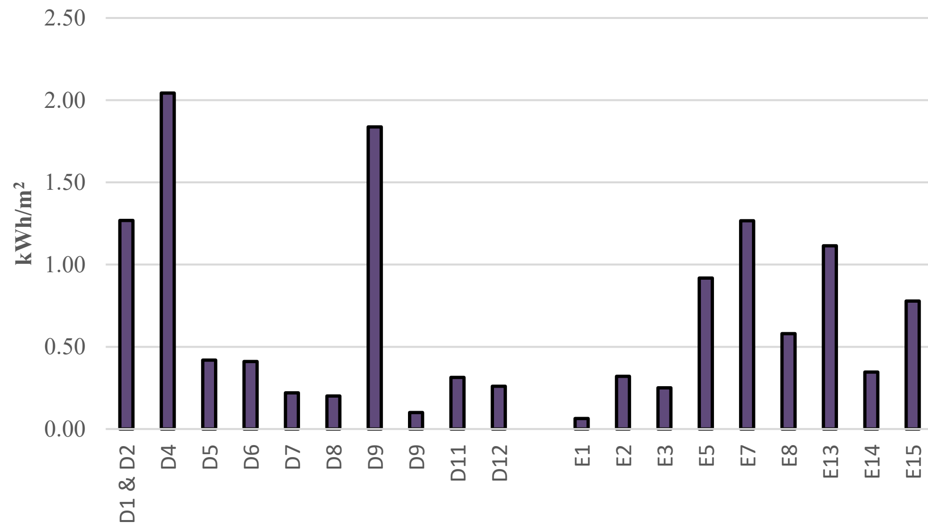

Fig. 9. Electrical Energy Index (EI) (kWh/m^2) for the DHS.

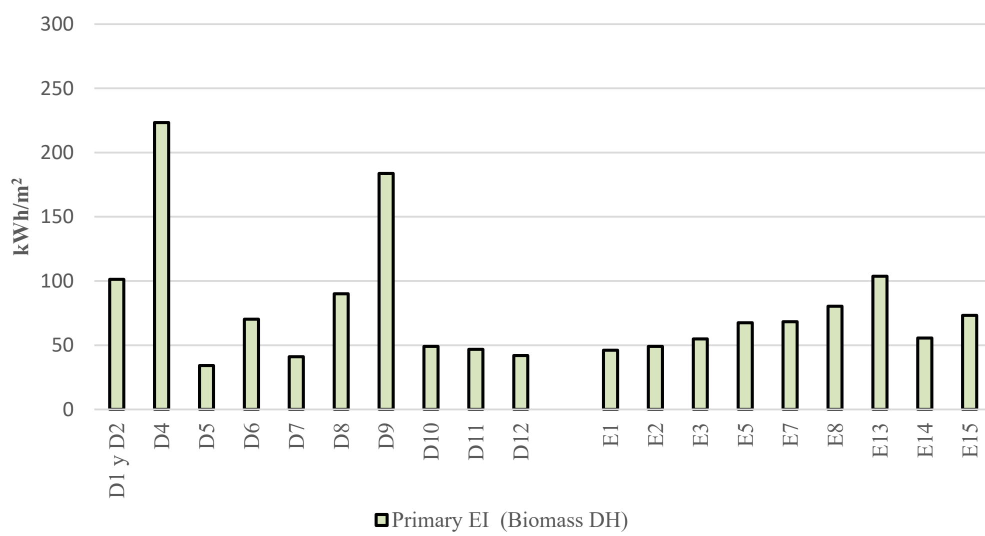

Fig. 10. Primary EI$_p$ DH for all buildings.

higher than the final energy, the amount of primary energy savings of all the buildings in the study, reaching per year 4756 MW, while the final energy savings with the change of heating system in the UVa campus is 2180 MW. Such a difference in values is due to the fact that the PEF of biomass (0.034) is smaller than that of Natural Gas (1.190) or Gasoil (1.179) [61].

It must be noted that currently a large part of the non-renewable consumption is due to the electrical consumption of the pumping system in the DHS. Studying the primary renewable energy, in each case shows that the ratio of renewable energy in the previous system is of a lower magnitude than with the current system. It is important to consider the proportion of renewable energy used in comparison to non-renewable sources. Comparing the ratio of renewable energy in the previous DHS system to the current system allows for an assessment of the progress made in transitioning to more sustainable energy sources. Table 4 shows the figures to analyse the data in more detail.

Following this evaluation, a primary energy consumption study is carried out for each building as a whole. For this purpose, both the energy consumption due to heating and other facilities, such as lighting, ventilation, etc, were analysed.

Each building's total primary energy consumption (thermal and electrical consumption), as well as EI total primary energy, non-renewable and renewable energy per building, have been calculated. Fig. 11 and Fig. 12 show the comparison of the total non-renewable and renewable energy indicators per building, considering the old heating system and the current DHS.

When comparing the output results to the Spanish Building Code for NZEB criteria, it was found that 17 out of 19 blocks can be classified as near zero-energy buildings, compared to only 2 buildings, when the heating system was running on NG/Gasoil fuels. A significant improvement has been achieved with the implementation of the current Renewable DHS. The overall renewable energy contribution of the 19 buildings together to the total energy consumption now stands at 50%, compared to only 10% when the previous heating system was in operation.

This substantial increase in the number of near zero-energy buildings demonstrates the positive impact of the new DHS on the energy performance of the University's buildings. It indicates a significant reduction in non-renewable energy consumption and a substantial increase in the utilization of renewable energy sources.

Furthermore, the overall renewable energy contribution of the 19 buildings combined to the total energy consumption has increased significantly.

These findings highlight the success and the effectiveness of the

Table 4
Comparison of renewable, EI_{p_r}, (kWh/m^2) and non-renewable primary energy EI_{p_nr}, (kWh/m^2) with old and current heating systems, DH.

Campus	Building	EI_{p_r} primary renewable (kWh/m^2)	EI_{p_nr} primary non renewable (kWh/m^2)
Miguel Delibes	D1 & D2	95.51	5.77
University Campus	D4	212.05	11.26
(D)	D5	32.24	1.93
	D6	67.15	3.10
	D7	39.23	1.77
	D8	86.71	3.34
	D9	174.15	9.57
	D10	47.22	1.80
	D11	44.66	2.14
	D12	40.04	1.88
	E1	44.43	1.63
Esgueva University	E2	46.82	2.23
campus (E)	E3	52.60	2.28
	E5	63.53	3.98
	E7	63.64	4.68
	E8	76.57	3.75
	E13	98.12	5.55
	E14	53.05	2.49
	E15	69.35	3.90

transition from the old heating system to the current DHS in terms of energy efficiency and sustainability. The increased utilization of renewable energy sources and the achievement of nZEB status align with the goals of reducing carbon emissions and promoting sustainable practices.

KPI's values (Fig. 11 and Fig. 12), provide the information if the building is performing as a nZEB, according to Spanish CTE. Fig. 13 shows the percentage of impact regarding nZEB, which the DHS has caused in the retrofitting of the university campus.

It is observed that the renewable DHS in the retrofitting of the university campus, achieves a retrofit of almost 80% of the buildings.

With a retrofitting percentage of nearly 80% of the buildings, the renewable DHS has played a crucial role in transforming the energy efficiency of the campus. This suggests that the implementation of the DHS has enabled a large portion of the buildings to meet or even exceed the energy performance requirements set by the Spanish CTE regulations for nZEBs.

By utilizing renewable energy sources in the heating system, the DHS reduces reliance on non-renewable fuels and decreases carbon emissions associated with traditional heating methods. This significant retrofitting impact demonstrates the positive environmental contribution of the renewable DHS, as well as its ability to align the university campus with the sustainability goals.

The substantial retrofitting percentage shows a strong strategy to apply in order to fulfill the European and Spanish Standards for reducing non-renewable energy consumption and environmental impact of building sector.

Finally, Fig. 14 shows the percentages of buildings, consuming EI renewable primary energy, by DH.

Therefore, using the new biomass retrofitted heating system, the percentage of renovation to nZEB in the entire UVa Campus amounted to 78.95% of the buildings analysed, thus achieving a much more sustainable and renewable UVa university campus. Overall, analysing the buildings of the university campus, and according to the criteria of the renewable Primary Energy Index, it is observed that with the old heating system, only 8.66% of the energy consumed was renewable, while currently this percentage increases to almost 50%.

The proposed retrofitting strategy for university campus differs from previously mentioned by Eisapour et al. [62] based on usage of wind turbine, solar PV, and CFP generator or Jin et al. using PV panels, heat pumps and hydrogen-related energy technologies [63,64].

The methodology applied in this study has successfully integrated the monitoring of a DHS with the evaluation of key sustainability Key Performance Indicators (KPIs) established by the framework of the European Union's EPBD and LEVEL's. Our approach focuses on energy efficiency and assessing the impact on decarbonization in high-energy-consuming buildings, in line with the Union's 2030–2050 decarbonization goals through the energy transition in buildings and compliance with nZEB standards set by the EU.

Through our innovative methodology, we have achieved effective integration of DHS monitoring with sustainability KPIs, which is crucial for evaluating energy performance and carbon emissions reduction in high-energy-consuming buildings. This methodology has been successfully applied in our study and has proven to be a valuable tool in the process of rehabilitating renewable heating systems.

4. Conclusions

The University of Valladolid has carried out deep energy renovation

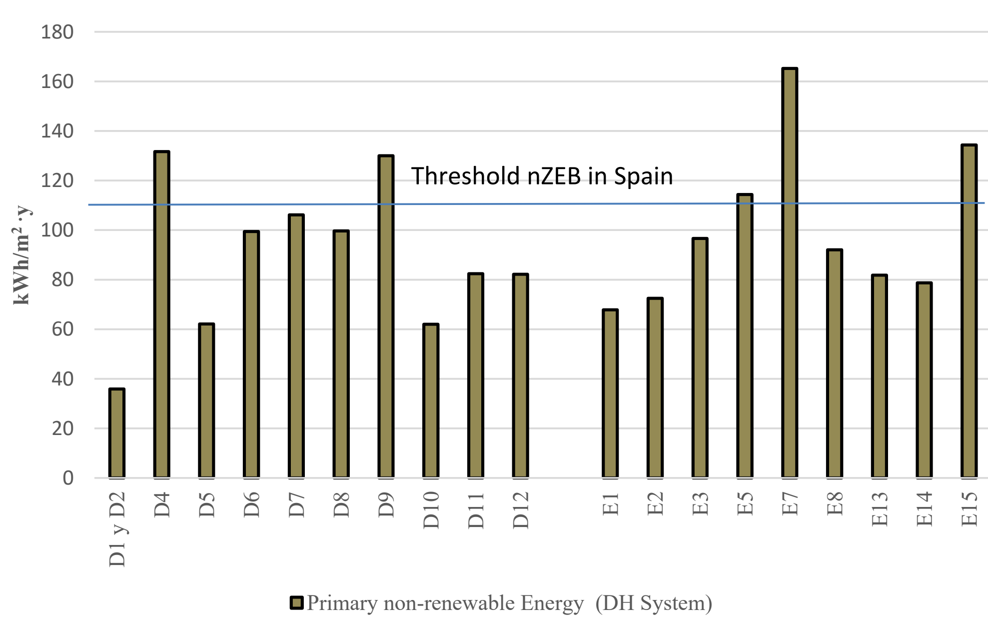

Fig. 11. EI_{p_nr}, biomass DHS (kWh/m^2·y).

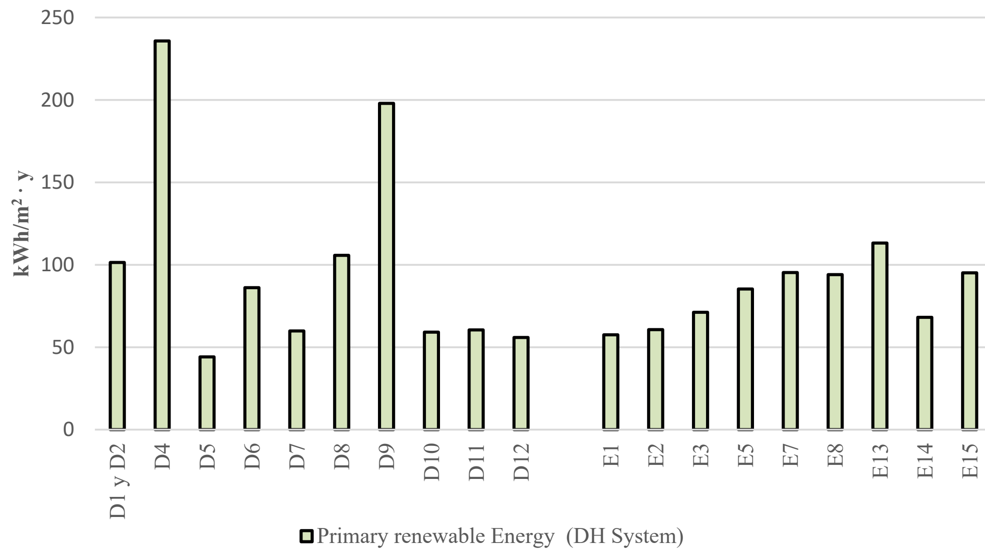

Fig. 12. EI_{pr} DHS (kWh/m^2·y).

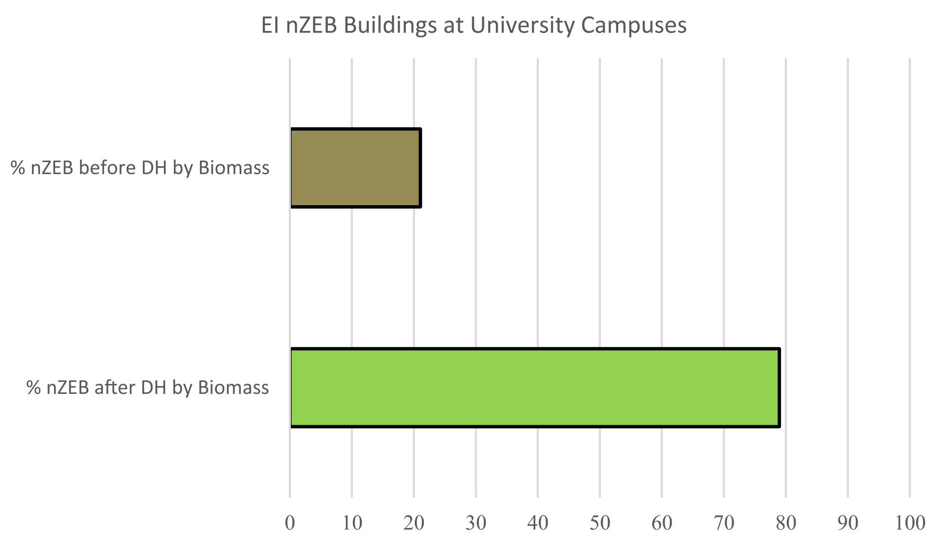

Fig. 13. Percentage (%) of NZEB buildings on campus running by DHS.

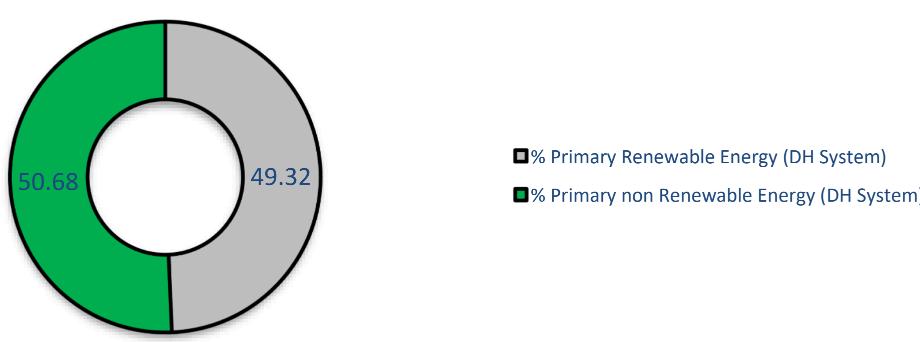

Fig. 14. Percentage (%) of Renewable Energy (kWh) using the biomass DHS.

of the heating system in 19 buildings on two different university campuses, through a biomass DHS, in order to achieve a near-Zero Energy Campus concept, and to increase the percentage penetration of renewable energies. As a result of the integration of the new biomass DHS, 84.6% of the buildings have passed the nZEB category threshold, according to the Spanish and European legislations, EI_{p_nr} and EI_{pr}. This renovation has transformed the campus categorically, thus exceeding the objectives set in the Spanish National Integrated Plan for Economy and Climate (PNIEC) for 2030, which requires a minimum renewable energy penetration level of 42%.

The results obtained from this study through the energy retrofit methodology was a final energy consumption of 15,025 MWh·y, of which 14,889 MWh·y was thermal energy consumption, and 136 MWh·y was electricity consumption due to the pumping system. A renewable primary energy consumption was 14,987 MWh·y, which represents 95.06% of the final primary energy consumption. The DHS achieved almost zero consumption of non-renewable primary energy, reaching 779 MWh·y, which represents the remaining 0.05% of total primary energy.

In terms of energy consumption savings compared to the old heating systems, the DHS has achieved a 12.67% decrease in final energy consumption, and a 23.17% decrease in total primary energy consumption. This represents a saving of 2,180 MWh·y of final energy, and 4,756MWh·y of primary energy. Reducing non-renewable primary energy consumption by 96.19%, which corresponds to a saving of 19,663 MWh·y. As for renewable primary energy, its use has increased by 94.7%, which corresponds to an increase in consumption of 14,907 MWh·y.

The current carbon emissions for both campuses stand at only 317 tonnes CO_2·y, which is 92.69% lower than when the older heating system was in use. As discussed above, the change of the heating system has achieved great improvements in all fields related to savings and energy efficiency improvement.

This advanced climate-resilient energy retrofit technology, has succeeded in reducing the use of non-renewable energy in all buildings Furthermore, it has achieved a growth in the generation of renewable thermal energy trends. Thus, it is demonstrated that biomass-fuelled DHS, is an optimal technology to achieve deep energy renovation strategies, supported by new sustainability targets in the European Universities and Cities. The proposed strategy can be applied on other university campuses located in a continental climate such as Valladolid (Spain) in a way to decarbonization.

CRediT authorship contribution statement

Javier M. Rey-Hernández: Methodology, Validation, Formal analysis, Investigation, Data curation, Writing – original draft, Writing – review & editing, Visualization. **Francisco J. Rey-Martínez:** Conceptualization, Methodology, Validation, Formal analysis, Resources, Writing – original draft, Writing – review & editing, Supervision, Project administration, Funding acquisition. **Charles Yousif:** Conceptualization, Validation, Investigation, Writing – review & editing, Visualization, Supervision, Project administration. **Dorota Krawczyk:** Investigation, Writing – review & editing, Visualization.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Data availability

The data that has been used is confidential.

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