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Energy Analyses and Optimization Proposals for Hotels in Sicily: A Case Study

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Abstract: The recent post-pandemic period has economically affected many business sectors. One of these is the hotel industry. As a result of this economic crisis, it is necessary to act on the economic costs of running energy-intensive buildings such as a hotel. The thermal and electrical energy consumption of an accommodation facility weighs heavily on the economic balance. Governments around the globe have moved to help those activities in need. To improve the sustainability of the hospitality sector from an environmental and economic point of view, the introduction of energy retrofit solutions is mandatory. Following European sustainability laws, the impact and efficiency of the building were calculated using smart readiness indicators. The purpose of this paper is to present a case study of a 5-star hotel located in southern Italy characterized by high energy consumption. Precisely these consumptions are due to air conditioning, lighting, hot water, catering, and all other utilities. The entire building and the systems serving it were characterized by means of software that studies consumption with dynamic models, Trnsys. The same software made it possible to model the case study by replacing the existing air conditioning system with one supplied by renewable energies. Two energy retrofit hypotheses were chosen to obtain the best economic and environmental results. First, the choice was to install solar cooling powered by flat solar panels, and the second choice was solar cooling powered by evacuated tube collectors. This paper reports the technical and economic characteristics of both proposed solutions, quantifying the energy and economic savings to identify the best solution.

Keywords: energy retrofit solutions; energy saving; solar energy; heritage building

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1. Introduction

Nowadays, the importance of an energy-saving approach is relevant in all economic sectors such as industrial, civil, and commercial. The geo-political conditions are pushing more than ever for a reduction in energy consumption for many reasons: rising energy prices, restrictions on air pollution, and restrictions on building performances. This case study focuses on the energy consumption of hotels, analyzing a building located in the north-west of Sicily Island. In general, the energy consumption related to the building sector reached 40% of the total energy consumption in the world [1]. The hotel trade sector has a huge impact on the world economy. The travel and tourism sector moved USD 9.2 trillion in 2019. After the COVID-19 pandemic, the sector lost USD 4.5 trillion [2]. After such a dark period for all hotel operators and suppliers, many countries have allocated funds to help all affected sectors, including the hotel sector [3,4]. In particular, in Italy, a national recovery and resilience plan has been drawn up to help businesses [5,6] in relation to the needs envisaged by the European Green Deal and regional energy plans [7,8] At the same time, it was necessary to reduce operating costs in order to try to recover some of the lost assets. The ability to reduce the consumption of fossil fuels and take advantage of renewable energy determines a positive impact on building efficiency. This analyzes everything article by means of software that defines the boundary of energy flows to which a hotel is subjected.

The tourism sector is fundamental to the Italian economy, its contribution amounts to about 132 billion US dollars in 2020 [9]. To ensure high-level accommodation facilities, considering the economic and environmental sustainability, it is necessary to invest in technologies able to reduce costs related to energy consumption, while simultaneously increasing the quality of the services. In hotels today, energy consumption significantly affects the economic balance. A hotel generally guarantees the following services: guest rooms, reception, communal areas, conference rooms, restaurants, swimming pools, and service areas [10].

Each of these services corresponds to a specific energy consumption which can be divided into the following macro-categories:

- Heating
- Cooling
- Production of domestic hot water
- Electrical energy for lighting, refrigeration, household appliances, and electric equipment in the common areas.

These macro-categories of consumption depend a lot on the characteristics of each single structure: geographical area, size and age of the building, type of envelope, exposure, number of rooms, number of days per year open to customers, catering service, type of conditioning system and domestic hot water production [11].

As seen so far, high consumption not only entails an additional cost for businesses but also represents a significant portion of the production of CO_2, which is released into the atmosphere and generates well-known consequences. The 2030 climate and energy framework, approved by the European Council on 23 and 24 October 2014 [12,13], sets three main objectives:

- A reduction of at least 40% in greenhouse gas emissions compared to the levels recorded in 1990.
- A share of at least 27% of renewable energy.
- An improvement in energy efficiency of at least 27%.

To consider the building impact using the European "smart readiness indicator", the U-CERT digital tool was used. The results confirm that the rating is low because the SRI is 28/100, the rating is F, the energy efficiency is 33%, the energy flexibility and storage is 37%, comfort is 43%, convenience is 30%, and health, wellbeing, and accessibility are 50% [14]. In the literature, several authors are working on this topic focusing on economic and techno-economic evaluations, smart management, load prediction, and energy-saving measures. In the following lines to mark the importance of this topic, some papers are cited. Haojie Luo et al. examine the use of a wave energy converter and an offshore wind turbine to power a zero-energy coastal building.

The simulations are carried out by TRNSYS 18. They obtained that the optimal choice of an energy mix (including Renewable Energy Sources) is a very important solution to power a building [15]. Yu Wang et al. analyzed the energy consumption in 15 hotels in Jiangsu Province, China. The results suggested that the (HVAC) system, the monitoring system, the lighting system, the domestic hot water system, and the building envelope are the energy upgrades that generate the most relevant energy savings, with no more than 10 years of payback time [16].

Adila Eli et al. studied how to optimize the energy consumption of Shanghai hotels. They implemented many machine learning algorithms to predict energy consumption. The results show that an artificial neural network is the best model to predict hotel consumption [17]. Minglei Shao et al. performed support vector machines to predict the energy consumption of a hotel. They have characterized the loads and carried out a great optimization problem with the machine learning approach [18]. Petr Scholz et al. proposed a study of a hotel in the Czech Republic, listing what interventions have been carried out in terms of energy saving and social and environmental aspects. They proposed good waste management, saving electricity consumption by using LED lamps, and saving water by implementing intelligent shower systems that recover water [19]. Yutong Wu et al. focused on the energy consumption of hotels after the COVID-19 pandemic. They list several energy-saving strategies in a hotel located in the south of China. They proposed how to improve the quality of external walls and windows, control the lighting system with automatic dimming devices, and use RES to supply the hotel. All these optimizations can reduce the energy consumption by 16–29% [20]. D. Wang et al. proposed several old systems replacements to improve the efficiency of the electrical and air conditioning systems of a hotel in China. By replacing the lighting system, the air conditioning system, and the building automation system, high levels of energy savings were achieved. The LED system is the one with the highest electrical savings [21].

This paper analyses the thermal and electrical loads of a hotel located in Trapani, Sicily, to implement some energy retrofit solutions, focusing the solar cooling technology with the aim of reducing energy consumption. Results obtained from simulations have shown that harnessing solar energy to meet a building's energy needs is very cost-effective in terms of energy and economic savings. This case study aims to demonstrate that saving energy in nonresidential buildings is possible, especially by using a solar source that is capable of air conditioning in summer. The proposed solutions can be easily replied to in a similar structure, increasing the economic and environmental sustainability of this sector.

2. Case Study

The property under study is a five-star hotel located in the province of Trapani. The resort consists of a central body represented by the original building and two more recent buildings that were built in 2004. The climate is mild with peaks of 40 °C in summer and rainy winters ranging between 0 and 17 °C. The area is characterized by a vast territory on which two large geographically opposite seacoasts are located. The adopted method involves an energy audit required to perform dynamic simulations of two proposed retrofit solutions. The first involves the use of flat-plate solar collectors to power an absorption machine and the second the use of vacuum collectors. Both scenarios were modeled with Trnsys in order to characterize energy consumption. Ultimately, the return on investment was estimated.

2.1. Methodology

The purpose of proposing a paper on the energy requalification of an accommodation facility is to give guidelines that can help reduce consumption and running costs, improving the sustainability of this sector. The proposed retrofit method is described as a guideline that is compatible with UNI CEI EN 16247-1 [22]. First, the operating conditions were analyzed, i.e., the number of hours and days in which the facility is open to the public during the year. Subsequently, electrical, thermal, and hot water loads were characterized. Once the case study was characterized, the model was created on “Trnsys” software. This is software used for dynamic systems. Simulations were carried out in both the actual state and the design state in order to quantify the energy savings. After the proposals and quantification of energy savings, an economic study analyzing the costs incurred and the payback time of the investment was conducted [23].

The considered period starts from October 2017 to September 2018 based on pre-pandemic COVID-19 data. On average, the business is active for the entire week, from Monday to Sunday, during the summer period from April to September. As for the winter period, the hotel structure remains closed to the public, while the restaurant with banquet activities continues to operate. Tables 1 and 2 summarise the operative hours per day and the operative days per month of this activity. The first analysis conducted was the energy audit.

Table 1. Number of daily hours of activity.

Daily Hours of Activity												
	Oct-17	Nov-17	Dec-17	Jan-18	Feb-18	Mar-18	Apr-18	May-18	Jun-18	Jul-18	Aug-18	Sep-18
Kitchen	10	5	4	3	3	9	6	8	12	18	18	14
Cold storage	24	4	9	10	10	10	6	8	15	15	15	14
Outdoor lighting	12	8	12	12	12	11	9	9	8	8	8	8
Air conditioning	10	6.5	8.5	4	5	4.5	4	8	8	8	8	8
Offices	8	8	8	8	8	8	8	8	8	8	8	8

Table 2. Number of days per month of activity.

Daily Hours of Activity												
	Oct-17	Nov-17	Dec-17	Jan-18	Feb-18	Mar-18	Apr-18	May-18	Jun-18	Jul-18	Aug-18	Sep-18
Kitchen	9	9	14	9	8	9	30	31	30	31	31	30
Cold storage	30	31	30	31	28	31	30	31	30	31	31	30
Outdoor lighting	30	31	30	31	28	31	30	31	30	31	31	30
Air conditioning	30	31	30	31	28	31	30	31	30	31	31	30
Offices	30	31	30	31	28	31	30	31	30	31	31	30

All of the devices in the facility were surveyed in order to check which ones consume the most gas and electricity.

During the energy audit, all electrical devices serving the hotel were classified and surveyed. The activities related to electrical consumption are as follows: indoor and outdoor lighting, equipment in the kitchen (dishwashers, hoods, extractors, ovens, and cold rooms), computers in the offices, and the fan coils and chiller for the air conditioning. The latter is an AERMEC RV1202 HDE chiller with 292 kW heat output and 120 kW electrical power input [19]. Fan coil characteristics are shown in Table 3.

The luminaries in the areas of the structure are mainly of the halogen type. The total installed power is approximately 20 kW.

Table 3. Fan coils' technical characteristics

Fan Coils Technical Characteristics			
Model	Flow Rate [L/s]	Thermal Power [kW]	Fan Power [W]
FC–90	0.33	8.5	80
FC–70	0.22	5.0	40
FC–60	0.18	4.2	30
FC–40	0.12	3.0	20

The monthly consumption calculation is calculated by using Equation (1), considering the electrical energy absorbed by the equipment of all the activities listed above, the number of days of activity per month, and the number of hours in which the given equipment is in operation in the given month:

$$\text{Monthly consumption} = \mathrm{P_{abs}} \cdot \eta \cdot \mathrm{n} \cdot \mathrm{f_c} \cdot \mathrm{N_{day}} \tag{1}$$

In detail, $\mathrm{P_{abs}}$ is the electrical absorption power, η is the efficiency, n is the ratio between the power actually absorbed under actual operating conditions and the power absorbed under nominal operating conditions, $\mathrm{f_c}$ is the ratio of the actual power absorbed to the maximum power, and $\mathrm{N_{day}}$ is the product of the number of operating days for the month under review and the number of operating hours per day for the given month. $\mathrm{N_{day}}$ is calculated in Equation (2).

$$\mathrm{N_{day}} = \mathrm{N_{d/m}} \cdot \mathrm{N_{h/d}} \tag{2}$$

where $\mathrm{N_{d/m}}$ is the number of days of activity for the month under review, $\mathrm{N_{h/d}}$ is the number of operating hours per day per given month. In Table 4, the electrical consumption considered for the hotel is shown.

Table 4. Average monthly electrical energy consumption.

Average Monthly Electrical Energy Consumption												
	Oct-17	Nov-17	Dec-17	Jan-18	Feb-18	Mar-18	Apr-18	May-18	Jun-18	Jul-18	Aug-18	Sep-18
MWhe	50.7	23.1	32.9	20.9	20.7	28.4	36.7	55.6	73.1	98.9	99	80.3

The domestic hot water production system consists of two gas boilers with the following characteristics:

- AR–BT floor-standing boiler with a rated output of 300 kWt
- SIME Murelle HE–EV wall-mounted boiler with a rated output of 55 kWt.

The domestic hot water demand has been calculated with the following Equation (3).

$$\text{Domestic hot water demand} = \mathrm{V_{water}} \cdot \mathrm{c_p} \cdot \Delta\mathrm{T} \cdot \mathrm{N_{day}} \cdot \mathrm{f_c} \tag{3}$$

where V_{water} is the monthly volume of water required, c_p is the specific heat of water, ΔT is considered to be 20 °C, N_{day} is the number of working days, and f_c is the conversion factor to Joule from kWh.

In Table 5, the domestic hot water demand is shown, which is split into kitchen demand and restroom demand. The gas consumptions are shown in Table 6.

Table 5. Domestic hot water demand.

Domestic Hot Water Demand [kWht]												
	Oct-17	Nov-17	Dec-17	Jan-18	Feb-18	Mar-18	Apr-18	May-18	Jun-18	Jul-18	Aug-18	Sep-18
Kitchen	113	113	176	113	100	113	188	176	176	176	188	188
Restrooms	132	293	293	132	117	102	220	205	205	205	220	220

Table 6. Gas consumptions.

Gas Consumptions												
	Oct-17	Nov-17	Dec-17	Jan-18	Feb-18	Mar-18	Apr-18	May-18	Jun-18	Jul-18	Aug-18	Sep-18
Scm/month	887	576	783	398	409	434	866	1071	997	986	1027	1040
MWh/month	21.2	13.8	18.7	9.5	9.8	10.4	20.7	25.6	23.8	23.6	24.5	24.9

2.1.1. Software Simulation

The study carried out consists of an initial simulation of the operation of the existing plant and its subsequent replacement in order to minimize electricity and natural gas consumption and with them also carbon dioxide emissions, a fundamental element in the new national energy scenario [24]. Trnsys software is used for the simulation of transient systems, including multi-zone systems. The software used is one of the best tools capable of simulating solar-powered renewable systems using UNI 10349-1:2016 [25]. The dynamic study was chosen to ensure hourly verification, over the course of a year, of the powers consumed in the two proposed scenarios. In this way, it is possible to evaluate the real operation of the thermal plant.

A project is generally set up by linking components graphically in the Simulation Studio section. Each type of component is described by a mathematical model and is characterized by inputs, outputs, and parameters. The model that is mainly used in the case of multi-zone buildings is known as Type 56. In addition to the Simulation Studio, there is another section that allows the details of the building structure to be specified, as well as everything necessary to simulate the building's thermal behavior, such as the properties of window elements, heating and cooling schedules, and the presence or absence of internal loads (such as people, computers, etc.). In practice, TRNBuild contains all the information needed to simulate the building, while the Simulation Studio allows a more specific simulation of the interaction between the building and the various system components. Prior to the use of TRNBuild, however, the structure was created using a 3D design software known as Sketchup, with the Trnsys3D extension that allows the creation of the thermal zones characterizing the structure [26].

2.1.2. TRNBuild

During the discussion of this chapter, the different building components of the envelope will be examined in detail. All characteristics relating to internal loads are considered using UNI EN ISO 7730 [27].

The building is partly built in a reinforced concrete framed structure with reinforced concrete pillars and partly in load-bearing masonry. In the following lines, the main building components are listed:

- The external walls are 30 cm thick tuff ashlars bonded with cement mortar.
- The floors are made of brick-cement with a 4 cm thick upper slab.
- The external roofs are partly flat, again in brick-cement with a bituminous waterproofing sheathing, and partly pitched with a Sicilian tile roof.
- The internal plastering is of the civil type, with a lower layer of mortar rendering.
- The exterior plastering is of the “Li Vigni” type, with a lower layer of mortar rendering and decorative plaster applied on top.
- The external windows are made of wood with double glazing and shutters.
- The interior ground floors are in stone.

The electrical loads considered in the previous paragraph are now loaded into the software considering the operation hours shown in Table 1. A schedule for each type of load is implemented considering the hours associated with it. Two other sections in TRNBuild are those relating to infiltration and ventilation. Considering infiltration, a value of 0.1 air change per hour was chosen. For the calculation of ventilation air, reference is made to UNI 10339 [28]. It is applied to aeraulic systems intended for the well-being of people that are installed in closed buildings.

A final step that must be performed in TRNBuild is the choice of outputs to be inserted. In the present case, it was decided to have the output for each of the following zones:

- Indoor temperature
- External temperature
- Relative humidity
- External humidity
- Incoming solar radiation from window surfaces

With these last steps, the structure determination phase ends, and the software simulation moves on to the next phase by working on the Simulation Studio.

2.1.3. Simulation Studio

Having completed the descriptive phase of the case study, the model of the case study was performed, focusing the analysis on the air-conditioning system. The centralized plant was uploaded in the Simulation Studio of Trnsys. The plant is composed of components called “Type”. These allow input and output data to be loaded from the model. First, the Type 15 climate file is inserted to simulate the model in the reference climate zone. All types that are used during the discussion are listed below:

- Type 56 represents the building.
- Type 941 models a single-stage air–water heat pump.
- Type 698 is a differential ON/OFF device that models a five-stage room thermostat that outputs five control signals that can be used to control the heat pump. It monitors the temperatures of the different five identified thermal zones in the building and compares them with the set point temperatures and thus outputs the on or off switching of the air conditioning and/or heating system.

- Type 114 is a component that models a constant speed pump that is able to maintain a constant fluid mass flow rate.
- Type 600 is a component that models a two-pipe fan coil unit that provides heating and cooling.
- Type 647 is a component that models a diverter valve that divides an incoming mass flow into several outgoing flows, with the fractions specified by the user.
- Type 649 is a component that models a mixing valve.
- Type 65a is a component that is used to display selected system variables as the simulation proceeds and offers the possibility of exporting data.

Two separate scenarios were analyzed for winter and summer operations in order to draw out the trends of the five outputs listed in the previous paragraph. The time step chosen for the simulation is 1 h, and the system is simulated for the entire duration of the year, which is a total of 8760 h. The thermostat has a control dead band of 2 °C in order to prevent the system from oscillating excessively. Figure 1 shows the scheme of the system modeled in Trnsys in the start condition.

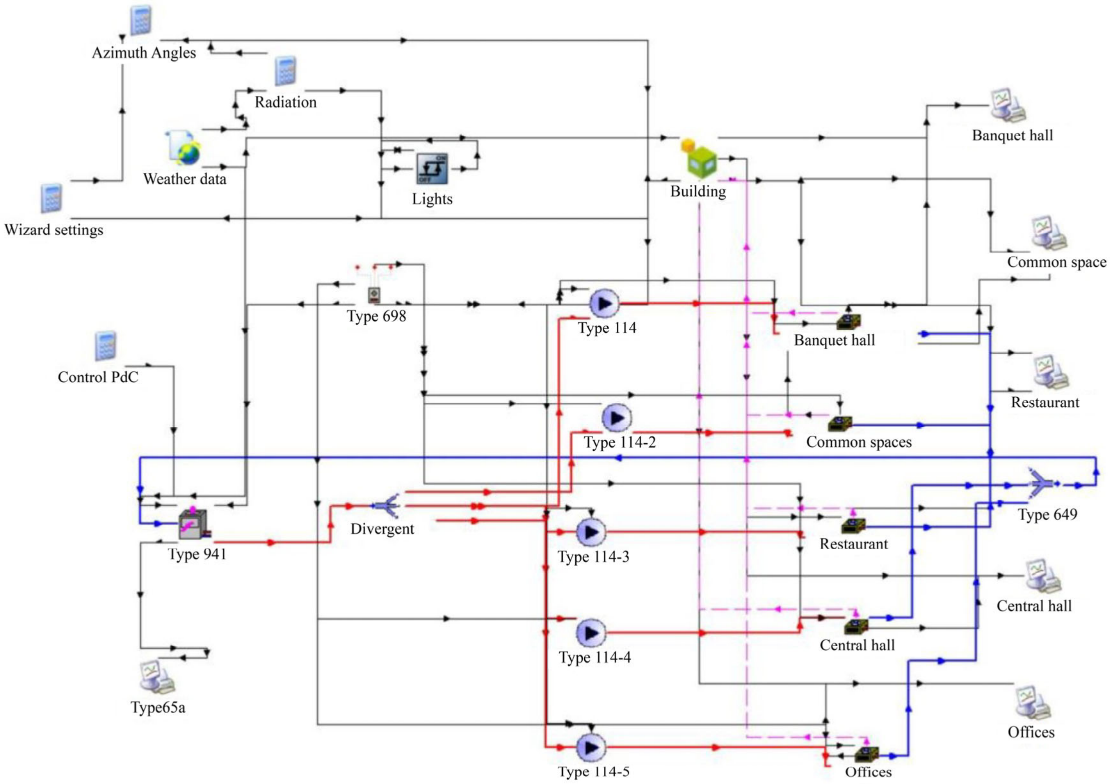

Figure 1. Trnsys start condition flow chart.

The modeling of the case study in its current state provided a snapshot of the starting conditions. This showed that the air-conditioning system is correctly dimensioned and energy retrofits can be carried out. By energy retrofit, we mean the set of actions implemented on the building in terms of structure and installations aimed at improving energy efficiency. The actions that are generally carried out during energy retrofitting are aimed at improving the comfort of indoor environments, containing energy consumption, reducing polluting emissions and the relative impact on the environment, and using resources rationally by resorting to the use of renewable energy sources in place of traditional technologies that use fossil fuels.

In this case, it was decided to act exclusively on the plant engineering part, replacing the heat pump with a solar cooling and heating system using a water and lithium bromide absorption machine fed by the following:

- Solution 1, a field of flat solar collectors
- Solution 2, a field of evacuated tube solar collectors

Solar cooling and heating systems utilize solar energy to meet both the heating and cooling needs of buildings, thus lowering the costs related to the consumption of either electricity or fossil fuels and contributing positively to the reduction of CO_2 emissions into the atmosphere, a topic central to environmental protection worldwide. The operation of this solar cooling system is briefly described and depicted in Figure 2. Solar thermal panels therefore absorb solar radiation and transfer it in the form of heat to the water fluid. This, in turn, feeds an absorption machine that produces cold water that is sent to the system to cool the rooms. Within the system, there is also a cooling tower or, alternatively, a dry cooler, which can dissipate the excess heat produced by the solar panels [28].

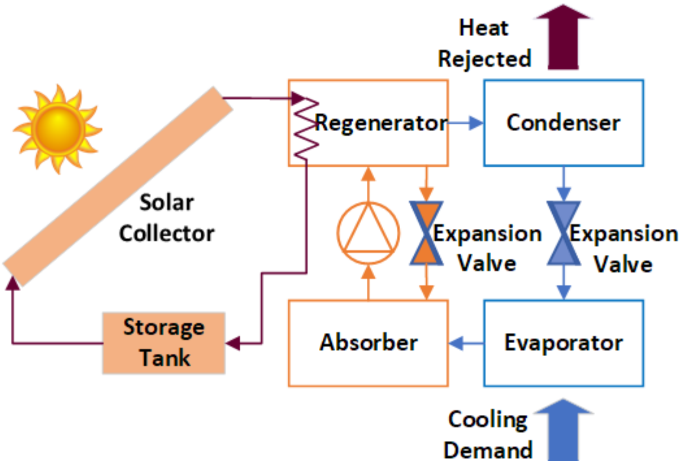

Figure 2. Solar cooling system.

The absorption machine used in the project is lithium bromide, which has water as the solute and lithium bromide as the solvent, so in this case, the refrigerant gas is water vapor. The feed water is brought to a boil by heating the aqueous solution of water and lithium bromide in the generator. This releases water vapor and leaves a concentrated lithium bromide solution. The solution is then fed into the absorber. The water vapor then reaches the condenser, where it condenses through the cooling circuit. The condensation heat is removed from the cooling water and expelled to an evaporative tower. The refrigerant then flows through a lamination valve to the evaporator, where it boils and absorbs heat by evaporating on the surface of the coil of the water circuit to be cooled. It then flows to the absorber in which the refrigerant vapour is absorbed by the concentrated lithium bromide solution. The condensation heat is removed from the cooling water. The dilute lithium bromide solution thus returns to the absorber.

The following Tables 7–9 show the technical characteristics of flat solar collectors, evacuated tube solar collectors, and solar absorption chillers.

Table 7. Technical characteristics of the solar collector.

Solar Collector Technical Characteristics	
Gross absorption area [m^2]	2.43
Net absorption area [m^2]	2.23
Weight [kg]	44
Absorption capacity %	95

Liquid content [L]	1.27
Peak power [W]	1751
First-order heat loss [W/m^{2}K]	3.72
Second-order heat loss [W/m^{2}K^2]	0.012
IAM Incidence Angle Modifier (50 °C)	0.95
F′ (τα)	0.795

Table 8. Technical characteristics of the evacuated tube solar collectors.

Evacuated Tube Solar Collector Technical Characteristics	
Gross absorption area [m^2]	3.26
Net absorption area [m^2]	2.83
Weight [kg]	63
Absorption capacity %	95
Liquid content [L]	2.33
Peak power [W]	2034
First-order heat loss [W/m^{2}K]	1.063
Second-order heat loss [W/m^{2}K^2]	0.005
IAM Incidence Angle Modifier (50 °C)	1.09
F′ (τα)	0.716

Table 9. Technical characteristics of the solar absorption chiller.

Solar Absorption Chiller Technical Characteristics	
Cooling power [kW]	210
Refrigerated water	
Outlet water temperature [°C]	12
Inlet water temperature [°C]	7
Flow rate [m^3/h]	85.5
Fluid supply to generator	
Outlet water temperature [°C]	95
Inlet water temperature [°C]	85
Flow rate [m^3/h]	25.6
Thermal input power	287

Five types are added for the simulation of the future state:

- Type 1289, to model flat-plate solar collectors.
- Type 538, to model evacuated tube solar collectors.
- Type 114, this component models a constant speed pump that is able to maintain a constant fluid mass flow rate.
- Type 4e, to model the storage tank.
- Type 659, to model an auxiliary heater.
- Type 909, this component models an absorption chiller based on user-supplied performance data files containing capacity and COP ratios.

2.2. Results and Discussion

2.2.1. Solution 1

For an installation power of 100 kW, given the characteristics of the collectors, the number of panels is 90. The flowchart of this plant is shown in Figure 3.

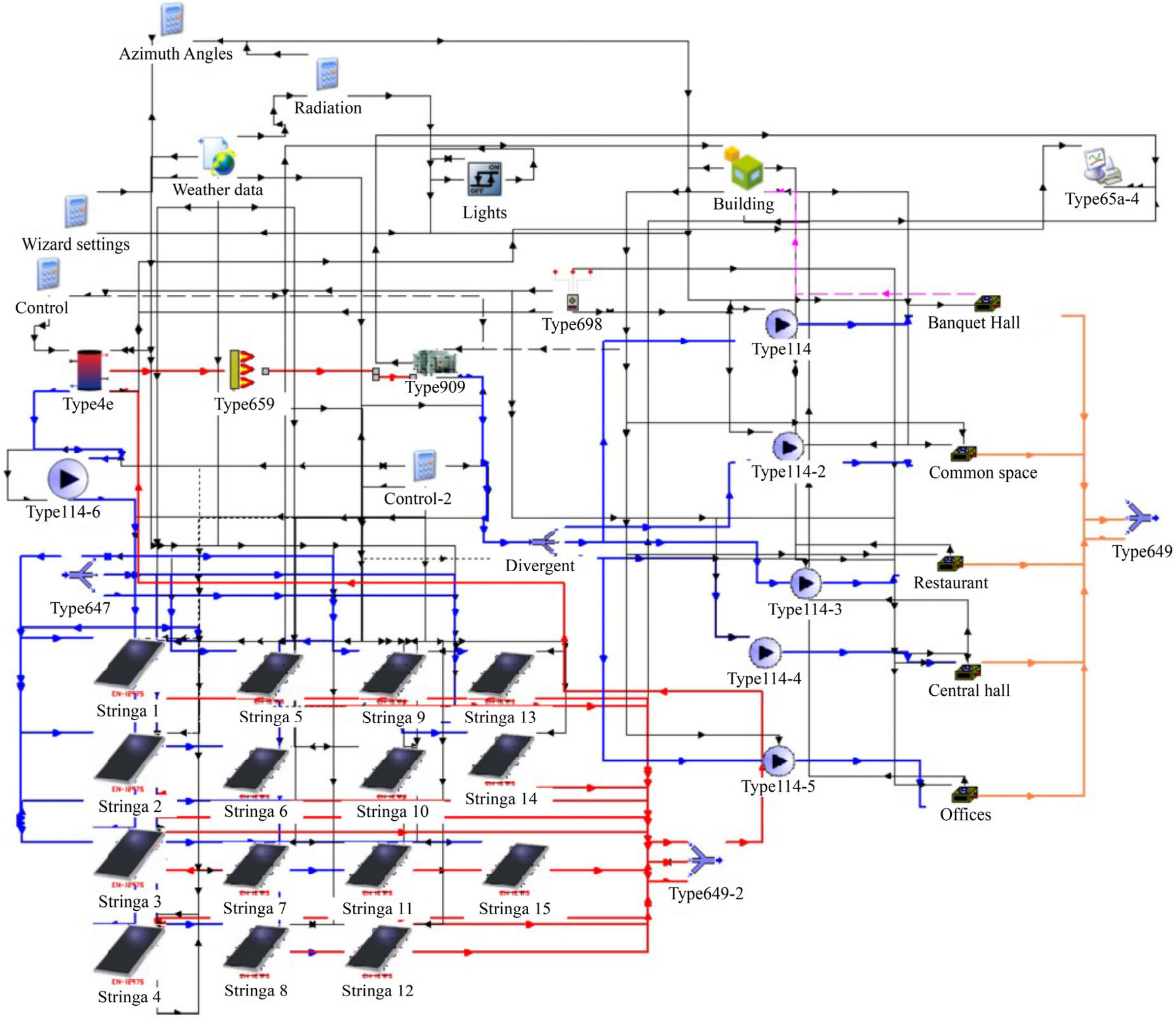

Figure 3. Solution 1 flowchart.

The results obtained in winter and summer simulations show that consumption is significantly reduced and that the proposed system requires only a limited amount of back-up energy. All winter needs are covered by the solar collectors alone. The auxiliary thermal power required to bring the fluid to the desired conditions is 35 kW, and the consumption for auxiliary heating amounts to 31,060.51 kWh/year. In summer, the temperature at the output of the solar collectors decreases during the hours of the night and increases in the presence of solar radiation. For these reasons, the required thermal power rate increases to 35 kW during the night, while it settles at around 2 kW during daylight hours. The thermal energy required for auxiliary heating in this case amounts to 55,937.91 kWh/year.

The simulations performed with the software report the dynamic consumption of the thermal zones described above. Figure 4 shows the annual consumption of the Banquet Hall. Figure 5 shows the annual consumption of the Central Hall. Figure 6 shows the annual consumption of the Common Space. Figure 7 shows the annual consumption of the Restaurant. Finally, Figure 8 shows the annual consumption of the Offices.

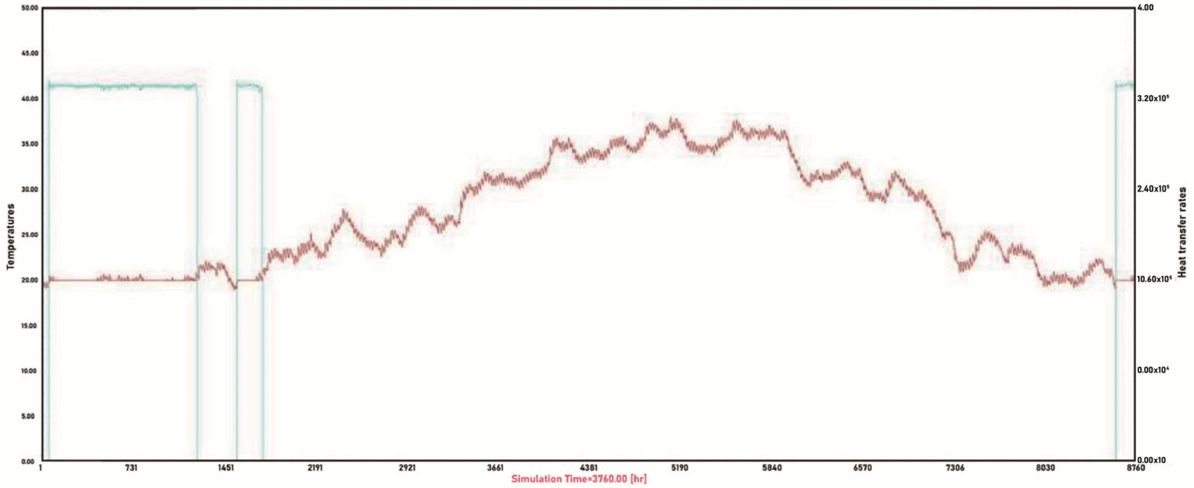

Figure 4. Winter operation "Banquet Hall" alternative 1.

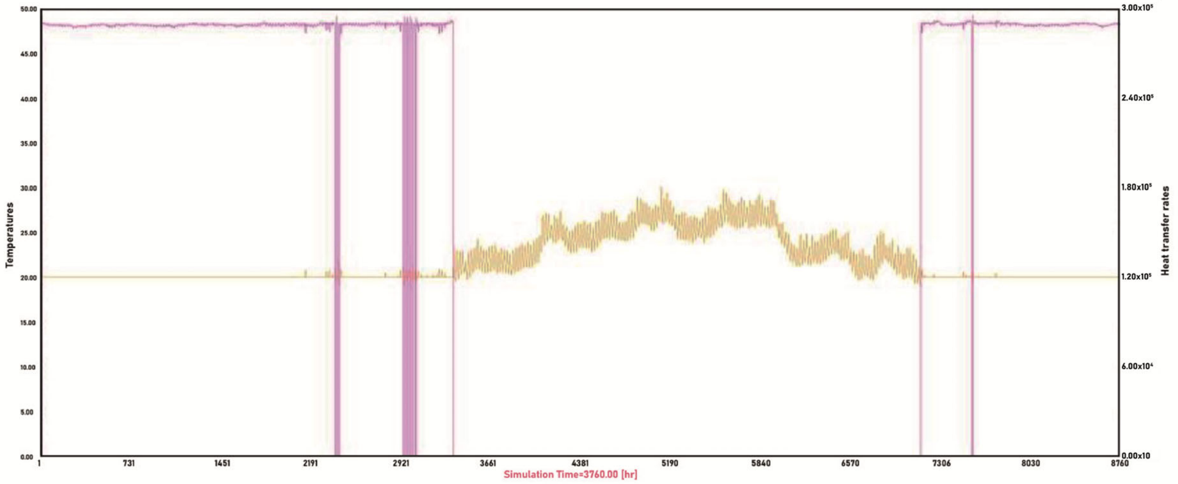

Figure 5. Winter operation "Central Hall" alternative 1.

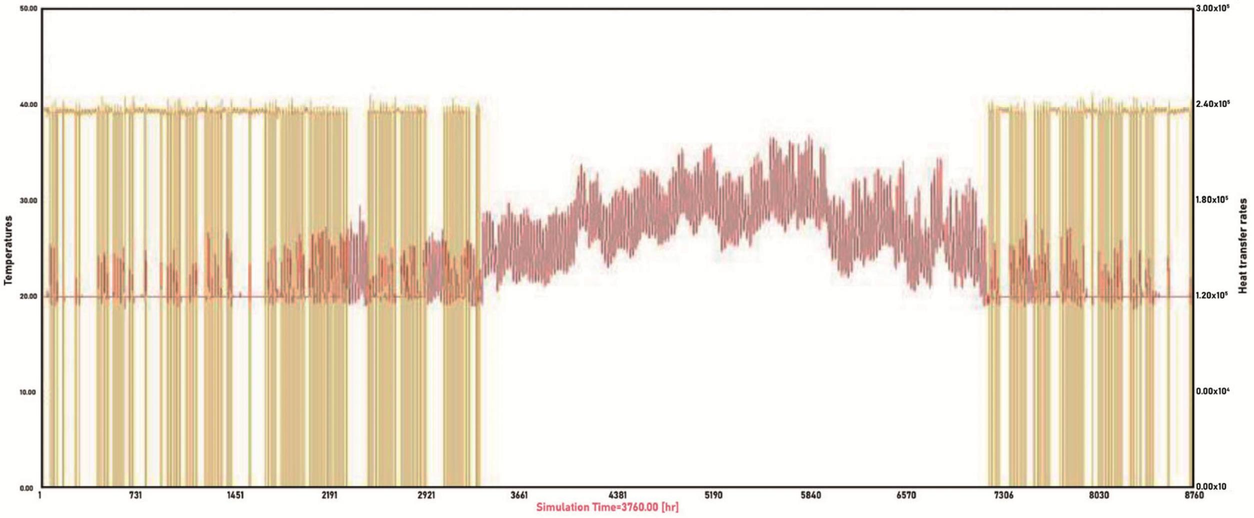

Figure 6. Winter operation "Common space" alternative 1.

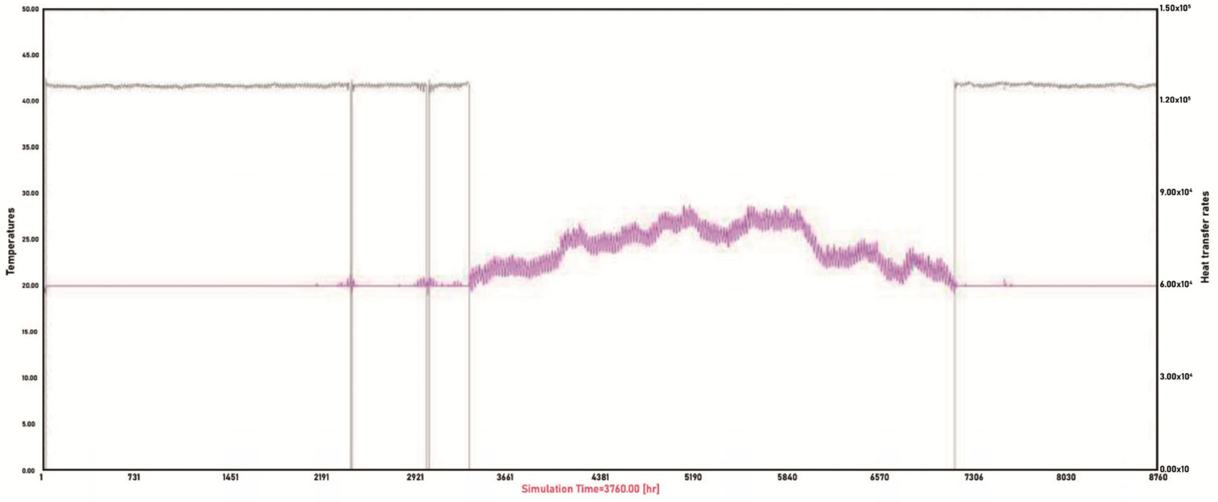

Figure 7. Winter operation "Restaurant" alternative 1.

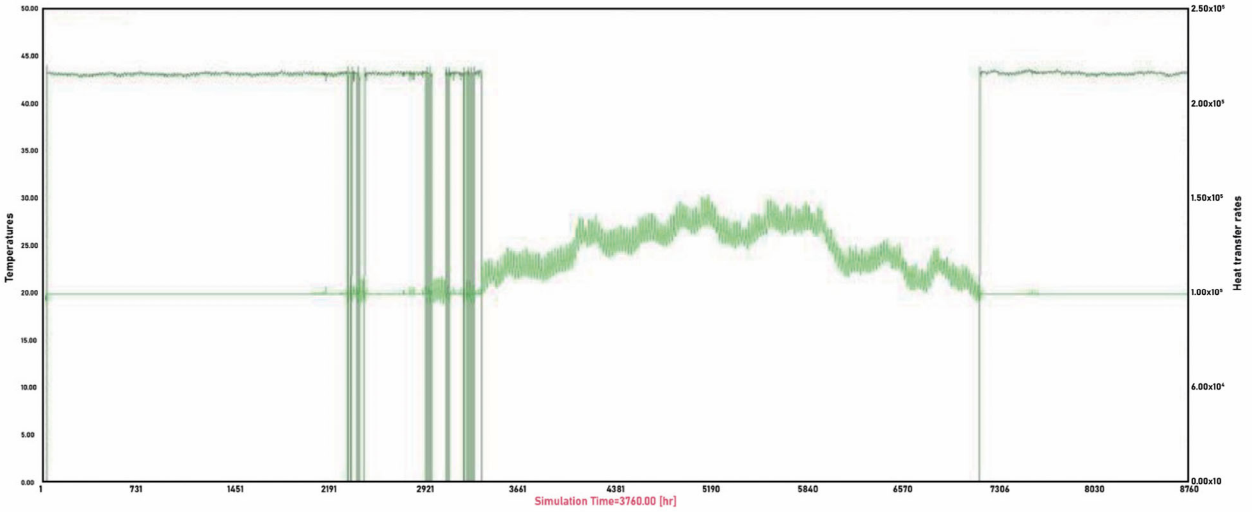

Figure 8. Winter operation "Offices" alternative 1.

Having demonstrated that a reduction in fossil fuel consumption has been achieved, an economic estimate is now presented.

Electricity and natural gas costs have a huge weight within the overall expenditure for the hotel. The first distinction that can be made is as follows:

- Basic consumption costs, where basic consumption includes all consumption related to the different electrical equipment and which will not vary with the type of air conditioning and heating system used.
- Equipment costs, which include all consumption related to the entire heating and cooling system and will obviously vary for each scenario analyzed.

The consumption of electricity and natural gas has already been analyzed in the previous paragraphs. The average cost of gas per standard cubic meter is 2.92 EUR/Sm^3.

The electricity cost considered is 0.178 EUR/kWh and can be divided into three different time bands, which correspond to the following:

- Time band F1 (peak hours), from 8 a.m. to 7 p.m. Monday to Friday, excluding national holidays.

- Time band F2 (off-peak hours), from 7 a.m. to 8 a.m. and from 7 p.m. to 11 p.m. Monday to Friday and from 7 a.m. to 11 p.m. on Saturdays, excluding national holidays.
- Time band F3 (off-peak hours), from 0:00 a.m. to 7:00 a.m. and from 11:00 p.m. to midnight Monday to Saturday, Sundays, and public holidays all hours of the day.

The zero-operating scenario, in fact, turns out to be the one on which comparisons will be made to verify the actual savings achieved by replacing the heat pump with a solar cooling system. The investment cost will, therefore, also in this case be the sum of the individual installations and is equal to 200,000 EUR. In this operating scenario, savings are mainly related to the lack of electricity consumption by the heat pump, obviously considering that which is absorbed by the absorption machine. The consumption of gas is not advantageous since the flat solar collectors reach low temperatures compared to those that must be obtained to send water as input to the absorption machine. For this reason, there is an increase in LPG consumption compared to the zero-operation scenario. The total annual saving is 95,584 EUR, and maintenance costs were assumed to be 1000 EUR/year.

Figure 9 shows the cash flow and the payback time related to the proposed retrofit Solution 1.

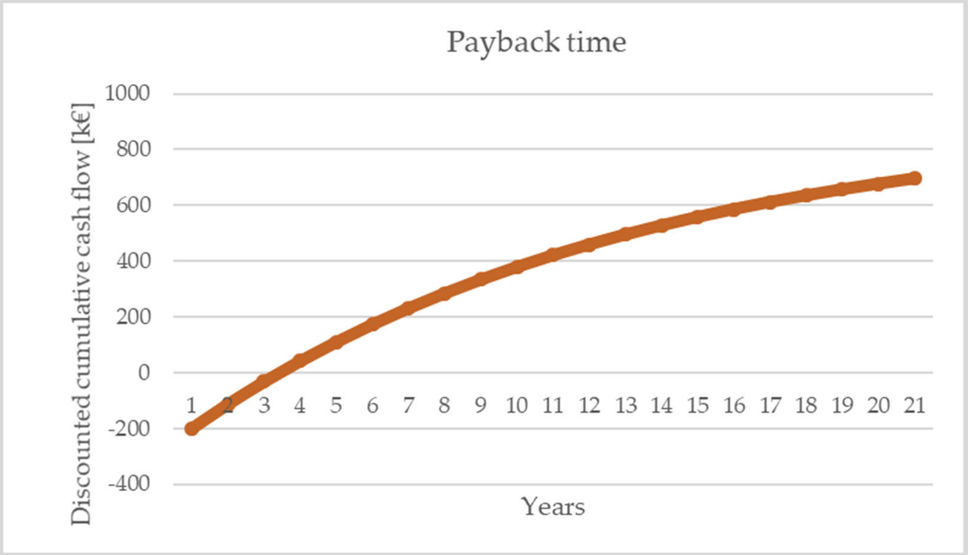

Figure 9. Cash flow related to the proposed retrofit Solution 1.

2.2.2. Solution 2

Evacuated tube collectors were chosen because heat loss to the outside environment was minimized in them. This is due to the vacuum created between the glass and the absorber. The temperatures reached by the heat-transfer fluid can also reach peaks of 110–120 °C, which is compatible with the operation of the absorption machine. Evacuated tube solar collectors have a lower optical efficiency than flat-plate solar collectors but, due to better thermal insulation, have a higher average annual overall efficiency than flat-plate solar collectors. The total number of panels to be installed is 70 in order to reach a power output of 100 kW. However, this system is coupled in series with a traditional gas-fired boiler capable of bringing the fluid to the desired set point temperature, thus the solar system could be unable to meet this condition.

During winter operation, the auxiliary heating is never recalled, as the outlet temperature of the solar collectors is compatible with the required inlet temperature of the fan coils. The total energy consumption for auxiliary heating in the winter period is therefore zero.

Auxiliary heating is used during the entire summer period since the temperature required to power the absorption machine is not reached during the night. The output from the simulation shows that auxiliary heating is used, with peak powers exceeding 35 kW. The total energy consumption for auxiliary heating is equal to 31,212.46 kWh/year.

The simulation performed with the software report shows the dynamic consumption of the thermal zones described above. Figure 10 shows the annual consumption of the Banquet Hall. Figure 11 shows the annual consumption of the Central Hall. Figure 12 shows the annual consumption of the Common Space. Figure 13 shows the annual consumption of the Restaurant. Finally, Figure 14 shows the annual consumption of the Offices.

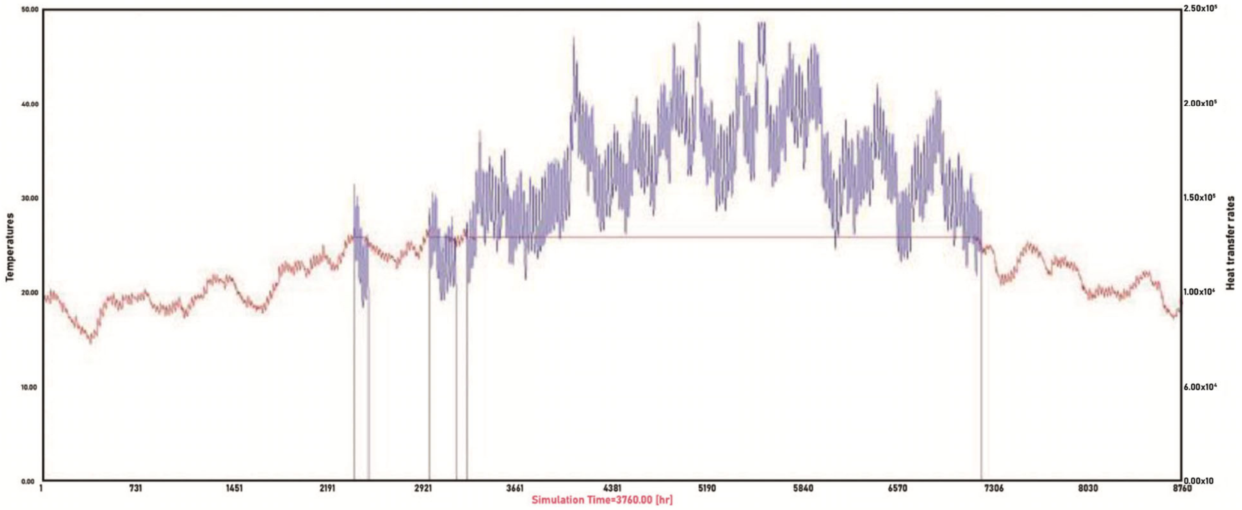

Figure 10. Winter operation "Banquet Hall" alternative 2.

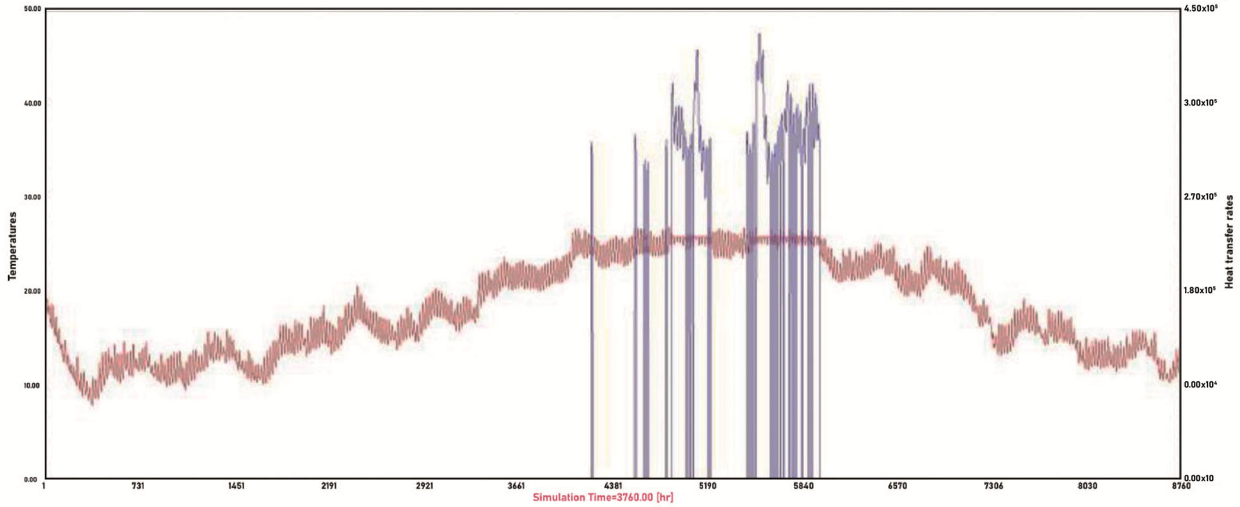

Figure 11. Winter operation "Central Hall" alternative 2.

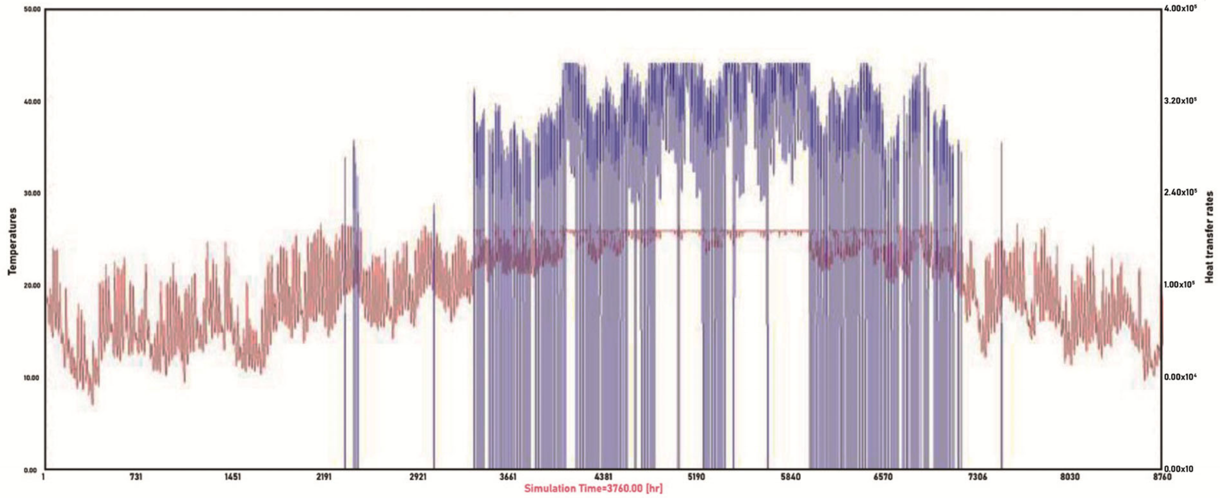

Figure 12. Winter operation "Common space" alternative 2.

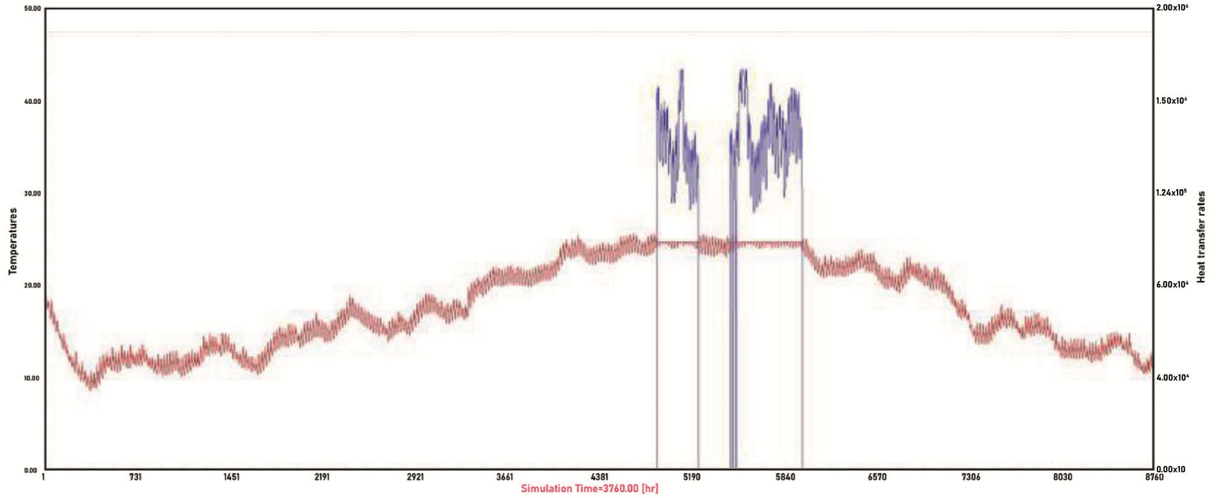

Figure 13. Winter operation "Restaurant" alternative 2.

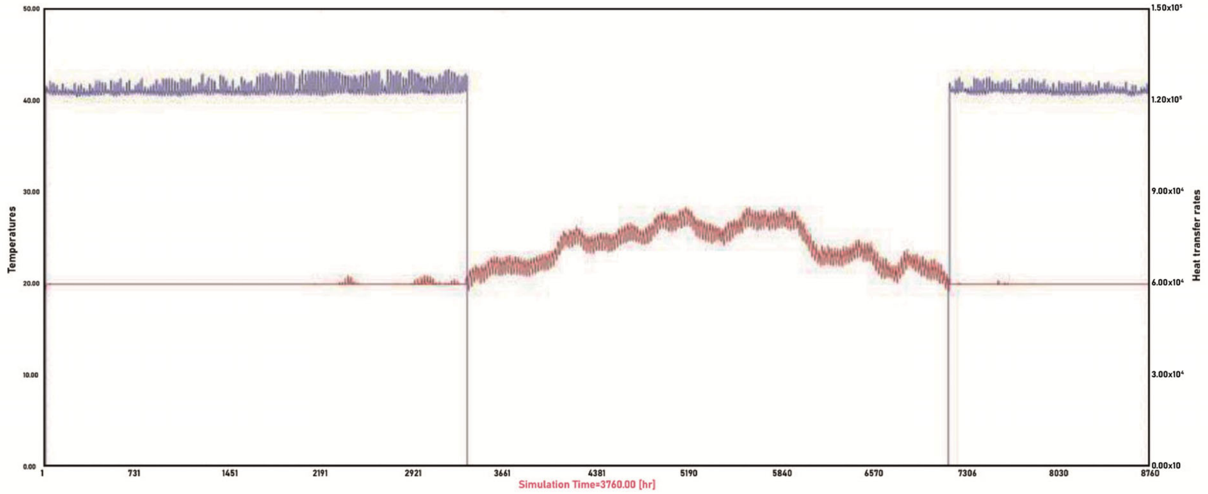

Figure 14. Winter operation "Offices" alternative 2.

The considerations regarding the purchase prices of electricity and gas, and the time slots considered in Solution 1, are the same also in Solution 2. To consider the flow chart diagram, see Figure 15.

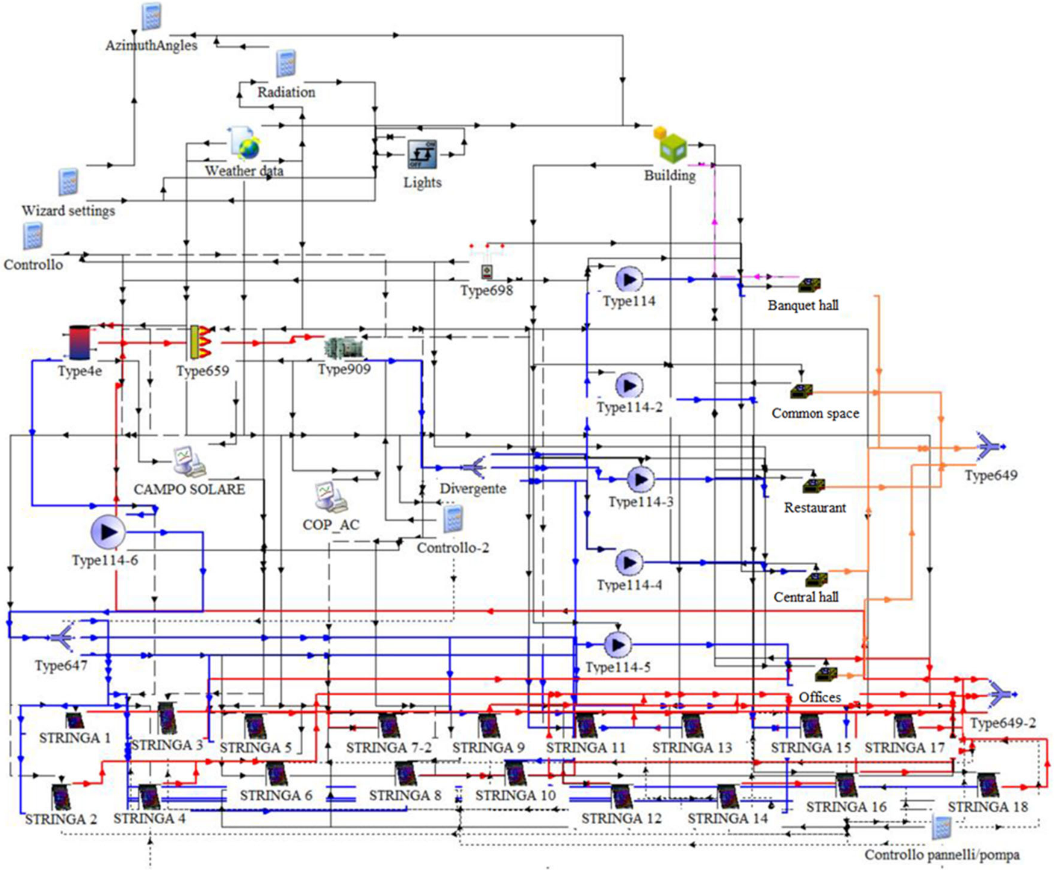

Figure 15. Solution 2 flowchart.

The total investment cost is 534,000 EUR, the total annual saving is 105,551 EUR/year, and maintenance costs were assumed to be 1000 EUR/year. Figure 16 shows the cash flow and the payback time related to the proposed retrofit Solution 2.

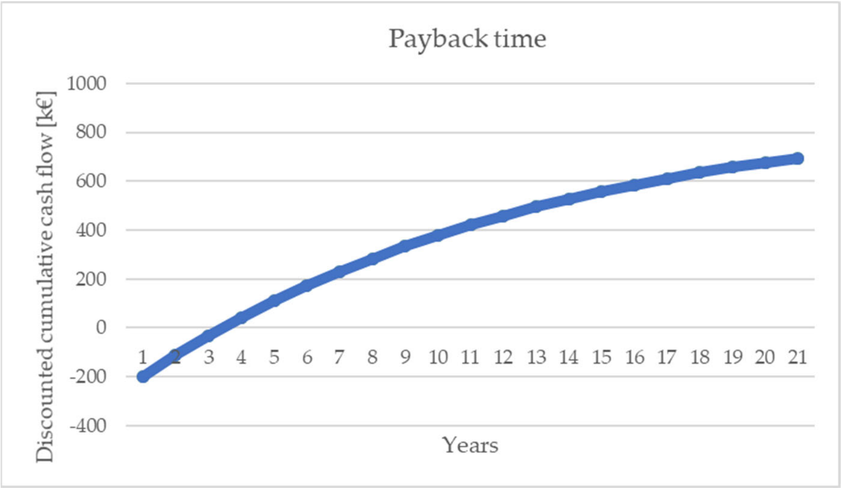

Figure 16. Cash flow related to the proposed retrofit Solution 2.

3. Conclusions

The energy analysis of the various optimization proposals for the structure under consideration provided clear results regarding the optimal solution to be used, considering not only the economic factor but also the environmental aspect. Solution 1 involves the installation of a water and lithium bromide absorption machine fed by flat-plate solar collectors. These have a significantly lower fluid outlet temperature than the evacuated tube solar collectors analyzed above and a lower cost per square meter installed. From an environmental point of view, they are more impactful due to the higher consumption of gas to reach the set point temperature of the absorption machine; from an economic point of view, on the other hand, they present a return on investment in about two years, less than half of the second hypothesis. The second solution involves the installation of evacuated tube solar collectors coupled to a water and lithium bromide absorption machine. It is necessary to install an auxiliary system that allows the desired water temperature conditions to be reached if the solar collectors do not reach the setpoint temperature of the absorption machine. This second solution is convenient from an environmental point of view because the consumption of electricity and gas is reduced, thus allowing a return on investment in about seven years.

For these reasons, Solution 1 may be considered more advantageous if the objective is purely economic. In contrast, Solution 2 is recommended if the main objective is pollution savings. In any case, the investment would return within an acceptable pay-back time. The simulations performed show the dynamic behavior of a building in terms of energy demand. The case study is a replicable example in all residential and nonresidential structures. A thorough initial audit allows for dynamic simulations capable of characterizing consumption and being able to perform energy retrofit interventions. Improved solutions are not necessarily only those proposed in this paper, but certainly, the possibility of using solar energy to air condition a hotel is a great economic advantage.

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