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Use of Renewable Energy Sources for Heat and Cooling Generation in Hospitals

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Abstract

Use of sustainable energy sources is necessary for mitigating climate change that is the most important global environmental problem in our era. The use of renewable energies and low carbon emission technologies for heat and cooling generation in hospitals has been investigated. The existing literature has been reviewed and various successful applications worldwide have been identified although the current use of renewable energies in hospitals is rather limited. Solar energy, biomass and geothermal energy have been used so far providing heat and cooling in hospitals while they can cover part or all of their heat and cooling requirements. Their technologies are mature, reliable and cost efficient while their use results in many economic, environmental and social benefits. Taking into account that hospitals are large energy consumers the use of benign energy sources reduces significantly their carbon footprint contributing in climate change mitigation and in energy transition to low carbon economy. Our work indicates that the use of benign energy sources for heat and cooling generation in hospitals is beneficial and it should be promoted.

Keywords: biomass; cooling; geothermal energy; heating; hospitals; renewable energies; solar energy; waste heat reuse.

1. Introduction

The necessity to cope with the global threat of climate change requires the transition to a low carbon economy minimizing the use of fossil fuels in all sectors. Hospitals require continuously large amounts of energy covering all their needs in heat, cooling, lighting, steam, domestic hot water and operation of many electric devices. They mainly utilize diesel oil, natural gas and grid electricity while the use of renewable energies is rather limited so far. Current research reviews the use of renewable energies and low carbon energy technologies in hospitals worldwide for covering their needs in heat, cooling and domestic hot water.

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Various renewable energy technologies are mature, reliable and cost efficient due to recent technological developments while they are used in many residential, industrial and agricultural applications. Therefore their use in hospitals is desirable and attractive since they reduce the carbon footprint due to energy use contributing in the energy transition to a low carbon economy. The present work is important since it indicates the opportunity of using various renewable energy technologies in hospitals mentioning successful applications worldwide and the resulting environmental and social benefits.

2. Literature survey

2.1 Energy consumption in hospitals

Use of sustainable energies in Mpodosakio hospital located in Ptolemaida, northern Greece has been reported [1]. The total covered surface in the hospital was at 20,000 m^2 while the annual specific energy consumption was at 287.25 KWh/m^2. The share of heat energy in the total energy mix was at 64.74 %. The hospital has installed a large solar thermal system providing warm water with a total flat plate collector's area at 900 m^2. The hospital also covers the heating needs in the rooms from the city's district heating system with capacity at 540 KW_{th} that uses the rejected heat from a nearby located coal-fired thermal power plant. A study regarding the increase of energy efficiency in thermal processes in healthcare Institutions has been made [2]. The authors stated that the share of heat ventilation air-conditioning [HVAC] and domestic hot water [DHW] in hospital buildings in South Africa is at 59%. They mentioned that the energy efficiency in these two major thermal energy-intensive processes can be significantly increased. A report regarding the energy use in hospitals in New Hampshire, USA has been published [3]. The report stated that large hospitals spend typically 1-3% of their total operating costs on energy. It is also mentioned that heat is required in hospitals for preheating and heating [83 %], service hot water [3%], steam [11%] as well as in the kitchen, labs, etc [3%]. Additionally various applications of solar thermal systems for DHW production and biomass boilers for heat generation in hospitals are mentioned. A study on heat requirements for DHW production in two large hospitals with capacity over 600 beds located in Bydgoszcz, Poland has been implemented [4]. The author mentioned that the specific annual energy consumption for DHW production in these two hospitals during the period 2003-2008 was at around 57.8 KWh/m^2 to 69.7 KWh/m^2. He also stated that the total amount of heating energy required for space heating, DHW production and process steam was at around 251.7 KWh/m^2 to 338.6 KWh/m^2. An estimation of the energy consumption and the carbon emissions in Venizelio hospital located in Crete, Greece has been realized [5]. The author stated that its annual specific energy consumption was at 280.4 KWh/m^2 while its annual CO_2 emissions were at 168 kgCO_2/m^2. He also mentioned that the combined use of solar thermal energy, solar photovoltaic [solar-PV] energy, solid biomass and ground source heat pumps could cover all the annual operating energy needs in the hospital zeroing its net CO_2 emissions due to energy use. A study regarding the energy consumption in a large hospital in China has been made [6]. The authors estimated its annual energy consumption at 259.45 KWh/m^2. They also stated that air-conditioning had the largest share in the overall electricity consumption at 52%, lighting at 12% while the other utilities had a share at 36%. The energy consumption in a hospital building located in Zhejiang, China with covered area at 77,000 m^2 has been investigated [7]. The authors stated that electricity had a share at 66% in the total energy mix while the rest 34% was attributed to natural gas. They also mentioned that the specific annual electricity consumption was at 105.9 KWh/m^2 while the consumption of natural gas was at 54.55 KWh/m^2. The energy consumption in Chinese

hospitals located in different climate zones has been studied [8]. The authors mentioned that electricity had the maximum share in the overall energy consumption. They also stated that the specific annual energy consumption varied between 250.4 KWh/m^2 and 476 KWh/m^2. The integration of solar thermal heat, solar-PVs and biomass in a Brazilian hospital has been investigated [9]. The authors stated that biomass was economically the most appropriate fuel for heat production in the hospital. An analysis of the energy consumption in healthcare facilities in USA has been realized [10]. The authors estimated that the annual energy intensity in USA hospitals varies between 640.7 KWh/m^2 in very hot zones and 781.1 KWh/m^2 in very cold zones with an average value at 738.5 KWh/m^2. They also mentioned that hospitals consume 2.6 times more energy than other commercial buildings while USA health care centers have higher energy intensity compared with hospitals in other countries. In USA hospitals during 2012 electricity had a share at 51% in the total energy mix, natural gas at 37%, district heating at 9% and fuel oil at 3%. The energy consumption in German hospitals has been evaluated [11]. The authors stated that the average annual energy consumption in a German hospital under normal operating conditions has been estimated at 270 KWh/m^2.

2.2 Solar energy

A report regarding solar heating and cooling in buildings has been published [12]. The report mentioned that deployment of solar thermal cooling systems is growing while 80% of their deployment is focused in Europe. It is also stated that 71% of solar thermal cooling systems use absorption chillers combined with solar collectors, 13% adsorption chillers and 16% desiccant systems. The performance of a solar adsorption cooling and heating unit has been evaluated [13]. The authors mentioned that the solar thermal cooling system was designed to operate at temperatures below 90^{o}C achieving a maximum coefficient of performance [COP] at 0.65. They also stated that its operation on a typical week on summer in Athens, Greece with driving temperature around 75^{o}C resulted in a COP at around 0.575 while the estimated mean energy efficiency ratio was at 5.8. A report on solar thermal heating and cooling in buildings has been published [14]. The author stated that in medium size hospitals the share of air-conditioning in the overall energy mix was at 39%, of hot water at 20%, of lighting at 18%, of laundry at 8% and of other uses at 15%. He also mentioned that Managua hospital in Nicaragua has installed a solar thermal cooling system with solar collector's area at 4,450 m^2 and cooling load at around 1,023 KW. A study on recent trends in solar thermal sorption cooling technology has been made [15]. The authors compared absorption and adsorption systems stating that absorption systems are mainly used in solar thermal cooling while their COP is low with maximum value at 0.8 compared to 2-3 for conventional cooling systems. They also mentioned that COPs in adsorption systems is even lower at 0.45 while the use of multi-stage systems can increase COPs in solar thermal cooling. The authors concluded that solar cooling is a promising technology because the cooling demand coincides with periods of high solar irradiance. A report on solar cooling has been published [16]. The report stated that more than 1,500 solar cooling systems have been installed in recent years mainly based on solar thermal collectors and thermally driven chillers. It is also mentioned that thermal absorption chillers with a cooling capacity larger than 350 KW have become cost competitive under certain climate and energy price conditions. A study regarding the technical and economic viability of a solar water heating system for a hospital laundry in northeastern Brazil has been realized [17]. The authors stated that the investment in the solar water heating system was profitable achieving a payback time at 5.4 years and an internal rate of return at 29.5%. The use of solar energy for DHW production in a large Malaysian hospital has

been investigated [18]. The authors stated that hospitals utilize more than 30% of their total energy consumption in water heating. In the hospital University Kebangsaan Malaysia they proposed a solar thermal water preheating system which was going to decrease significantly the liquid pressurized gas [LPG] used in hospital's boilers producing DHW. The use of renewable energies [REs] in medical buildings has been studied [19]. The authors stated that solar-based technologies can be applied in heating and cooling of hospitals and other healthcare facilities. The advantages and challenges of using REs in healthcare facilities have been evaluated [20]. The author stated that solar energy can provide hot water in hospitals. He mentioned that the required energy for hot water production in hospitals typically has a share at 25% in the total energy consumption. The applications in solar thermal cooling have been reviewed [21]. Solar thermal cooling systems include absorption systems, adsorption systems and systems using desiccants. They also mentioned that the most commonly used solar thermal cooling systems are related with lithium bromide absorption chillers. The efficiency of these systems depends on sunlight conditions while they are more attractive in areas with high solar irradiance. The possibilities of increasing environmental sustainability in hospitals have been investigated [22]. The authors stated various hospitals using: a] geothermal heat pumps for air-conditioning their buildings, b] solar thermal systems producing the necessary DHW, and c] solar thermal cooling systems with thermal chillers for space cooling. A report on the potential use of solar thermal systems for heat generation in hospitals in South Africa has been published [23]. The report stated that solar thermal energy can cover around 20-40% of their annual heating needs while the payback time of the solar energy investments has been estimated at 12.3 years.

2.3 Biomass

The feasibility of using biomass for the production of heat and cooling in hospitals with reference Extremadura, Spain has been examined [24]. The authors stated that the use of heating systems based on biomass is attractive in hospitals since their requirements in thermal energy are high. They evaluated the economic performance of two biomass heating systems using olive kernels and almond shells installed in two health care facilities mentioning that the payback period of the energy investments is at around five years. The use of biomass boilers in hospitals has been studied [25]. The authors implemented a case study in a hospital located in Brazil with annual hot water demand at 1,947 MWh and annual demand for steam production at 138 MWh. They examined three different biomass sources including firewood, pellets and sugarcane biomass concluding that firewood was the cheapest biomass fuel while pellets were the most expensive option. An announcement regarding the use of solid biomass boilers to heat the premises in two hospitals in England and Italy has been made [26]. The hospitals located in Manchester, England and in Emilia Romagna, Italy were using wood chips to fuel their boilers while the payback time of the energy investments has been reported at around 5-6 years. The use of landfill gas for energy generation in Gundersen hospital, Wisconsin, USA has been reported [27]. The hospital has installed two co-generation of heat and power [CHP] systems utilizing methane produced in a nearby landfill as well as wood waste from nearby lumber operations. Electricity and heat co-produced were both used in the hospital. The possibility of using solid biomass for covering the heating needs in hospitals located in Crete, Greece has been investigated [28]. The author stated that the annual specific heating needs in Cretan hospitals have been estimated at around 300 KWh/m^2. He also mentioned that olive kernel wood which is abundant in Crete could be used for providing heat in regional hospitals while its use is profitable. The use of biogas for heating hospital rooms in Germany has been reported [29]. The hospital in Nauen, Germany with

capacity at 327 beds used biogas produced in a plant located in the city covering 50% of its warm water demand. Biogas was produced from co-digestion of cattle's manure and maize silage and it was used for co-generation of heat and power.

2.4 Geothermal energy

Evaluation of an aquifer thermal storage system in a Belgian hospital has been realized [30]. The system was consisted of an aquifer for thermal energy storage and a heat pump for heating and cooling the hospital. The authors stated that the overall seasonal performance factor for heating was at 5.9 while the payback period without financial subsidies was estimated at 8.4 years. The use of a heat pump for air-conditioning in a hospital building located in Taiwan has been examined [31]. The authors stated that during hospital's retrofitting a water source heat pump was installed providing cooling and hot water in the hospital. They also mentioned that the estimated COP of the heat pump was at 3.62 in heating and at 2.62 in cooling while the payback period of the energy investment was at 1.2 years. The use of a geothermal heat pump for heating and cooling the Massachusetts general hospital in Boston, USA has been studied [32]. The authors stated that using a ground source heat pump with a vertical closed loop system significant reduction of the heating and cooling costs will be achieved. They also mentioned that the payback period of the energy system was estimated at 1.5 years. The geothermal heating system at Rotorua hospital in New Zealand has been assessed [33]. The authors mentioned that the capacity of the hospital was 120 beds while the shallow geothermal field was covering all its heating requirements. They also stated that the temperature of the geothermal fluid was at 160^{o}C delivering heating power at around 150 MWh/week to 370 MWh/week with water temperatures at around 130-140^{o}C. The operation of a heat pump supplying hot water in a medium size hospital located in central Taiwan replacing a natural gas boiler has been studied [34]. The author stated that the heat pump was recovering heat from the air conditioning system supplying steadily hot water with temperatures at around 45-50^{o}C. They also mentioned that the heat pump reduced the energy cost while its payback period was estimated at 1.8 years. Existing research indicates that there are many successful applications worldwide regarding the use of various renewable energies generating heat and cooling in hospitals. The most popular renewable energies used so far were solar thermal energy, biomass and ambient heat combined with heat pumps. Use of solar energy and biomass in hospitals depends on their local availability. Their technical and economic feasibility has been already proved.

Aims of the current work are:

a) The presentation of various renewable energy technologies which could be used for heat and cooling generation in hospitals, and

b) The presentation of their characteristics and advantages.

After reviewing the existing research the energy consumption in hospitals has been mentioned. The use of solar energy, biomass, geothermal energy as well as low and zero carbon emission technologies in hospitals have been presented. Their environmental and social impacts have been stated followed by discussion of the results, presentation of the findings and citation of the related literature. The work is limited to qualitative aspects of using various renewable energy technologies in hospitals worldwide without giving further insight regarding the

sizing of these energy systems.

3. Energy consumption in hospitals

Hospitals are large and complex organizations operating 24 hours daily and 365 days annually. They require energy for covering their needs in heating, cooling, lighting, domestic hot water production and operation of electric devices and equipment. Energy consumption in hospitals is higher than in other public buildings while they require more heat and cooling energy than electricity. The share of heat and cooling energy in their energy mix is usually at 60-65%. Most of them utilize conventional energy sources including grid electricity, diesel oil and natural gas while the use of renewable energies is so far limited. The energy consumption in hospitals in various countries is presented in table 1.

Table 1: An example of a table

Country/Year	Total energy consumption [KWh/m^2]
USA, 2019	640.7-781.1
Germany, 2018	270
China, 2019	250.4 – 476
China, 2004	259.45
China, 2019	160.45
Greece, 2018	280.40
Greece, 2017	287.25

Source: Various authors

4. Use of solar Energy

Solar energy has been mainly used with solar thermal systems for hot water production and space cooling in hospitals.

4.1 Use of solar energy for hot water production

Hospitals utilize hot water in the patient's rooms, in the laundry, in the kitchen as well as in other sectors. It has been estimated that the energy required in DHW production in hospitals has a share at around 20-30% in the total energy mix. In areas with satisfactory solar irradiance hot water at around 60-70^{o}C could be provided with solar thermal systems covering the most of the annual energy requirements. However an additional energy source is required for the production of hot water during the days of low solar irradiance. Solar energy can be also used for water preheating in the steam production unit. Flat plate solar collectors or collectors with vacuum tubes can be used for that. Hybrid hot water production systems are used in hospitals combining solar thermal

energy with another energy source including either fossil fuels like diesel oil, gas and grid electricity or renewable energies like biomass and geothermal energy. The payback period of the investment in solar thermal systems for DHW production in hospitals has been reported between 5 and 12.3 years. The flat plate solar collectors can be placed on the rooftop in hospital's buildings if there is space availability. Solar thermal technology for DHW production is a reliable, mature, well proven and cost efficient technology that can be used both in small and large scale health care facilities.

4.2 Use of solar energy for space cooling

Solar thermal cooling systems have increasing applications in various sectors although their use is not propagated so far compared with the use of DHW production systems. The most common technology used is related with absorption chillers while the use of adsorption chillers and desiccant systems is rather limited. Space cooling is required in hospitals during the hours of high solar irradiance that favors the use of solar thermal cooling systems. The energy efficiency of these systems depends on hot water temperature while higher water temperatures result in higher efficiencies. Multistage systems have also higher efficiencies than single stage systems. The installation of solar collectors requires large surfaces which usually are available in hospital's premises. Solar thermal cooling can cover a significant amount of their annual space cooling requirements. Taking into account that air conditioning in hospitals has a high share in the total energy mix use of solar energy for cooling reduces significantly the grid electricity consumption. The use of solar energy for heat and cooling generation in hospitals worldwide is presented in table 2.

Table 2: Use of solar energy for heat and cooling generation in hospitals worldwide

Author, year, country	System/energy source	Estimated payback period [years], Internal rate of return [%]
Finerpor report, 2017, Greece	Solar thermal energy and district heating system	-
Lima and his colleagues 2015, Brazil	Solar thermal energy producing hot water	5.4 years, 29.5%
Ooshaksaraei and his colleagues 2010, Malaysia	Solar thermal energy producing hot water	-
Haghighi Bardineh and his colleagues 2018, various countries	Solar thermal heating and cooling	-
Vallve and his colleagues 2018, Lebanon	Solar thermal energy producing hot water	-
Burger and his colleagues 2010, Australia	Solar thermal heating and cooling and geothermal heat pumps	< 5 years
Report, 2018, South Africa	Solar thermal energy	12.3 years, 10%

Source: Various authors

5. Use of biomass for heat generation

Solid biomass and biogas can be used for heating and cooling hospitals.

5.1 Use of solid biomass

Solid biomass has been used for heat generation in hospitals although its use is limited so far. Various types of locally available biomass resources have been used that can cover all the annual heating needs regarding space heating, DHW production, heating in the kitchen and the laundry, as well as in other sectors. The profitability of biomass heating systems in hospitals has been proved while payback periods of the energy investments at around 5 years have been reported. Burning of solid biomass is a well known, mature and reliable technology that can produce hot water in higher temperatures compared with temperatures achieved with solar thermal heating systems. The quantity of solid biomass needed to cover all the heating requirements in hospitals is large and the appropriate infrastructure for storing it is required. Apart from heat production, biomass can be used for space cooling with thermal absorption or adsorption cooling systems although this technology is more complex and it is not broadly propagated so far.

5.2 Use of biogas for heating

Biogas is usually produced by anaerobic digestion of organic matter including organic solid and liquid wastes. It is mainly consisted of CO_2 and CH_4 having satisfactory heating value while it is used by burning for heat generation or co-generation of heat and power. When biogas is available nearby hospitals it can be used for heat generation covering part of their heating requirements. The use of biomass for heat generation in hospitals worldwide is presented in table 3.

Table 3: Use of biomass for heat generation in hospitals worldwide

Author, year, country	Fuel/Use	Estimated payback period [years]
Sanz-Calcedo and his colleagues 2011, Spain	Solid biomass for heating- olive kernels and almond shells – heat production	5 years
Bandeira de Mello Delgado and his colleagues 2018, Brazil	Solid biomass for heating- firewood, pellets, sugarcane biomass – heat production	-
Announcement, England and Italy	Wood chips for heating	5-6 years
Report, 2015, USA	Biogas, CHP system	12 years
Wisconsin	Biogas producing warm water	-
Report, Biogas heat, 2012, Germany		

Source: Various authors

6. Use of geothermal energy

Geothermal energy can be used for heating hospitals either with direct use of geothermal fluids or with heat

pumps utilizing the ambient low enthalpy geothermal energy.

6.1 Direct use of geothermal energy

Low or medium enthalpy geothermal fluids at 60-150^{o}C can be used for heat production in hospitals provided that the geothermal spring is located nearby the hospitals avoiding the fluid transportation cost. The cost of geothermal heat is low although occasionally processing of the fluid is required removing any pollutants and minimizing the environmental impacts.

6.2 Use of geothermal heat pumps

Heat pumps are energy efficient devices which are increasingly used in many sectors. They are powered by electricity using the ambient low enthalpy geothermal heat producing 3-4 times, or even higher, more heat and cooling compared with the electricity consumed. They can be used in hospitals covering part or all of their requirements in heating, cooling and DHW production. Since they are using grid electricity their on-site environmental impacts are minimal while when they are powered with solar electricity the carbon emissions due to energy use are minimized. The capital cost of heat pumps is high compared with the cost of other conventional or unconventional heating systems. However due to their high energy efficiency their use in hospitals is in the long term cost efficient. The use of biomass for heat generation in hospitals worldwide is presented in table 4.

Table 4: Use of geothermal energy for heat generation in hospitals worldwide

Author, year, country	System/fuel	Estimated payback period [years]
Vanhoudt and his colleagues 2011, Belgium	Heat pump for heating and cooling	8.4 years
Chiang and his colleagues 2017, Taiwan	Heat pump for heating, cooling and hot water production	1.2 years
Zgvith and his colleagues 2018, USA Boston	Heat pump for heating and cooling	1.5 years
	Direct heating with geothermal fluid	-
Steins and his colleagues 2012, New Zealand	Heat pump for hot water production	1.8 years
Shen and his colleagues 2009, Taiwan		

Source: various authors

The characteristics of the abovementioned renewable energies regarding their use for heat and cooling generation in hospitals are presented in table 5.

Table 5: Characteristics of various renewable energies used in heat and cooling generation in hospitals

Renewable energy source/Technology	Generated energy	Energy efficiency	Cost of energy source	Capital cost of the energy system
Solar thermal energy/Flat plate solar collectors	Heat	30-40 %	Zero	Medium
Solar thermal energy/Absorption or adsorption cooling systems	Cooling	40-80 %	Zero	Medium to high
Solid biomass/Burning	Heat	70-80 %	Low	Medium
Biogas/Burning	Heat	70-80 %	Low	Medium
Geothermal fluids/Heat exchange	Heat	70-90%	Low	Low to Medium
Ambient heat combined with electricity/Heat pumps	Heat and cooling	300-500%	High	High

Source: various authors

7. Use of other low and zero carbon emissions energy technologies

Various low and zero carbon emissions energy technologies can be used for heat and cooling generation in hospitals including waste heat reuse, CHP systems and fuel cells.

7.1 Waste heat reuse

Rejected industrial heat can be reused for covering the heating needs in hospitals when temperatures at 60-90^{o}C are required. This can be achieved either directly when hospitals are located nearby the industry that discharges cooling water or indirectly if hospitals are using district heating systems fueled by rejected industrial heat. In both cases fossil fuels are not used zeroing the carbon impacts during hospitals' heating.

7.2 Heat and power co-generation systems

Hospitals require continuously energy both heat and electricity. Use of heat and power co-generation systems can cover part or all of their annual electricity and heat requirements. Their overall energy efficiency is high at around 80-90% while they are mainly powered by natural gas. Alternatively they can use biogas or hydrogen if available. CHP systems are energy and cost efficient with low carbon impacts due to natural gas use. The technology is mature, reliable and well proven already used in many sectors.

7.3 Fuel cells

Fuel cells are novel energy generation systems. They generate continuously both heat and electricity while their

total energy efficiency is high at around 80-85%. They are fueled by natural gas or hydrogen if available. Like CHP systems they can cover part or all of the annual heat and electricity requirements in hospitals. The technology is still expensive and requires capital subsidies in order to be competitive with other energy technologies. Fuel cells are expected to be used broadly in many sectors during the coming years.

8. Environmental and social impacts

The use of conventional fuels and grid electricity for heat and cooling generation in hospitals results in GHG emissions. The use of renewable energies and low carbon energy technologies lowers their carbon footprint due to energy utilization. Taking into account that heat energy has a high share in hospital's energy mix the use of renewable energies for heat production could significantly reduce their total carbon impacts. This is highly desirable contributing in climate change mitigation while it is aligned with the efforts for energy transition to low carbon economy. However in cases like using solid biomass for heat generation adverse environmental impacts are resulted. The polluted burnt gases should be processed and cleaned. Replacement of fossil fuels with endogenous benign energy sources in hospitals offers many social benefits in the local communities. It assists local energy companies to manufacture, install and maintain various renewable energy systems increasing the local employability in scientific and technical staff. It also helps local farmers to produce, process and standardize various local biomass sources based in agricultural and forest residues and by-products that can be used for heat production in hospitals. The benefits due to renewable energies use for heat and cooling generation in hospitals comprise:

1. Lower carbon emissions due to energy use. Compliance with the targets of climate change mitigation and energy transition to low carbon economy,
2. Decrease of energy dependence in hospitals,
3. Economic benefits in hospitals since the use of renewable energies is cost efficient,
4. Reduction of expenses regarding fossil fuels imports in countries without fossil fuels resources,
5. Increase in sustainable energy investments,
6. Assistance to local enterprises related with manufacturing, installation and maintenance of renewable energy systems as well as in production and processing of local biomass fuels,
7. Creation of local jobs in the field of sustainable energy technologies, and
8. Increasing the energy performance in hospital's buildings.

9. Discussion

Our results mentioned various worldwide uses of renewable energy technologies for heat and cooling generation in hospitals. These technologies are mature, reliable and cost efficient offering many economic, environmental and social benefits. Use of sustainable energy technologies in hospitals increases the energy performance and the energy rating in hospital buildings assisting their transformation to nearly zero energy buildings according to recent regulations in many countries. Use of benign energy sources also decreases their energy dependence on conventional energy sources and fuels while it increases their energy self-sufficiency. Apart for heat and cooling generation sustainable energies can be used for electricity generation in hospitals or co-generation of heat and

power. Solar-PV systems, CHP systems and fuel cells have been already used in hospitals worldwide. Use of local indigenous renewable energy sources in hospitals promotes the environmental and social sustainability in local societies. The findings are important since they indicate that the use of benign energy technologies in hospitals is technically and economically feasible while their use contributes positively in climate change mitigation and in energy transition to low carbon economy. The results though do not indicate which renewable energies should be used in specific hospitals.

10. Conclusions

The use of renewable energy technologies for heat and cooling generation in hospitals has been studied. Hospitals are big energy consumers requiring continuously large amounts of energy all over the year. They currently use fossil fuels and electricity derived by them while the use of renewable energies is limited so far. The main renewable energies examined were solar energy, biomass and geothermal energy while the use of low carbon energy technologies comprising CHP systems, fuel cells and waste heat reuse has been mentioned. Renewable energies are already used in various hospitals worldwide mainly for DHW production as well as for heat and cooling generation while the existing sustainable energy technologies are mature, reliable and cost efficient. Their use can cover part or all of their heat and cooling requirements while they can also be used in hybrid energy systems. Existing applications in various countries indicate that their use is profitable resulting in attractive payback times and internal rates of return. The local availability and the cost of benign energy sources indicate the possibility of using them in hospitals. Replacement of fossil fuels with renewable energies in hospitals has positive impacts in climate change mitigation and in energy transition to low carbon economy. Their use for heat and cooling generation in hospitals replacing fossil fuels should be increased in the future and various barriers hindering their utilization should be removed. Sustainable energy investments in hospitals can be realized either with public funds or by private financing and public private partnerships. Further research should be focused in various case studies examining the use of different renewable energies in hospitals located in different areas assessing their economic, environmental and social impacts.

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