

Possibilities of Using Sustainable Energy Technologies including CHP Systems, Solar Photovoltaics and Heat Pumps in Hospitals

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ABSTRACT

Hospitals consume large amounts of energy in their daily operations. The necessity to comply with the global targets for climate change mitigation requires the decrease in their energy and fossil fuels consumption as well as reduction of their CO₂ emissions. The aims of the current work are to study the possibilities of using several clean and low carbon emission technologies for heat, cooling and electricity generation in hospitals. The use of solar-PV panels, CHP systems and heat pumps has been examined as well as the possibility of financing these environmentally friendly energy technologies with external funding. Our results indicate that the abovementioned sustainable energy technologies are mature, reliable and cost-efficient providing heat, cooling and electricity in hospitals having also positive economic, social and environmental impacts. Their combined use with other low or zero carbon emission technologies could help in the transformation of hospital buildings to nearly zero energy buildings minimizing or zeroing their carbon footprint due to energy use. Various financial tools have been developed so far utilizing mainly private funds for financing clean energy investments in hospitals with external resources. Present work is important since it indicates that the previously mentioned sustainable energy technologies can be used in hospitals assisting in their transformation to low carbon emission organizations since in coming decades the mitigation of climate change in our societies will be necessary and crucial.

Keywords: CHP systems, energy, financing, heat pumps, hospitals, low carbon, solar-PV, sustainability.

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I. INTRODUCTION

Hospitals operate continuously all over the year consuming large amounts of energy. They usually utilize grid electricity and fossil fuels while the use of renewable energies is rather limited so far. However, the necessity to contribute to the global targets for climate change mitigation requires to increase the use of renewable energies and other sustainable energy technologies in their premises reducing their environmental impacts. Current research presents various aspects of using low carbon energy technologies in hospitals focused on solar photovoltaic (solar-PV) systems, co-generation of heat and power (CHP) plants and heat pumps. These benign energy technologies have been already successfully used in several hospitals providing electricity, heat, and cooling while their increased use in the future is necessary and highly desirable. Their use increases hospital's resilience and facilitates their adaptation to climate change offering also many economic, environmental, and social benefits to all stakeholders related with hospital's operation. The future use of clean energy technologies is important and necessary since their use will assist hospitals to significantly

reduce their energy consumption as well as the fossil fuels use and their GHG emissions that is a necessary step for decarbonizing our societies during 21st century.

II. LITERATURE SURVEY

The literature survey is separated in five sections including energy consumption in hospitals, use of solar-PV panels, use of CHP systems, use of heat pumps and financing clean energy investments in hospitals.

A. Energy Consumption in Hospitals

Reference [1] has analyzed the energy consumption in a hospital located in Zhejiang, China stating that its annual energy consumption is at 160.5 KWh/m². Reference [2] has reviewed the energy consumption in healthcare facilities in USA. The authors mentioned that the annual energy consumption in US hospitals is in the range of 640.7 KWh/m² to 781.1 KWh/m² with a mean value at 738.5 KWh/m². The authors also stated that the average annual energy consumption in European hospitals is significantly lower at 333.4 KWh/m².

TABLE I: ANNUAL ENERGY CONSUMPTION IN HOSPITALS

Country	Reference	Electricity consumption (KWh/m ²)	Heat consumption (KWh/m ²)	Total annual energy consumption (KWh/m ²)
USA	[2]			738.5
Taiwan	[3]			259.45
Greece	[11]			407
China	[4]			338.42-382.65
Spain	[10]			70-103
Greece	[12]			280.4
Norway	[5]	163-190		
Norway	[6]			400-500
Germany	[7]			270
Spain	[8]			270
Brazil	[9]			190-460
Various countries	[1]	150.90	54.55	160.45
EU average	[2]			333.4

Reference [3] has studied the energy consumption in a large acute hospital located in Taiwan estimating its annual energy consumption at 259.45 KWh/m². Reference [4] has evaluated the energy consumption in Chinese hospitals. The authors stated that their annual energy consumption varies in the range of 338.42 KWh/m² to 382.65 KWh/m² depending on their capacity. Reference [5] has calculated the energy consumption in a large teaching hospital in Norway. The authors mentioned that its annual electricity consumption is in the range of 163-190 KWh/m² while its overall consumption is approximately double. Reference [6] has studied the energy consumption in hospitals in Norway mentioning that in large University hospitals the annual energy consumption is at 400-500 KWh/m². Reference [7] has evaluated the energy consumption in German hospitals stating that their average annual energy consumption is at 270 KWh/m². Reference [8] has assessed the energy consumption in Spanish hospitals mentioning that their average annual energy consumption is at 270 KWh/m². Reference [9] has studied the energy consumption in Brazilian hospitals. The authors stated that their average annual energy consumption is in the range of 190-460 KWh/m². Reference [10] have evaluated the energy consumption in healthcare facilities located in Extremadura, Spain stating that their annual energy consumption is in the range of 70-103 KWh/m². Reference [11] has assessed the energy performance of healthcare buildings in Hellas. The authors stated that the average annual energy consumption in Hellenic hospitals is at 407 KWh/m² while in clinics at 275 KWh/m². Reference [12] has estimated the energy consumption in Venizelio hospital located in Crete, Greece mentioning that its annual energy consumption is at 280.4 KWh/m². The annual energy consumption in hospitals worldwide, according to the published research, is presented in Table I.

B. Use of Solar-PV Panels

Reference [13] have studied the opportunities of integrating solar thermal heating, solar-PVs and biomass in Brazilian hospitals. The authors stated that the use of solar-PVs is attractive when the hospital is required to achieve a net zero energy balance. Reference [14] have investigated the viability of installing a grid-connected solar-PV system in Near East University hospital in Northern Cyprus. The authors mentioned that the solar energy potential at hospital's site was excellent while the solar electricity cost was low and competitive to grid's electricity cost. Reference [15] has investigated the use of a hybrid energy system consisted of a

solar-PV unit, a fuel cell and an electric battery in a Malaysian hospital. The authors mentioned that the proposed system is an attractive alternative system to conventional energy systems used in hospitals. Reference [16] has assessed the use of a solar-PV system in a Malaysian hospital. The authors stated that although the initial installation cost is high its use results in attractive profits for the hospital. Reference [17] have studied a novel renewable energy system for a hospital located in Naples, Italy. The system was consisted of both concentrating photovoltaic thermal collectors and solar heating and cooling technologies. The authors stated that the energy and economic performance of the system was excellent while its payback period was estimated at around 12 years. Reference [18] has reported on solar-PVs installed in hospital's buildings. The authors stated that Lewisham hospital in London, England has installed a solar-PV system at 13.7 KW_p generating 10,300 KWh/year while Oregon Health Science University has also installed in its premises solar-PV panels at 60 KW_p. A report concerning the use of solar-PVs in rural healthcare facilities in developing areas has been published [19]. The report stated that in small off-grid healthcare centers located in rural areas with low daily electric load existing experience shows that autonomous solar-PV systems are considered to be the best energy option. A report concerning guidelines for installing on-site commercial solar-PV systems in healthcare centers has been published [20]. The report mentioned various benefits that hospitals would have installing solar-PVs in their premises including:

- Lower consumption of grid electricity and lower electricity bills,
- Protection against future rising costs in grid electricity,
- Improvement of public health with the use of clean energy technologies without GHG emissions, and
- Higher energy resilience in hospitals.

C. Use of CHP Systems

Reference [21] has reviewed the use of CHP systems in hospitals in UK. The author stated that CHP systems can provide reliable heat and power in hospitals while they are widely used in England. A study regarding the use of CHP systems in hospitals has been published by [22]. The report mentioned that hospitals equipped with CHP systems provide reliable off-grid power during major disruptions increasing hospital's resilience. A guide for CHP applications in hospitals has been published by [23]. The guide provides useful information to hospitals regarding the application of CHP systems in their premises. It is stated that these systems

address holistically the energy, environmental and security issues in hospitals. A report regarding the CHP systems that provide resilient energy in critical facilities like hospitals has been published by [24]. The report mentioned that CHP systems improve hospital's resiliency mitigating the impacts of extreme weather events and major disruptions. A best practice report on de-centralized biomass fired CHP plants has been published by [25]. The report stated that CHP plants based on biomass resources can be fueled with solid, liquid and gaseous biomass while there are more than 1,000 biomass-based CHP plants operating in EU28 (2016). It is also mentioned that these plants are based on either biomass combustion or anaerobic digestion. A detailed guide for CHP developers has been published by [26]. The guide provided useful information concerning the different CHP technologies, the fuels used, their atmospheric emissions, as well as the possibility of using tri-generation plants and the thermal absorption cooling technology. The advantages of using CHP systems in US hospitals have been analyzed [27]. These advantages include: Increase in energy reliability and hospital's resilience in the event of disasters, reduced energy costs, covering their needs in electricity and hot water as well as in space heating and cooling. The potential of existing and future CHP capacity in US hospitals has been evaluated [28]. It is mentioned that their existing capacity is at 772 MW while the potential future capacity is much higher at 7,312 MW. These systems are reliable, increasing hospitals' resilience while they eliminate hospitals' needs for expensive back-up systems. Reference [29] has examined the applications of distributed electricity generation systems in hospitals. The author mentioned several sustainable energy technologies that could be used in hospitals offering many economic and environmental benefits. These DEG technologies favor also the mitigation of climate change and their adaptation to it.

D. Use of Heat Pumps

Reference [30] have studied the application of heat pumps in hospitals. Ground source heat pumps used for heating and cooling in hospitals offer significant financial and environmental benefits. The authors stated that heat pumps are already used for heat recovery from air-compressors producing hot tap water in the summer and heating water for space heating in the winter achieving payback periods at around 2-4 years. Reference [31] has studied the heat recovery with heat pumps in hospitals in USA. The author stated that the payback time of these heat recovery systems was attractive at around 3 years. Heat pumps should be the preferred heating systems in new buildings when electricity use is expected to decarbonize the economy according to [32]. It was stated that the electricity supplied to heat pumps can be "green" while heat pumps are more energy efficient, less costly while their CO₂ emissions are lower. The use of a hybrid PV/T system combined with heat pumps in a hospital located in tropical climate has been studied. Reference [33] investigated heat pumps using the heat produced by hybrid PV/T systems achieving high efficiencies at around 51-69%. The successful use of a heat pump replacing a natural gas boiler for hot water production in a medium-size hospital has been examined, [34]. Reference [35] studied the heat pump's technology stating that since around 50% of the total energy demand in EU is used for heating and cooling applications

heat pumps are ideal technologies for hospitals achieving payback periods at around 5-10 years. Various aspects in geothermal heating and cooling in healthcare facilities have been reported [36]. The author stated that ground source energy is not geothermal but it is generated by capturing the indirect solar energy. Heat pumps are approximately 30-40% more energy efficient when they are using the earth instead of the air. It is also mentioned that when land area is available it is 25-60% cheaper to install a horizontal than a vertical heat exchanger. Reference [37] mentioned that 17 projects combining solar thermal systems and heat pumps have been implemented in Lithuanian hospital buildings. Three Northland hospitals that have replaced the old fossil fuel central boiler system with heat pumps providing heat and hot water with payback time at around 2 years have been reported, TRANSPower, 2019. Reference [39] studied the successful integration of a water source heat pump with the existing HVAC system in a hospital building in Taiwan. The use of shallow geothermal energy systems for heating and cooling various Swedish hospitals has been reported indicating that it is an attractive option for these organizations [40].

E. Financing Clean Energy Investments in Hospitals

Reference [41] has reported on energy retrofitting of various hospitals and clinics in Italy. The authors mentioned that energy saving, increase in energy efficiency of equipment and use of renewable energies resulted in the reduction of the overall energy consumption in healthcare facilities at 33-79% while the payback period of the energy investments was estimated in the range of 9.3-20 years. A guide to energy performance contracting for healthcare facilities [42]. The guide stated the economic benefits for the hospitals as well as the environmental and social benefits resulted from the implementation of clean energy projects in them. Reference [43] has studied the decarbonization of public hospitals in Ireland. The authors stated that hospitals are energy inefficient organizations while the cost of retrofitting them is high. They also mentioned that financing clean energy investments in hospitals is a major issue while they should try to contribute to the global efforts for climate change mitigation and adaptation. World Bank has published a study regarding low carbon and resilient strategies for the healthcare sector [44]. The report mentioned that low carbon healthcare institutions have multiple positive economic, social and environmental impacts for all stakeholders. It is also stated that many clean energy projects in hospitals have attractive payback periods less than five years.

Aims of the current work are:

- The review of the energy consumption in hospitals worldwide according to published research,
- The presentation of various characteristics of solar-PV panels, CHP systems and heat pumps,
- The investigation of available options for financing low carbon energy investments in hospitals, and
- The assessment of the benefits due to sustainable energies use in hospitals.

The paper starts with the literature review followed by an estimation of energy consumption in hospitals. Next, the characteristics of various sustainable energy systems used in hospitals are stated as well as the necessity for using them

nowadays coping with global environmental problems and climate change. In the following sections the characteristics of the solar-PV panels, CHP systems and heat pumps are presented as well as the available financing options of clean energy investments in hospitals together with the resulted economic, social and environmental impacts. The paper ends with discussion of the findings, the conclusions drawn and the citation of the published research used.

III. ENERGY CONSUMPTION IN HOSPITALS

Hospitals and healthcare facilities operate continuously twenty-four hours daily and 365 days annually. Their annual energy consumption is high compared with the consumption in other public and private buildings. It has been estimated that hospitals utilize around two times more energy than other public buildings while in USA they utilize two and half times or even more energy annually. Energy consumption in hospitals and healthcare facilities is influenced by many factors including the type and the year of construction of their buildings, their capacity in beds, the local climate, the gross domestic product (GDP) of the country, the number of employees, the type of the hospital and the services offered, the machinery and medical equipment used as well as the energy behavior of the staff and the patients.

TABLE II: BREAKDOWN OF THE OPERATIONAL ENERGY CONSUMPTION IN HOSPITALS [2]

Sector	%, of total energy consumption
Space heating	29
Space cooling	11
Ventilation	12
Water heating	11
Lighting	9
Cooking	7
Refrigeration	3
Office equipment	2
Computers	5
Others	11
Total	100

TABLE III: BREAKDOWN OF THE OPERATIONAL ENERGY CONSUMPTION IN HOSPITALS [45]

Sector	%, of total energy consumption
HVAC	30
Domestic hot water	28
Lighting	15
Equipment	1
Cooking	10
Refrigeration	1
Others	15
Total	100

Old hospital buildings that had been constructed when the building regulations did not require advanced thermal insulation have poor energy performance compared with new hospital buildings that have been constructed recently and have better thermal insulation. The most existing hospital buildings have been constructed before the concept of nearly zero energy buildings was introduced. The current building regulations require that all new buildings should have low energy consumption, high energy performance and low environmental impacts. It is foreseen that before 2030 hospitals should zero their net carbon emissions due to energy

use eliminating gradually the use of fossil fuels and the emissions of GHGs. Achieving this target requires the use of low or zero carbon emission fuels and technologies as well as the radical transformation of their existing energy systems. The breakdown of the operational energy consumption in hospitals in various countries according to the published research is presented in Table II and III.

IV. USE OF SUSTAINABLE ENERGY SYSTEMS IN HOSPITALS

Hospitals utilize mainly fossil fuels and grid electricity while the use of renewable energies and low carbon emission technologies in their premises is rather limited. The current necessity to mitigate climate change requires the decrease in hospital's energy consumption and the replacement of conventional energy fuels used so far with clean energy sources and technologies with low or zero climate impacts. Various renewable energies can be used in hospitals for heat, cooling and electricity generation including solar energy, wind energy, solid and gaseous biomass as well as geothermal energy. Various low carbon emissions energy technologies can be also used including CHP systems, fuel cells, heat pumps and district heating and cooling systems. Application of benign energies increase hospital's resilience to extreme and unusual weather events promoting their adaptation to climate change. Their use depends on their availability at or nearby the hospital's location, on the feasibility of installing them at their premises, on existing legal regulations as well as on the economics of their use. In general application of sustainable energy systems in hospitals is desirable and attractive resulting in economic, environmental and social benefits. Their use helps them to reduce their climate footprint due to energy use, to increase their energy resilience and to comply with current regulations and global targets regarding climate change mitigation. Future retrofitting of the old and energy inefficient hospital buildings, transforming them to nearly zero energy buildings or/and to net zero carbon emission buildings, requires scientific and technological support from energy experts as well as availability of the required financial resources. Fortunately, various financial tools and mechanisms have been developed and used so far as well as specialized energy service companies (ESCOs) offering advice and support in hospital's energy renovation. The implementation of sustainable energy projects in hospitals is facilitated with energy performance contracting that is a one-stop shop approach in the design, realization and monitoring of the required clean energy investments. Some characteristics of three sustainable energy systems that can be used in hospitals reducing their carbon footprint are presented in Table IV.

TABLE IV: CHARACTERISTICS OF SOME SUSTAINABLE ENERGY SYSTEMS USED IN HOSPITALS

Energy system	Fuel used	Energy generated	Carbon emissions at hospital's site	Commercial use in hospitals	Energy efficiency
Solar-PV panels	Solar energy	Electricity	No	Yes	15-20%
CHP system	Natural gas, biogas, solid and liquid biomass resources	Electricity, heat, cooling	Yes	Yes	80-95%
Heat pump	Electricity and ambient heat	Heat, cooling	No	Yes	250-400%

V. USE OF SOLAR PHOTOVOLTAICS

Solar energy can be used for electricity generation either with photovoltaic technology or with solar thermal technology. Solar-PVs are broadly used to day in small, medium and large-scale systems for power generation while their use has been accelerated due to sharp decrease in their prices during the last ten years. The profitability of solar-PV technology depends on the value of solar irradiance while in areas with high annual solar irradiance their use is very attractive. The technology is reliable, mature, well-proven and cost-efficient. Solar-PVs can generate electricity for at least 25 years although the generated electricity is slightly reduced annually. Their use increases the energy security and resilience in hospitals since they do not depend on grid electricity but on a local benign renewable energy resource. The requirements for maintenance are low while solar electricity generation does not produce any atmospheric emissions. Hospitals usually cover their power requirements with grid electricity while in areas without electric grid's infrastructure they often use diesel generators with back-up batteries. Generation of solar photovoltaic electricity is attractive for them provided that the solar irradiance at hospital's site is satisfactory. Their use has many economic and environmental benefits while it can help in their clean energy transition reducing or zeroing their net carbon footprint due to energy use. Various solar-PV systems have been already installed in many hospitals worldwide located either in areas with existing electric grids or in areas without grid's infrastructure. Taking into account that hospitals consume approximately 2.5 times more energy than other buildings the use of solar-PV systems can reduce their annual electricity bills allowing them to invest more funds on patients' care. Solar-PV systems can be combined with other low or zero carbon emission energy technologies, like wind turbines and co-generation systems, covering the most or even all of their annual electricity requirements. They can provide "green electricity" to high efficiency heat pumps that produce heat, cooling and hot water. In developing countries, including sub-Sahara countries in Africa with limited electric grid's infrastructure, solar-PV systems consist of a reliable and cost-efficient energy technology providing reliable electricity to healthcare facilities and hospitals replacing the use of diesel generators. These systems utilize the local renewable energy resources avoiding the consumption of imported fossil fuels. Stand-alone solar-PVs are accompanied with electric batteries that store electricity which is required in hospitals when the solar irradiance is low or during the night. Solar-PV systems can be installed on-site or off-site the hospital. They can be placed on the terrace of the buildings or on the rooftop of the carparks. They can also be placed

vertically on the building's facades while semi-transparent solar panels can be integrated into the building envelope generating electricity and providing thermal and optical benefits. The efficiency of solar-PV cells is in the range of 15-20% that is relatively low compared with the efficiency of other benign energy technologies.

VI. USE OF CHP SYSTEMS

Heat and power co-generation (CHP) systems are energy generating systems that co-generate simultaneously heat and power from the same machine. They can cover part or all of the heating and electricity needs of consumers, including hospitals, while nowadays they find extensive applications in many sectors including hotels, hospitals, large-scale buildings as well as in industry and agricultural greenhouses due to their advantages. Apart from heat and power generation they can co-produce cooling, that is also required in hospitals, using thermal absorption chillers operating as tri-generation systems. Hospitals are ideal candidates for using these efficient energy systems since they operate continuously, 24/7, all over the year consuming both heat and electricity. CHP systems can provide continuously and reliably space heating, steam, domestic hot water and electricity in a cost-efficient way. Their overall energy efficiency is high, at 80-85% or even at 90%, while they reduce the environmental impacts due to energy use. CHP systems encompass different energy generation technologies co-producing heat and electricity including internal combustion engines, gas turbines, micro-turbines, fuel cells, and Stirling engines. The most common fuel used in CHP systems is natural gas while other systems consume light or heavy oil or even coal. They can also utilize biomass like agricultural and forest residues, by-products and wastes, bioethanol, bio-diesel or biogas produced from various organic wastes. The use of CHP systems in hospitals is currently increasing due to their economic and environmental benefits. Their reliability is high while they can provide heat and electricity during severe storms and disasters increasing their resilience in extreme weather events. CHP systems include various types of machines that are categorized as:

- Gas turbines,
- reciprocating engines, and
- steam turbines

They also include small-size packaged CHP units including:

- Gas engines CHP,
- Small-scale gas turbine CHP

Large turbines are widely used in large-scale modern CHP plants. Their sizes vary from 1 MW to 200 MW. They are very reliable systems while their maintenance is minimal.

They can operate continuously at optimum efficiency achieving annual availability at 94-98%. They can also provide high grade heat while the usable heat to power ranges from 1.5:1 to 3:1. The most popular fuel used in these systems is natural gas while light oil fuel, biogas and landfill gas can be also used. The electric efficiency of gas turbines ranges from 20% to 35%. The reciprocating engines used in CHP systems are internal combustion engines that operate on the same principle as the petrol and diesel automotive engines. They are energy efficient engines that can achieve annual availability at 85-92%. There are two types of reciprocating engines used in CHP systems:

- Spark-ignition gas engines with size up to around 4 MW operating on gaseous fuel only, and
- Compression-ignition (diesel) engines that are available at power outputs of up to 15 MW operating on light oil fuel, heavy light fuel or a mixture of gas and oil. The efficiency of reciprocating engines is higher than that of gas turbines while the heat to power ratio ranges from about 1:1 to 2:1.

The steam turbines are important CHP options because they can use the energy derived from any fuel – solid, liquid or gaseous. The fuel is burnt in a boiler and the produced high-pressure steam is then “let down” through the turbine generating electricity and providing also lower pressure steam or hot water for site use. Steam turbine CHP systems are very reliable and capable of achieving long-term availability of up to 99%. Steam-turbine CHP has more limited applications than gas turbines and engine-based systems. The ratio of useable heat to power in steam turbine CHP plants is unlikely to be less than 3:1 and may be 10:1 or even more. Taking into account the increased use of electricity in various sectors steam turbines have limited applications. Combined cycle systems are usually gas turbine systems allowing the heat produced to be reused generating steam at high pressure and temperature. The steam can generate additional electricity and heat. These systems can convert 40% or more of the original fuel energy into electricity. The characteristics of several CHP systems are presented in Table V.

TABLE V: CHARACTERISTICS FOR TYPICAL CHP SYSTEMS [46]

	Reciprocating engines	Gas turbines	Micro-turbines	Steam turbines
Electrical efficiency	30-42	24-36	25-29	5-7
Overall efficiency	77-83	65-71	64-72	80
Installation cost (\$/KW)	1,400-2,900	1,300-3,300	2,500-3,300	670-1,100
O+M cost (¢/KWh)	0.9-2.4	0.9-1.0	0.8-1.6	0.6-1.0

VII. USE OF HEAT PUMPS

Heat pumps are heat and cooling production devices that are currently used in many sectors including hospitals. They are capable to generate three or more times more heat and cooling compared to the electricity consumed achieving an energy efficiency significantly higher than other heating and cooling systems. Their use in hospitals is increasing while they are capable to cover part or all of their requirements in

air-conditioning and hot water production. Heat pumps can be categorized according to the system that are installed as follows.

a) Air source heat pumps

In these systems heat is extracted from ambient air drawn across its heat exchanger. Source temperature is very much dependent on prevailing ambient temperature and varies through the year depending on geographic location.

b) Ground source heat pumps

In this type of heat pumps a closed pipe-work loop of water solution is buried in the ground either vertically via boreholes or horizontally in trenches and the heat pump is used to extract the heat.

c) Water source heat pumps

Typical systems include closed loops consisted of a close pipe-work loop of water solution that is sunk into a river, lake or the sea.

VIII. FINANCING AND IMPLEMENTING CLEAN ENERGY PROJECTS IN HOSPITALS

Hospitals are frequently energy inefficient organizations requiring energy refurbishment. Financing energy investments is important for the implementation of clean energy projects in hospitals. Taking into account that frequently hospitals either they do not have the necessary financial resources or they do not want to spend them in implementing clean energy projects in their premises the best option for their funding is through Energy Performance Contracting (EPC). This is a scheme that allows in a third party with the necessary expertise in energy issues, like an Energy Service Company (ESCO), to realize the project as a turnkey solution. ESCOs finance the energy projects either using their own financial resources or using external financial tools and resources including:

- hospitals' own funds,
- bank loans,
- public funds, including governmental subsidies, focused on this type of investments,
- energy cooperatives,
- crowdfunding
- external donors and charities, and
- other types of funds that might be available

Usually, different financing tools are combined to assist in the implementation of clean energy projects in hospitals. The funds for clean energy investments can be internal, external or mixed. The financial risk should be evaluated and reduced. Taking into account that clean energy investments result in social and environmental benefits public support is frequently offered. Involvement of ESCOs through EPC in the realization of energy projects is an excellent solution for their successful implementation taking into account that hospitals do not have the required expertise in energy issues neither the skilled staff that is required in the design, evaluation, supervision, monitoring and maintenance of these projects.

IX. ADVANTAGES AND DRAWBACKS CONCERNING THE USE OF THE ABOVEMENTIONED LOW CARBON ENERGY TECHNOLOGIES IN HOSPITALS

The use of the abovementioned three sustainable energy

systems in hospitals results in many benefits including:

- a) The energy consumption in hospitals is reduced due to the use of high efficiency energy technologies like CHP systems and heat pumps as well as solar-PV panels,
- b) The annual consumption of fossil fuels in hospitals is decreased as well as the CO₂ emissions due to energy use. This improves hospital's environmental sustainability complying with the global targets for climate change mitigation,
- c) These technologies are mature, reliable, well-proven and cost-efficient. Their use reduces the energy cost in hospitals,
- d) Clean energy investments in hospitals have positive social impacts in the local societies increasing the local growth and creating new local jobs,
- e) Installation of CHP systems in hospitals offers undisruptive reliable electricity and heat assisting them to continue their operation in cases of extreme and unexpected weather events and catastrophes promoting their resilience and the adaptation to climate change,
- f) Improve the energy performance and rating in hospital's buildings.

The drawbacks related with the use of these energy technologies in hospitals include:

- a) Implementation of clean energy investments in hospitals is not a high priority since they are focused on patient's treatment,
- b) There are various difficulties in financing clean energy projects in hospitals particularly with own financial resources,
- c) The necessary know-how and the qualified energy experts required to design and implement the clean energy investments are not usually available in hospitals.

X. DISCUSSION

Our results indicate that the use of the abovementioned sustainable and low carbon energy technologies in hospitals is technically, economically and environmentally feasible and attractive. Their application increases the energy efficiency in healthcare organizations reducing their carbon footprint. They also indicate that using existing reliable energy technologies in their premises can obtain economic and environmental benefits contributing in the global efforts for climate change mitigation. Usually, it is advisable that hospitals should try first to reduce their energy consumption either with better thermal insulation of their buildings or with the use of modern and energy efficient lighting, equipment and machinery. Hospitals are energy intensive organizations utilizing mainly fossil fuels and grid electricity while in the future era of net zero carbon economy they should modernize their energy infrastructure improving their energy and environmental performance. Use of distributed energy generation technologies, like solar-PVs and CHP systems, in their premises increase hospital's resilience in extreme and unexpected weather events while it promotes their adaptation to climate change. Our results can help healthcare organizations to lower the energy consumption and carbon emissions in their buildings using clean and efficient energy technologies complying with current regulations for transforming their premises to nearly zero energy buildings

and/or net zero carbon emission buildings. The use of the abovementioned technologies can significantly reduce hospital's carbon emissions due to energy consumption while the use of a carbon offsetting scheme could allow them to remove any remaining carbon emissions in a cost-efficient way. Often carbon offsetting is the cheapest option for removing any remaining carbon emissions, achieving complete decarbonization in hospitals, compared with the additional use of clean energy technologies. Although financing clean energy investments in health care facilities is an important and difficult issue various financial tools have been developed to facilitate the implementation of sustainable energy projects in them. The previously mentioned low carbon energy technologies are mature, reliable, well-known and cost-efficient while they can be used in hospitals to lower their dependence on fossil fuels and to increase their resilience adapting them to climate change. Our results do not evaluate the profitability of these sustainable energy technologies neither estimate the carbon emissions savings achieved with their use. Further research should be focused on the examination of using different renewable energy and low carbon emission technologies, including solar thermal energy, biomass, fuel cells, district energy systems, in hospitals and healthcare facilities.

XI. CONCLUSIONS

The possibility of using various sustainable energies in hospitals, including solar-PV panels, CHP systems and heat pumps has been investigated. Hospital buildings have high specific energy consumption compared with other commercial or residential buildings while they mainly use conventional energy sources and fuels. The necessity for climate change mitigation requires the replacement of the fossil fuels currently used with low or zero carbon emissions renewable energies and other sustainable energy technologies. Present research indicates that hospitals can use solar photovoltaic systems for electricity generation, CHP systems co-generating heat and power and heat pumps producing heat and cooling. These technologies are reliable, mature, well-proven and cost-efficient while there are already used in various hospitals. Their use, combined with the use of other renewable energy technologies, reduces environmental impacts transforming them to nearly zero energy hospitals with low atmospheric carbon emissions due to energy use. Their use also contributes in the adaptation of healthcare facilities to climate change increasing their resilience in extreme weather events. Improvement in hospital's environmental sustainability requires investments in modern low or zero carbon emission energy technologies. Various financial mechanisms and tools, using both private and public funding, have been developed so far to facilitate the sustainable energy investments since frequently hospitals do not have the necessary own capital to finance these clean energy investments. Therefore, the use of the previously mentioned clean energy technologies in hospitals has many positive internal and external economic, social and environmental impacts.

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