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Research Article

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Energy performance of healthcare facilities in 3 climatic zones in Cyprus

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Abstract. Safeguarding affordable and energy-efficient medical services has emerged as a crucial necessity to sustain national healthcare systems, especially in view of the current pandemic. While a set of national standards and guidelines aim to set minimum energy requirements for the building facilities, more insight into the healthcare sector's energy consumption in Cyprus is deemed necessary, since it is the 4th most energy-demanding sector per square meter in this country. This is the first extended research on energy consumption in healthcare facilities across the different climatic zones of Cyprus and the types of fuel favoured in each zone, which marks the novelty of this work. The findings of the study highlight that the coastal and inland climatic zones are the most energy-challenging regions, with more than 60% of the final energy needs covered by electricity. On the contrary, in the mountainous region, approximately 80% of the final energy needs are covered by oil and attributed mainly to heating purposes. The average national primary energy consumption of healthcare facilities was found to be 497 kWh/m^2 in air-conditioned spaces. Therefore, this study highlights that the mean primary energy consumption per building surface is approximately 4 times higher than the national threshold for nZEBs; compelling critical consideration of intervention for their energy enhancement. Moreover, healthcare facilities in mountainous regions in Cyprus are heavily reliant on conventional fuel; an unreliable and highly polluting energy option. The work demonstrates the prominent challenge and high potential for energy retrofit of the examined facilities and their upgrading to nZEB-Hospitals, towards the endeavour to a climate-neutral energy transition.

Keywords: Healthcare / energy consumption / energy cost / nZEB-Hospitals

1 Introduction

The continuously increasing energy consumption patterns in the buildings sector and the consequent release of greenhouse gas emissions pose alarming threats to environmental health and sustainability of cities and surrounding areas [1]. The building sector is responsible for 40% of the EU's energy consumption and 36% of greenhouse gas emissions [2]. Non-residential buildings account on average for 25% of the energy consumption for Europe's building stock, representing a heterogeneous sector compared with the residential [3]. Hospitals have large ecological footprints; they consume large amounts of energy and release potentially harmful pollutants [4–7]. In light of the ongoing health crisis, their role has never been more important. According to the World Health Organisation, the potential economic benefits of improving the health sector's climate footprint are significant [8]. In recent years, health systems around the world have seen their budgets shaken by volatile energy prices. The cost of fossil fuels promises to increase further in the years to come, so conservation, efficiency and alternative energy measures will carry long-term financial benefits [8]. The challenge to provide affordable and appropriate healthcare to more than 10 billion people on an ecologically stressed planet is urgently calling for action to make healthcare facilities greener and in line with the principles of sustainability [9]. If anything, the recent public health crisis has revealed that the lack of preparedness has been a major contributor to the struggles experienced by medical service providers around the world [10]. At the same time, the endeavour to decarbonize the buildings' sector in the EU calls for environmentally friendly models of construction, refurbishment and operation of hospitals. Therefore, the healthcare sector is summoned to rise to a dual challenge: meeting increased demand for health services while decreasing the voracious patterns of energy consumption in hospitals [11].

Although hospitals and medical facilities offering healthcare services are major energy consumers, accurate and informed data relating to consumption is largely lacking, especially when it comes to open-source platforms.

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For this reason, studies are primarily presenting case studies with a national focus. For instance, one of the early investigations of energy consumption in medical buildings comes from Australia, where three institutions were examined and main drivers of energy consumption were identified [12]. Petrovic et al. conducted an extensive overview of the literature regarding energy consumption of hospitals in Europe and compared them with respective on-site data recorded in Serbia [13]. According to the study, the mean energy consumption in European hospitals ranges between 290 kW/m^2 (in Sweden and Belgium) and 555 kW/m^2 (in the Netherlands) [13].

Subsequent research focused on assessing the energy performance of existing healthcare facilities and benchmarking, something which allows for comparisons among case studies in national and international contexts [14,15]. For instance, Li et al. (2021), employed three benchmarking modelling methods to analyse information on energy consumption and building features for a number of public hospitals in Shanghai; an approach suggested in cases of scarce data [16]. Studies where data was readily available also have dealt with benchmarking following different methodologies; for instance, an Italian case study used energy audit information and national standards to define indicators applicable to the private healthcare sector of Italy [17].

A recent review study highlighted the importance of thermal comfort both in patient recuperation and in energy-efficient management of resources in hospital buildings [18]. Furthermore, Fotovatfard and Heravi (2021) developed a number of key performance indicators and determined that energy savings, improved functionality and reduced maintenance costs are interlinked, with some of the most prominent factors being the replacement of old appliances and preventative maintenance [19]. The overall potential for reducing the energy footprint of the healthcare sector is further highlighted through a number of cases around the world that succeeded reducing the energy consumption of hospitals by installing solar water heaters and solar lighting to illuminate hospital grounds [8]. Moreover, the role of energy services in hospitals is addressed in Prasad et al. (2022), who compared the environmental footprint of different units of a single facility using lifecycle analysis. Their results reveal that emissions produced both in low- and high-intensity in-patient care are largely owed to energy consumption, indicating that decarbonisation of hospital energy sources should be prioritised [20].

Finally, in terms of examining the energy performance of buildings in specific climatic conditions, William et al. (2020) presented retrofitting strategies that consider the hot and humid climate of Alexandria, Egypt, and Cyganska et al. (2021) assessed the effects of different climatic zones on the electrical and thermal energy costs [21,22]. The former adopted a simulation approach while the latter used financial and resource information and found that facilities in warmer climates are characterised by higher energy consumption. Dimoudi et al. (2022) also examined the energy consumption of hospitals in Greece according to climatic characteristics of the region. In their study, energy consumption in northern areas of Greece (where climate is cooler) is higher than the rest of the country and attributed to elevated heating needs [23].

Concluding the state of the art analysis, an arsenal of different studies has been presented to showcase that healthcare facilities are a major energy drain, in international and national contexts. Attention is therefore drawn on the pressing need to study energy consumption patterns in such complex buildings, in order to identify best practices proficient capable of reducing their environmental footprint and achieving the untapped energy savings potential hospitals have. The main objective of this research is bridging the knowledge gap on the energy consumption patterns of healthcare facilities in different climatic conditions, focusing on the island of Cyprus, in the Eastern Mediterranean Region.

1.1 The healthcare sector in the case of Cyprus

In Cyprus, the vast majority of the national building stock was built prior to 2007, before the first normative energy requirements were established, making this sector a major energy consumer and greenhouse gas emitter [24,25]. The health provision sector is amongst the highest consumers in terms of total energy demand and energy demand per square meter; therefore, holding a great potential for energy savings [26]. A recent study investigated 83 public and private hospitals and health centres of an average area of 17,354 m^2 and estimated that the average national final energy consumption of healthcare facilities in Cyprus is 386.30 kWh/m^2, while the average final energy consumption of public hospitals rises to 509 kWh/m^2 [26]. This indicates the great potential of energy savings that lays within the public and private healthcare sector. Both in public and private hospitals, primary energy consumption can be reduced significantly if a nearly zero Energy refurbishment is implemented [27].

The healthcare system in Cyprus has been state-funded since 1957, when the island was a British colony, and propositions for universal health care under a General Health System (GHS) have been underway since 1992. These were only materialised in 2019, almost three decades later and as from the beginning of 2021, the GHS in Cyprus has not been fully realised. It is therefore evident that citizens have been relying on private healthcare services and facilities, making the private sector equally significant as public amenities. Public health services are offered by 6 general hospitals, 3 specialized centres, 2 rural hospitals and 39 health centres, as well as many sub-centres for the provision of primary health care services [28]. Services are also offered privately through 74 hospitals, polyclinics and diagnostic centres, all profit organisations.

This work presents energy data from the current state of 28 hospitals (public and private) and health centres in different climatic zones in Cyprus, analysing energy consumption trends under different climatic conditions and for different types of facilities. Meteorological regional characteristics, geography, ground morphology, as well as altitude and distance from the sea, determine climatic variations in Cyprus. These parameters therefore affect outdoor ambient temperature and humidity conditions and consequently, energy consumption of buildings. Four climatic zones are distinguished; i.e. Coastal (CZ1), Inland (CZ2), Semi-Mountainous – elevation <600 m (CZ3) and Mountainous – elevation >600 m (CZ4) [29]. Buildings in mountainous regions were found to have generally three times higher heating demand and seven times lower cooling demand than other zones [30]. Moreover, the high humidity levels in coastal areas of Cyprus demand strategies of mechanical ventilation (air conditioning) to improve thermal comfort conditions [29].

In order to effectively plan and implement an environmentally responsive and energy-efficient strategy, a thorough understanding and mapping of the current energy consumption of the existing healthcare building stock should be performed; a gap which is partially filled by this work in the case of Cyprus. The focus is mainly on the total final and primary energy consumption per surface area and/or heated area and the type of energy fuel. The subsequent section presents the detailed methodology adopted to carry out this investigation, and it is followed by results and discussion, ultimately concluding on the prospects of energy refurbishments in healthcare facilities in Cyprus.

2 Methodology

2.1 The case study area

Cyprus is located at the Eastern Mediterranean Sea and can be characterised by three climatic zones, as presented in Figure 1. The average daily minimum and maximum temperatures of representative regions for each climatic zone can be observed in Table 1. Here, the distinction of zones albeit the island's small scale becomes clear, since the mountain region can be significantly cooler, up to 11°C in winter and 10°C in summer. As a result, it is expected that buildings located in mountainous settings have higher heating energy demands in winter and lower cooling demands in summer.

2.2 Selection criteria and performance indicators

A representative sample of 28 public and private healthcare facilities was selected across 3 healthcare districts: (a) Nicosia, (b) Larnaca and Famagusta, (c) Limassol and Paphos, located in different climatic zones (Fig. 1). The selection criteria of the facilities were based on the climate characteristics of the location, the size of the facility (in order to assure representation of large, medium and small-size facilities), the type of the facility (Hospital or Health Centre), as well as the management authority of the facility (publicly or privately owned). More specifically, for the purposes of this study, the selected healthcare facilities are the following:

- GH – General Hospitals: Publicly owned hospitals that offer a variety of specialisations, as well as inpatient care, located in urban areas.
- RH – Rural Hospitals: Publicly owned hospitals that offer a variety of specialisations for inpatient and outpatient care and are located in rural areas. RHs are usually smaller in size than GHs.

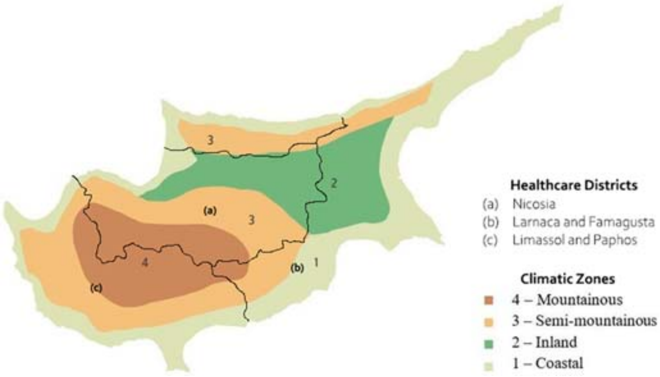

Fig. 1. Map representing the three healthcare districts of Cyprus and the climatic zones of Cyprus.

- HC – Health Centres: Publicly owned community healthcare facility that offer outpatient services. HCs serve remote communities and areas in the outskirts of urban centres.
- PH – Private Hospitals: Privately owned hospitals that offer a variety of specialisations and are located in urban areas. They are divided into General PHs and Specialised PHs.

A set of generic and energy-related data were collected in collaboration with the State Health Services Organization (SHSO), the Cypriot Association of Private Hospitals, the Electricity Authority of Cyprus (EAC) and each institution's administrative staff. The generic data concerned information such as: the total and air-conditioned surface area, year of construction, operation schedule and number of patients and staff. The retrieved energy data concerned the monthly energy consumption and energy cost for two years (2018 and 2019).

The energy data analysis is focused on the total and primary energy consumption per surface area (kWh/m^2). The study assesses conventional fuel types, such as electricity, liquid petroleum gas (LPG) and oil, while the incorporation of RES was not considered. The healthcare facilities' consumption is further discussed by size and the services provided. As there is only one selected case located in the Semi-mountainous zone (CZ3) at a location very close to the inlands (CZ2) where the climatic differentiations between the two zones are nominal (Tab. 1), those two zones are merged and discussed together for the purposes of the overview characteristics but discerned in the energy consumption overview and the comparative analysis.

The limitations of the study concern the availability of data, especially as far as the public health institutes are concerned, as no record of the energy bills was held by the State Health Services organization (SHSO). Additional parameters that were impeding the collection of data across facilities were the lack of a central management reference point for the HVAC installations and the lack of a database with architectural documentation containing data on the

Table 1. Minimum and maximum temperatures for the three climatic zones. Source: adapted from [29].

Zone	Temp (C)	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
CZ1 - Coastal (Limassol)	Mean daily max	17.6	17.8	20.0	22.9	26.9	30.8	33.2	33.3	31.3	28.6	23.5	18.9
	Mean daily min	8.8	8.5	10.4	13.0	16.7	20.1	22.4	22.7	20.6	17.7	13.5	10.1
CZ2 - Inland (Nicosia)	Mean daily max	15.5	16.2	20.1	24.2	29.6	34.6	37.8	37.1	33.4	28.7	22.5	17.2
	Mean daily min	5.4	5.7	7.8	11.0	15.4	20.2	22.8	22.4	19.2	15.7	10.7	7.3
CZ3- Semi-mountainous (Lythrodontas)	Mean daily max	14	14	17	23	28	32	35	35	32	27	20	15
	Mean daily min	4	4	6	9	13	18	21	20	18	14	9	6
CZ4 - Mountainous (Prodromos)	Mean daily max	6.3	6.6	10.3	15.1	20.5	25.0	28.1	27.9	24.4	19.6	12.8	8.0
	Mean daily min	0.7	0.3	2.8	6.3	11.1	15.2	18.4	18.2	14.9	11.3	6.2	2.5

building surface area and layout, construction materials and year of construction (especially in the cases of small and medium-size health centres in suburban areas). Actions are being taken by SHSO in the direction of data collection and availability.

3 Results

3.1 Overview of the buildings' characteristics

Among the 28 healthcare facilities under study, 12 are located in the coastal zone (CZ1), 11 in the inland zone (CZ2), 1 in the semi-mountainous zone (CZ3) and 4 in the mountainous zone (CZ4). Approximately half of the sample regards public facilities, i.e., 7 General Hospitals (GHs) and 6 Health Centres (HCs); while 15 Private Hospitals (PHs) were also selected (specifically, 4 Specialized and 11 General PHs). Despite the fact that the number of private facilities outweighs the public ones, the total building surface area (m^2) of the private facilities (53,224 m^2) is less than a third of the corresponding surface area of the public facilities (193,175 m^2), due to the large size of public GHs.

From the facilities under study, the average size of a public General Hospital is around 36,000 m^2, Rural Hospitals are approximately 4200 m^2 and Health Centres 740 m^2. Regarding the private sector, sizes of surface area ranges from 360 to 9400 m^2, averaging 3684 m^2. As most of the population is located along the coast, the coastal zone CZ1, gathers the majority of the healthcare facilities. The inland region, i.e., CZ2, where the capital of the island is located, is the second most populated region.

As observed in Figure 2, the building surface area of the selected facilities in CZ2 is the largest, which is associated with the size of the hospitals in the particular climatic zone. Specifically, the General Hospital of Nicosia alone covers approximately 90,000 m^2 of spaces, whereas CZ 4 comprises of a few small-scale Health Centres and a Rural Hospital.

3.2 Energy consumption

3.2.1 Overview of national final and primary energy consumption

According to the energy data of the selected healthcare facilities in each climatic zone, assessments for each energy type (electricity, oil) were retrieved. Specifically, oil and electricity are used in all climatic zones. In the coastal and the jointly studied inland and semi mountainous regions, the principal energy fuel used is electricity. In mountainous (CZ4) the main source of energy is oil. Specifically, 64% of the final energy needs in coastal (CZ1) are covered by electricity and 36% by oil. The corresponding values in CZ2 & CZ3 are 62% of electricity and 38% for oil. Respectively, in CZ4 only 21% of the energy needs are covered by electricity and the remaining 79% by oil (Fig. 3). It is worth noting that although the inland (CZ2) and the semi-mountainous zones (CZ3) are jointly presented in Figure 3, the energy consumption per energy use corresponds primarily to the inland zone (CZ2), which accounts for 11 case studies, as opposed to the single semi-mountainous

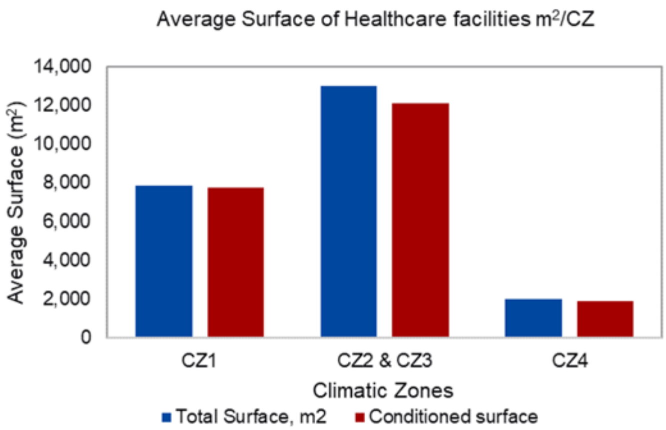

Fig. 2. Average building surface area of healthcare facilities under study in each climatic zone (m^2).

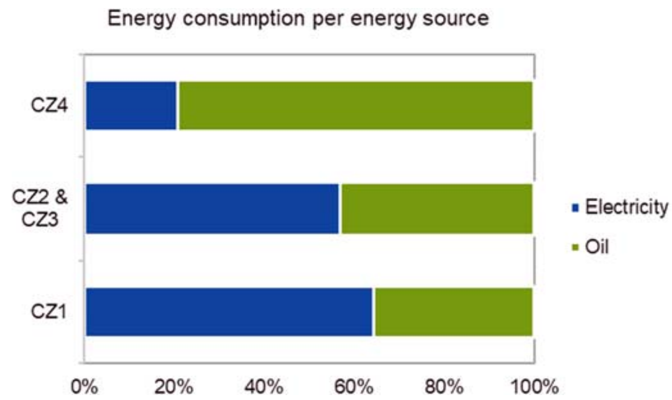

Fig. 3. Percentage of energy consumption per energy source in each climate zone.

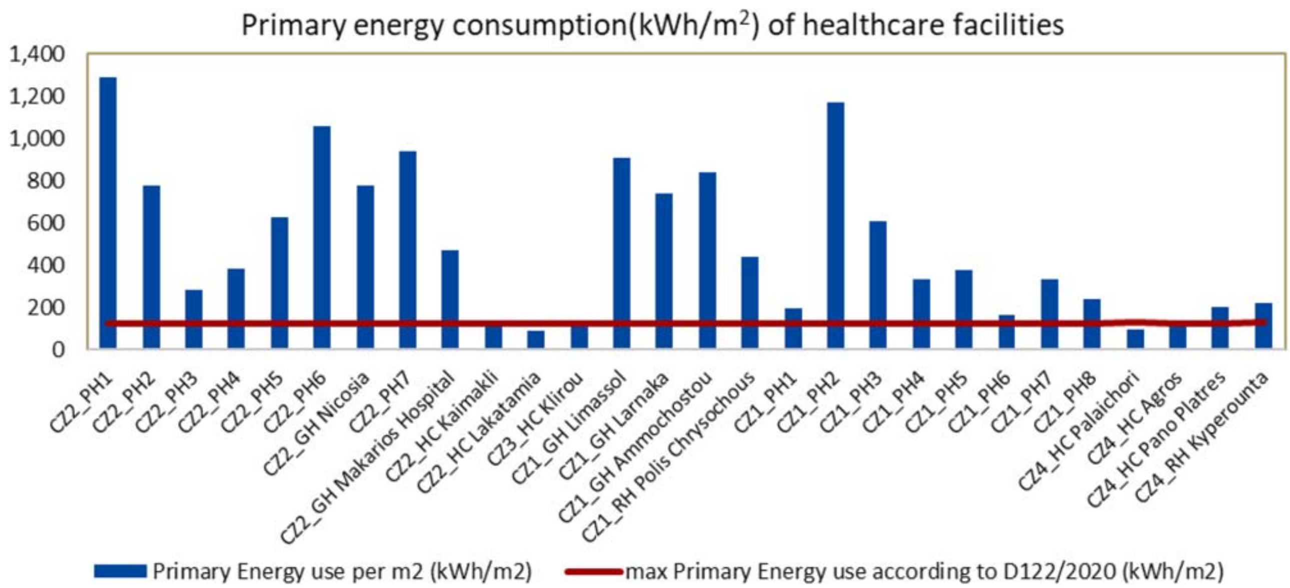

Fig. 4. Primary energy consumption (kWh/m^2) of the healthcare facilities compared with the national nZEB threshold.

case included in this study (CZ3). In fact, the collective energy data indicate that in the latter zone, oil is mainly used to cover heating requirements.

The average final energy consumption of all the investigated facilities is 233 kWh/m^2 of conditioned surface area and the primary energy consumption is 497 kWh/m^2. Excluding Health Centres, which have different operating schedules, the average final energy consumption rises to 277 kWh/m^2 of conditioned surfaces and the primary energy consumption to 598 kWh/m^2. Considering the energy consumption data reported in previous literature [13,23], this range is close to other European countries, such as Slovenia, Spain and France.

According to the national regulation on the energy consumption thresholds for nearly zero energy buildings (nZEB), Decree 122/2020 [27], non-residential buildings may consume up to 125 kWh/m^2/annual primary energy (excluding any consumption related to equipment). An overview of the registered primary energy consumption of the facilities under study over the national nZEB threshold is presented in Figure 4. As observed, the facilities that are close to this target are mainly Health Centres, which are small-scale facilities with no inpatient care and represent a small share of the total facilities in total building surface. Considering that the mean primary energy consumption of the rest of the examined facilities (mainly hospitals) is 598 kWh/m^2, which is approximately four times higher than the national threshold for nearly energy buildings, the immense energy savings potential of the healthcare sector is clearly demonstrated here.

3.2.2 Comparative analysis

3.2.2.1 Type of facility

Figure 5 presents a comparative analysis of Private Hospitals (PHs) and Health Centres (HCs), with similar

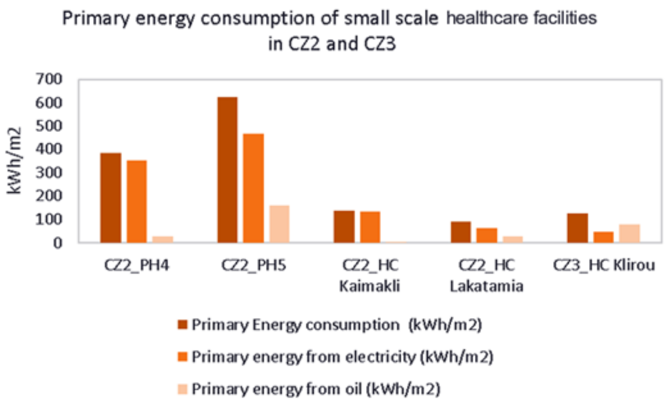

Fig. 5. Primary energy consumption of small-scale healthcare facilities.

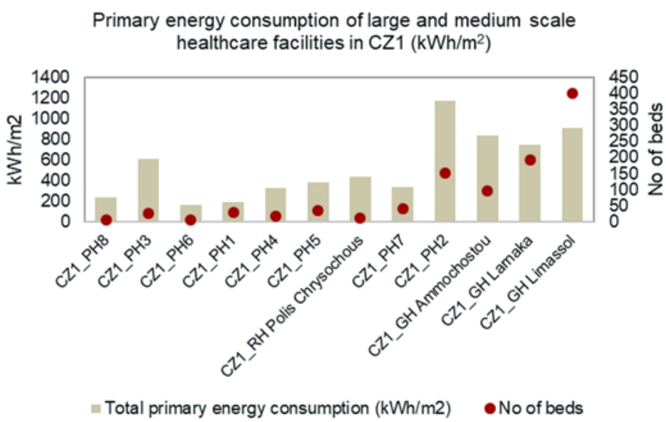

Fig. 6. Primary energy consumption of hospitals related to size and number of beds in CZ1.

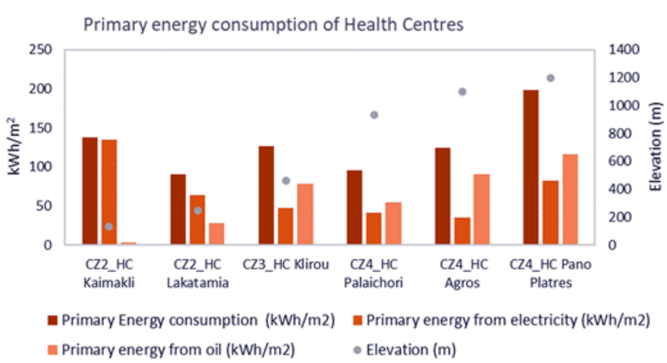

Fig. 7. Primary energy consumption (kWh/m^2) in Health Centres located in different climate zones.

building surface area, located in CZ2 and CZ3. The PHs and the HCs offer different services, as well as operation schedule (PHs work on a 24/7 basis whereas HCs operate only on weekdays for approximately 5 h). Considering the type of facility, PHs which operate throughout the day and offer services such as surgeries, kitchen and laundry in support of inpatient care, consume more than double the energy than Health Centres in the same climatic zone.

3.2.2.2 Size of facility

Excluding the 6 small-scale Health Centres from the sample, the average overall energy consumption per conditioned surface area rises as the number of beds increases. Specifically, the average final energy consumption of public and private Hospitals is 277 kWh/m^2 of conditioned surface areas and the primary energy consumption is 598 kWh/m^2. Figure 6 presents the primary energy consumption of Private Hospitals (PH) and General Hospitals (GH) in the coastal zone (CZ1). The facilities under investigation have approximately the same operation schedule (24/7) and services, yet they vary in terms of conditioned building surface area and number of beds. As it is observed and illustrated in Figure 6, the primary energy consumption per surface area is significantly larger when the number of beds exceeds 50.

3.2.2.3 Climatic characteristics

A comparative analysis of selected Health Centres in different climatic zones is observed in Figure 7; representing CZ2, CZ3 and CZ4. The HCs have similar operation schedule and services, providing attendance only during the day (no provision for overnight stay).

As the altitude of the facilities' location increases, i.e., from the Inland Climatic zone (CZ2) climbing up to the Semi-Mountainous (CZ3) and to the Mountainous climatic zone (CZ4), oil consumption prevails over electricity consumption, as oil fuel is primarily used for heating purposes in the mountains. Despite climate variations, the total primary energy consumption, ranging from 96 kWh/m^2 (HC Palaichori) to 199 kWh/m^2 (HC Pano Platres) cannot be certainly linked with the climate. In the mountains winters are harsh, temperatures drop below zero and evidently energy consumption (primarily oil) for heating increases. Nevertheless, in the lowlands, both coastal and inland, summers can be extremely hot with temperatures rising to over 40°C for prolonged periods of time, demanding high energy use for cooling by means of mechanical ventilation.

4 Conclusions

This study has evaluated a representative sample of 28 public and private healthcare facilities across 3 healthcare districts and different climatic zones; specifically, 7 public General Hospitals, 6 public Health Centres, and 15 Private Hospitals. According to the findings, the average national final energy consumption of healthcare facilities in Cyprus is 233 kWh/m^2 and the primary energy consumption rises to 497 kWh/m^2. Health Centres were found to have considerably lower levels of primary energy consumption per conditioned surface area compared to the General Hospitals, independently of the climatic zone. This is attributed to (a) the offered services (inpatient care, number of beds, kitchen, laundry and specialised energy-demanding equipment) and (b) the occupancy schedule of

General Hospitals, in comparison to the small-scale Health Centres. Excluding the small-scale Health Centres from the sample, the average final energy consumption of public and private Hospitals is 277 kWh/m^2 of conditioned surfaces and the primary energy consumption is 598 kWh/m^2.

Regarding the impact of climate on energy consumption, it is observed that consumption of oil fuel (per m^2) in the mountainous region, is greater than the respective inland facilities. This is linked with the increased heating needs in the climatic zone of the mountains which are mainly covered by oil (80% of the total energy consumption). Coastal and inland climatic zones are the most energy-demanding regions with more than 60% of the final energy needs covered by electricity. The higher consumption of electricity in these two zones could be attributed to their relatively higher temperatures during the summer, which result to higher cooling energy demand and consumption. Further investigation is needed to draw comprehensive conclusions on the impact of climate on energy consumption, considering key building parameters such as shape, orientation, layout, as well as the building envelope, which are significant to the energy consumption of buildings.

Bearing in mind that the national energy consumption threshold that applies to nearly zero energy buildings (nZEBs) of the tertiary sector is 125 kWh/m^2, excluding equipment related to energy consumption, the deviation rate of the mean primary energy consumption per m^2 of each examined healthcare facility is found to be 380%, i.e. approximately four times higher. This marks the great challenge of the energy-improvement interventions for enhanced energy-efficiency and upgrade of healthcare facilities to nZEB-Hospitals. This is particularly important for the inland zone, which is the most energy-demanding territory mainly due to the bigger number of healthcare facilities it encompasses and to the elevated cooling energy demands (resulting from the higher summer temperatures in this region).

This study is the first extensive research and attempt to create a database linking climatic, energy-consumption data, as well as building characteristics in the healthcare sector in Cyprus. The results contribute to raising awareness and highlighting the immense potential for energy savings that lies within the particular building stock. The findings of this research can be broadened with further research on the creation of a more inclusive and detailed dataset so as to investigate the role of other key factors affecting the hospitals' energy consumption. Additional parameters that should be investigated refer to the type of hospital (i.e., General, Rural or Private), building typology and construction parameters (e.g., thermal insulation, fenestration), occupancy schedules, heating and cooling systems, appliances and equipment, as well as incorporation of renewable energy sources and smart management systems.

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