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Heating ventilation and air-conditioned configurations for hotels an approach review for the design and exploitation

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Abstract

The tourism sector is one of the main worldwide economic sectors with sustained growth, demonstrating its strength and resilience. In this sector, energy uses have increased to ensure quality, guest comfort, and rate level requirements being a building with great energy consumption. Several factors influence and can produce a significant variation in hotel consumption even in facilities located in the same region; the difference in a four-star hotel can reach 114 kWh/m^2/year. This paper deals with related aspects such as hotel design, operation, type of service, occupancy patterns, operating point and efficiency of a heating, ventilation, and air conditioning (HVAC) system where 30 to 50% of the energy is consumed. Also, previous works based on the implementation of non-conventional energy resources such as photovoltaics projects to replace fuel dependence and high costs in electricity bills were reviewed. where there are savings of up to 30% in electricity and 60% in gas consumption. However, the initial capital investment and payback period are high and require new features to be considered in these facilities.

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Keywords: Hotels; Facilities; Heating ventilation and air conditioned (HVAC) system; Energy uses

1. Introduction

The tourism sector remains as one of the leading economic sectors worldwide. According to the World Tourism Organization (UNWTO), tourism has had a sustained growth, despite the occasional crisis, demonstrating its strength

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Table 1. Benchmark of different hotels in Lagos, Nigeria.
Source: Prepared by the authors based on data from [7] and [8].

Hotel star rating	Total floor area (m^2)	Age (year)	Annual energy consumption (MWh)
2	5346.02	36	3217.27
2	1822.99	15	831.12
2	20460.00	4	558.25
3	4284.00	64	828.15
3	4500.00	15	884.69
3	6405.00	4	1407.47
4	28392.00	72	9210.17
4	12567.00	5	4721.46
4	10197.07	2	5167.74
5	40907.04	37	26400.26
5	4200.00	5	847.87
5	35904.00	1	6940.70

and resilience. International tourist arrivals have increased over the last century; in 1950 it reached 25 million of tourist, 278 million in 1980, 674 million in 2000, 1186 million in 2015 and more than 1400 million in 2018 [1]. However, this unstopped growing implies more consumption of energy, natural resources and produce a massive amount of waste and contamination [2,3]. In 1995, the U.S. Energy Information Administration (EIA) reported that hotels were ranked as the first five highest energy consumption buildings in commercial and service sector, while the Annual Report on China Building Energy Efficiency in 2012 showed that hotels were the highest energy consuming buildings after shopping malls. Energy consumption could vary enough among different locations and categories of hotels however in general, hotels are energy intensive facilities [4,5]. Today, tourism accounts for 8% of Global Green House Emissions (GHGs) most of which are attributed to transporting guests and supplies, as well as ensuring their comfort experience in the hotel [6]. Several factors influence the energy consumption of a hotel to achieve better indoor comfort and service quality. [7] and [8] analyze factors such as category, total floor area, and age. The results are shown in Table 1.

Other factors analyzed are energy quality, water systems, operational practices, maintenance plans, customer profiles (vacations or business), the type of service. All these factors cause a significant variation in energy consumption also in facilities located in the same region. Table 2 shows the variations of the Energy Use Index (EUI) as an example of this variation.

In hotels, several studies confirmed that a great percentage of energy consumption is due to HVAC systems. According to [11] in a sample of one hundred and eighty-four selected hotels, half of the energy was consumed by the HVAC systems. A study conducted by [19] quantifies that in subtropical hotels, HVAC systems consume between 35% to 50% of electricity. In [20] electrical consumption was measured in two tropical hotels, as shown in Figs. 1a and 1b. In both cases, chillers accounted up to 61% and 48% of the total energy consumption, respectively. Therefore, hotels energy savings in HVAC systems is an important issue.

The energy consumption of these systems is influenced by many features such as the continuous operation of their services (24 h a day, 365 days per year); the different functional areas that it comprises the occupation patterns and the differences in customer preference related to indoor comfort, which could be influenced by culture and environmental consciousness [21].

This article aims to summarize the fundamental issues that impact on the design of an air-conditioned scheme for hotel facilities. The research reviews the characteristics of hotel facilities that influence in the use of air conditioning systems, and the most used HVAC schemes in hotels, considering different approaches that allow energy savings. The design of an effective system requires a thorough knowledge of HVAC technology, hotel facilities and their operation.

2. Hotel characteristics

Considering an architectural approach, hotels facilities are a well-designed combination of three functional areas offering different services for their guest [22].

Table 2. Average EUI (kWh/m^2/year) for worldwide hotels.

Reference	Country	Hotel category	EIU
[9]	USA	Resort	407.5
		Luxury upscale	397.3
		Mid-market	312.6
[10]	Shanghai	Two-star	61.95
		Three-star	73.18
		Four-star	86.64
[11]	Europe	Mid-market	269.9
		Upscale	336.3
[12]	Vietnam	Two-star	101
		Three-star	143
		Four-star	141
		Resort	78
[13]	Balearics Island, Spain	Three-star	179.6
		Four-star	199.8
[14]	Nepal	Luxury hotel	197
[15]	India	Luxury hotel	260
[7]	Hong Kong	Upscale three-star	416
		Upscale four-star	525.1
[16]	Taiwan	International hotels (boutique)	280.1
		Standard hotel	237.7
		Hotel enterprises	186.3
		Bed and breakfast facilities	143.6
[17]	New Zealand	Bed and breakfast	83
		Motel	69
		Backpacker	171
[18]	Turkey	Five-stars	338.8

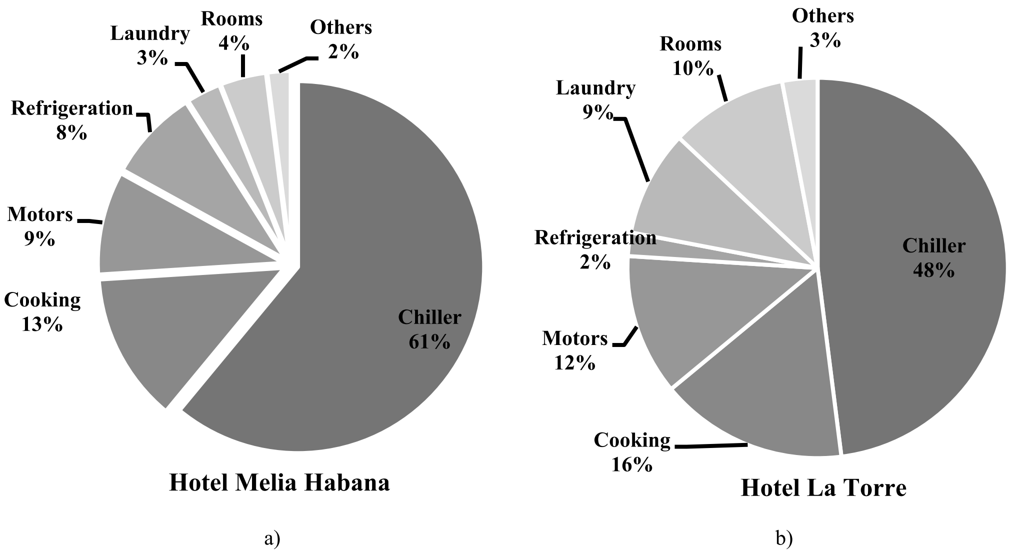


Fig. 1. Distribution of electrical consumption for (a) “Meliá Habana Hotel”, (b) “La Torre Hotel” Data. *Source:* Prepared by the authors based on data from [20].

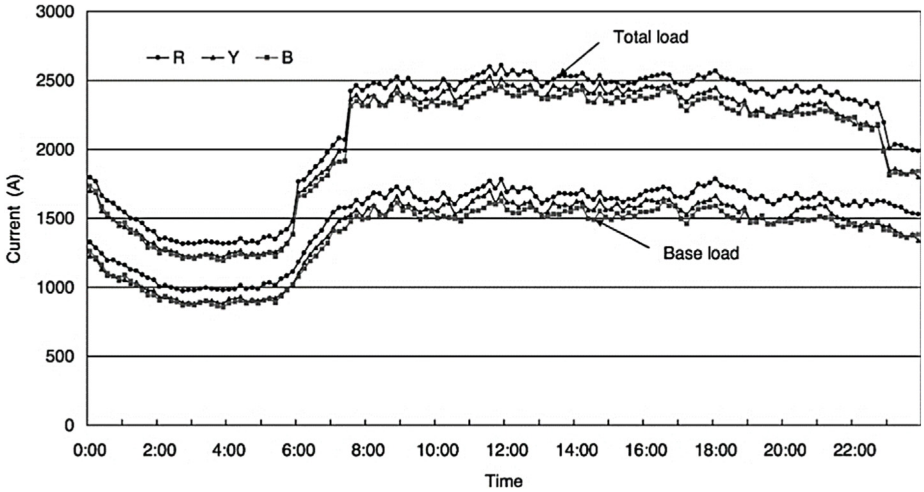


Fig. 2. Electrical load schedule on a typical summer day in a tropical hotel.
Source: Deng [21].

• Guest unit area: it includes rooms and suites. The main features arethe individual spaces with variable load according with the guest behavior, preferences and service requirements. The comfort temperature room set can be an example of this variations and preferences.

• The public area: it includes common areas such as: reception, lobby, swimming pools, shops, restaurants, meeting and conference rooms, among other. An important feature, is the high heat transfer rate with the outdoor space and the high internal loads, resulting from an intense occupancy rate, lighting and electrical equipment and appliances.

• Service area: This includes the kitchen, warehouses, laundry, machine rooms, administrative areas, offices, staff facilities, among others to provide service to guests. They have different occupational patterns compared with the rest of the areas and energy uses. They are defined by intense lighting, a great number of electronic and electric equipment, as well as steam appliances. In general, the comfort requirements of these area depend on the technical standards related to the use of this equipment, except offices and staff facilities.

Thermal load patterns

The thermal load caused by occupancy patterns is a significant step to consider in HVAC design. A hotel facility is not completely occupied all the time. Load diversification in a one-day cycle is a common phenomenon due to the guest rooms transient occupancy, with greater use of rooms at night and the variations related with support facility operation.

Some cases are shown in [21,23], Figs. 2 and 3. There papers describe the daily electricity load behavior based on the unit pattern of a hotel. The load decreases at dawn and increases between 06:00 until 23:00 when it starts to decrease again. According to the authors, these variations are possible due to the normal business hours of the functional areas. Otherwise, the increase in night-time load is linked to lounges and public areas that provide service to their guests such as restaurants, cabaret, among others.

It is possible to determine the thermal load variation if the analysis considers the intermittent operation of the public areas during their normal working hours. In [24] different hotels located in Korea were reviewed, they proved that electrical load patterns vary on weekdays and weekends due to time use and facility activity levels hourly as is shown in Figs. 4a and 4b.

Otherwise, [25] proposed to eliminate the load diversification caused by occupancy, through reordering heating/cooling demands and virtually repositioning occupancies. Guests with similar occupancy profiles could be located in the same zones. It is said, a guest in a specific zone may have similar behavior patterns in order to eliminate the occupancy diversity. Also, managers use to accommodate the same type of guests on the same floor area [19].

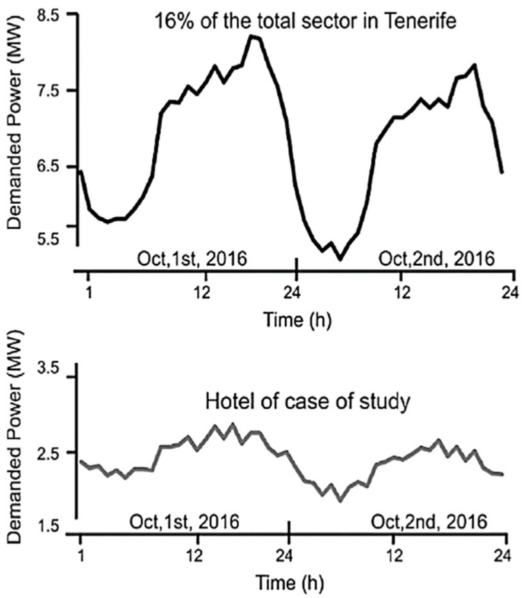
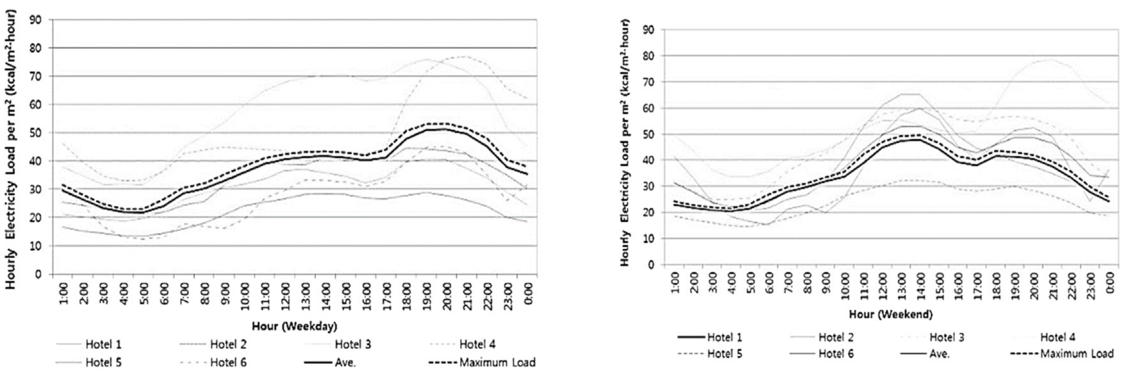


Fig. 3. Power demand profile (MW) in hotel sector.
Source: Casteleiro-Roca et al. [23].



a) b)

Fig. 4. Hourly electricity load per m^2 (a) Weekday, (b) Weekend.
Source: Ji-Hye et al. [24].

For the thermal load requirement and to select the HVAC system, it is necessary to consider that the different functional areas have a unique comfort requirement. This can be regulated by the standard or specific local building codes. This is shown in Table 3.

Partial load conditions

HVAC systems in hotels commonly work at partial load conditions. Usually, the HVAC equipment only handles partial or low loads, peak loads rarely happen. [27] evaluated the annual cooling energy of a hotel, the cooling peak load fluctuating ratio variates between 0.5 to 1 account for 47% of the full operating hours of its chillers. [28] propose improving chiller efficiency, establishing a chiller sequencing and operating fewer chillers to avoid efficiency fluctuation. Also, [29] evaluated different options for chiller sizing; analyzing the hours operation by chiller for one year in a tropical hotel. The results showed a low rate of use rounded by 33.5% (average). Besides, the study of the operating hour's versus cooling capacity showed that only during 153 h of operation the plant demanded more cooling capacity (461 RT) and that was lower than the installed load (720 RT). The solution allowed a 10.5% of energy saving per month.

Table 3. Hotel design criteria.
Source: Prepared by the authors based on data from [26].

Categories	Inside design conditions		Suggested air supply rate/L*s^{-1}	Filtration grade*	Noise ratings NR
	Summer temperature (°C)	Winter temperature (°C)			
Bedrooms	21–23	20–22	12	F5–F7	20–30
Bathrooms	23–25	19–21	10	F5–F7	40
Corridor, lobby	21–23	19–21	10	16	40
Kitchens (commercial)	18–21	15–18	17	G2-G4	40–45
Restaurant /dining rooms	24–25	21–23	10	F5-F7	35–40
Small shops	21–23	19–21	10	F5–F7	35–40
Pools halls	23–26	23–26	0–15L*s-1 of wet area	G3	40-50

Table 4. Estimated sound levels of several air-conditioning systems.
Source: Prepared by the authors based on data from [30].

Condition	Air conditioning systems	Equipment	Estimate noise levels (dbA)
Poor	Room Ac systems	Windows unit	45–50
Acceptable	Four pipe fan coils	Fan coil unit	35–40
Good	Variable Air Volume reheat central systems	Air Handling Unit, Variable Air Volume box	25–35
Excellent	Single zone VAV central	Air Handling Unit	15–20

Based on the condition explained above there are several HVAC systems configurations; each air conditioning system has numerous variations. For that reason, choose a system is not an easy task. The HVAC system selection and adjustments are considered since the design. In this stage exist the maximum opportunities to reduce energy consumption and guarantee energy efficiency in all facilities.

Noise levels

Noise can cause hearing problems, stress, alter sleep patterns and affect the audible range rate. Medium and high-quality equipment must be selected for different areas to fulfill the noise criteria. For example, [30] reported noise levels in the occupied zone for different air conditioning systems, see Table 4. The ASHRAE guideline applications (2007) suggests that noise level and acoustic privacy should be controlled by acoustical means. Chapter 47 provides guidelines and specifications for the acoustical design and related construction phases related with HVAC systems, for troubleshooting sound and vibration problems. Another consideration is that air-conditioned equipment needs to be isolated to reduce noise caused by generation or transmission systems. For example, the cooling tower (condensing unit) must be designed and located to avoid disturbing occupants of the building or nearby buildings.

As a general recommendation for HVAC system design criteria, the following factors to consider are shown in Table 5.

3. Applicable HVAC systems recommended

Moreover, countries may adopt code regulations that can influence the decision of what HVAC systems employ in the hotel facilities, Table 6 shows HVAC requirements adopted by the World Tourism Organization [34,35]

For hotels located in a humid climate, ASHRAE standards suggest maintaining the minimum airflow necessary to satisfy air quality and to reduce costly mold and mildew problem. In this region where the on/off unit cycles or the space pressurization is inadequate, the AC unit will not dehumidify or remove the excessive moisture of air properly. Priyadarsini et al. [36] reported that in several hotels in Singapore the AC stayed turn on in rooms also when guest are not inside, the set-point temperature is a little higher (25 °C) than comfort temperature (24 °C). Udawatta et al. [37] reported that as a practice most of the quality hotels maintain room temperatures around 26 °C although unoccupied, to prevent odors or discomfort. Therefore, unoccupied rooms can be considered as partially loaded.

Acosta et al. [38] and Lara Boris et al. [39] reported that the HVAC systems installed were central air conditioning system chiller plants, composed by a primary loop (four air-cooled chillers) and secondary loop (fan coils units),

Table 5. Guidelines or recommendations for the design criteria of HVAC.
Source: Prepared by the authors based on data from [31–34].

Area	Tips for design	System recommended	Special concern
Public and service areas	Design elements such as corridors with natural ventilation and open areas that eliminate the need for air conditioning. Install separate systems for individual's local. Use air curtains in areas such as the lobby, bars, etc. to avoid infiltrations. Use CO_2 sensors to avoid heat gain through infiltration. Areas such as swimming pools, leisure rooms, and gymnasiums need efficient de-humidification The kitchen needs constant ventilation and must be isolated from the rest of the areas to avoid the transport of odors.	Chillers with constant or variable volume	Select automatic systems that regulate the on and off functions depending on the occupation and allow flexible control of temperature and humidity Considering that the lobby is the guest's first impression, use an efficient interior design (supply diffuser, grill, air, outlets, etc.) Choosing cooling systems that work with satisfactory operation at part-load and low-load conditions. Kitchen air can be recirculated through the treated air (example, hoods with activated charcoal filters) rather than exhausted
Rooms	Integrate automatic systems with reservation of hotels that allow: On and off when the guest registers. The temperature control in different thermal zones or reduce the airflow when the room is unoccupied Switch off or on when opening external windows or doors Temperature setting for upper and lower limits of thermostats	All water (two and four-pipe fan coils) Unitary systems (air to air or water source heat pumps, package terminal air-conditioned	To control the moisture of conditioned outside air in a humid climate to avoid, mold, microbial contamination, and guest complaint Acceptable noise levels Toilet room exhaust Minimum use of space

Table 6. Minimum HVAC system requirements for hotels.
Source: Prepared by the authors based on data from the World Tourism Organization.

Hotel rating (Star)	Service provided
☆	Heating or fan cooling when necessary
☆☆	Heating or fan cooling when necessary. Central heating and comfort cooling seasonally available.
☆☆☆	Central heating and comfort cooling seasonally available. Individual heat control in bedrooms. Temperature maintained within the range of 18–25 °C
☆☆☆☆ And ☆☆☆☆☆	Central heating and comfort cooling available in entire premise. Individual heat and air conditioning control in all rooms. High quality equipment with very low noise emission level.

commonly used to deliver chilled water and maintain the comfort required for indoor areas. In [21], in the same weather conditions, was provided with central air conditioning all year. The central air conditioning plant consisted of four identical seawater-cooled centrifugal chillers, each at 2040 kW cooling capacity. Other HVAC systems include fans used in air handling units (AHU) and primary AHU, finally primary and secondary chilled water pumps. In a hotel located in Hong Kong the system contained three identical water-cooled centrifugal chillers to improve flexibility and back up capacity at part load conditions [27]. The chiller arrangement started to operate until each operating chiller was running at full load. Cooling towers relied on the water evaporative in the rejection process, leading to considerable water consumption when the chillers were operating.

Table 7. Case studies analysis of green approaches and participation of the operators.
Source: Prepared by the authors based on data from [48].

Green approaches measure on HVAC systems	% of participation
Sub-metering	100
Percentage of energy reduction	100
Install occupancy-based room unit controllers	100
Air-conditioned set to 23 to 24 degrees	100
Regular maintenance of air-conditioning systems	100
Indoor air quality meets the requirements	100
Mold measures	100
Use of green roof	50

In motels, low-rise apartments, and residences located in mild climate, evaporative type cooling units are popular, in others, for example, the upscale (Hilton) hotels located in Europe were typically equipped with centralized systems, including boiler, chillers, and cooling towers [11]. In the case of mid marked (Scandic) hotels space heating and hot domestic water were provided by centralized equipment while cooling by decentralized systems. A hotel located in Nepal was equipped with a standard air-to-air heat pump as an individual HVAC system for every guest room using thermostat setpoints of 20 °C for heating and 26 °C for cooling [14]. Also operated in mixed-mode, natural ventilation for cooling was considered. Finally, another example is the research conducted by [13] for 20 hotels classified with 3 stars, and 11 hotels with 4 stars from the Balearic Islands (beach hotels), all facilities were equipped with chillers and fan-coils. Also, most of them have a central heating installation with diesel boilers, and a hot water centralized system.

If it is considered a central plant, it is an important enhancement that could provide good opportunities for thermal energy storage (TES). The correct design allows the reduction of the installed capacity, as well as reducing peak demand and energy consumption in times of increasing electricity cost [40]. In [41–45] are described the main important issues concerning TES systems. Another advantage is the heat recovery systems. In the hotel facilities with centralized air conditioning, the sanitary hot water production system is composed of water chillers that incorporate sensible heat recovery, in which the thermal potential of the refrigerant is extracted at the output of the compression process. This potential can be exploited in all plant operating conditions and can also be used for heating, cooking or laundry services. Finally, it is important to recall that system with multiple chiller systems are more used than systems with a single chiller. They can often operate with one chiller because the system load can vary over a wide spectrum.

4. Green approach on HVAC systems in the hotel industry

Nair and Anantharajah [46] reported that the basic area of green approaches was to reduce energy, water, and waste consumption. The green approaches concept focuses on 3Rs-reuse, reduce and recycle' and the 2Es energy and efficiency'. Nezakati et al. [47] reported based on the Green Hotel Association (GHA), Green Hotels refers to the pro-environmental lodging properties that implement various green practices such as saving water, energy and reducing the solid waste, recycling and reusing the durable service items to protect the earth. Lately, the area has expanded to indoor air quality control, noise reduction, purchasing of green products and materials, paperless technologies, site management [48]. According to the report of the Department of Environment (DOE), the UK reported that by the green approaches applications, energy-saving can be achieved up to 20%. Several hotels assume green approach in the HVAC systems, especially in the management position, Table 7 shows several measures adopted by Malaysian Green Hotels and Resorts.

Wang [49] investigated the Green Best Practices for Hotels in Taiwan. The measured adopted were: (1) use electrical equipment with energy-saving features, (2) use renewable energy sources such as wind, solar, and geothermal power when possible; (3) install programmable thermostat; (4) perform regular maintenance on HVAC equipment; (5) evaluate insulation in ceilings and finally (6) install ceiling fans to promote air circulation and reduce the requirements for air conditioning. An area that has less impact on the operational costs of a hotel could be the use of renewable energy such as solar energy. Milojković et al. [22] suggest using distributed energy resources (DER) when it is feasible. González and Yousif [50] reported that in Mediterranean hotels, efforts have been made to explore the feasibility to use solar cooling, but that option should require a large roof space area, limiting this option. Also, investment and maintenance are not cost-effective in small systems.

Otherwise HVAC configuration and selection are restricted due to space, flexibility, energy resources, being these factors to be reviewed according with the technology selected. In a survey made by the Quality Assurance in Solar Heating and Cooling Technology (QAiST) [51] they reported only five hotels worldwide installed solar cooling systems with this HVAC schemes. Practical cases are described below:

• "Rethimno Village" Hotel, located in Greece. Since 2000 put into operation an absorption chiller of 105 kW of cooling capacity and drive-by 450 m^2 of flat plate-selective surface solar collector installed on the roof. The solar cooling system provides service to the restaurant area of 3000 m^2. Other components of the solar cooling systems are 7 m^3 of heat storage, a gas boiler of 290 kW for auxiliary heating support systems and auxiliary chillers of 170 kW of cooling capacity. Hydronic systems are composed of chillers, fan coil units, and wet cooling towers. The COP of the plant was 0.52 during the first years of operation. According to the installers, the initial cost was 146 000 €, it was founded by 50% from the Greek Ministry of Development, the payback 5 years, electricity saved was 70 MW/years and Diesel oil for heating approximately 20 Ton/years.

• Iberotel Sarigerme Park Hotel, located in Dalaman, Turkey with a 408 rooms capacity, has a solar cooling plant start in 2004, is a double-effect absorption chiller of 140 kW of nominal cooling capacity and 1.3 COP. Chiller is driven by 20 compounds parabolic solar collector PTC 1800, with an area of 180 m^2. Solar plant covers between 40%–80% of their thermal energy demands, and the rest by an auxiliary gas plant. A Part of the generated steam is used for the laundry needs, reducing the gas consumption of the hotel. During the winter season, the solar plant field is used to produce hot water for heating propose of rooms and pools. These systems allow 30% of electric energy savings and 60% of natural gas consumption. Economics savings were estimated at 200 000 € that means 51% of the operating cost of conventional systems (electrical chillers and steam boiler).

• Lentzakis SA hotel, located in Rethimno, the island of Crete, which caters mainly for tourism with a capacity of 150 beds. Single effect absorption chiller of 105 kW is driven by relatively low temperatures (70–75 °C). This is an important advantage that allows solar collectors to operate with high-efficiency rates. This installation uses, 448 m^2 of flat plate collectors for central air conditioner and 152 m^2 polypropylene collectors providing hot water for the heating of the swimming pool. Flat plate solar collectors' plant also feeds a 5000 L sanitary hot water boiler. For the coverage of the peak load has been installed an 80 kW conventional electrical chiller. Also, a gas boiler of 600 kW substitutes the collectors' field when it is cloudy or whenever there is a need for AC during nights. During winters the hot water is directed to the local AC units. The total cost of investment was 264,000 € where 50% was subsidized by the National Operational Program for Energy (Greek Ministry of Development). The primary energy savings: 576 MWh/year and the Environmental Savings: Emission 1070 tons/year.

• Turtle Island Resort in Fiji installed a photovoltaic (PV) system in 2013. Solar arrays contend 968 PV panels. Electricity output is 1.2 MW per day and provides 100% of the resort energy demand. The PV system also have battery storage. Capital cost was 1.5 million US$ and the payback period estimated was 6 years. Environmental benefits are Diesel fuel savings 0.25 million US$ per year and CO_2 emissions reduced 220 tons per year.

• Eco-Hotel Pousada du Parque, located in Couibá, Brazil. Since 2011 cold water from 10 kW Inversor HTC 18 adsorption chillers has been used for cooling rooms of the building. The pilot demonstration plant also contains 36 m^2 of flat plate solar collector. During the cold seasons, the systems offer the possibility of heating the rooms as well. About 50% of the project was financed by the Public–Private Partnership (PPP) programmed of the German Federal Ministry for Economic Cooperation and Development (BMZ) and the German Investment and Development Company (DEG).

The Mandalay Bay Convention Center, located in Las Vegas, US, can generate nearly 25% of the convention center's energy requirements. With 26,000 photovoltaic panels they are considered the largest roof-top solar array in USA. The convention center installed the first part of its rooftop solar array in 2014, and a $70 million expansion to the venue was just added. The expansion created 350,000 m^2 of additional event space, enabling the owner of the convention center, MGM Resorts International, to add eight acres of solar panels for a total of 28 acres in the array. The array generated 8.3 Megawatt. The solar array will produce enough electricity to power 1340 U.S. homes for one year and offset enough fuel to take more than 1700 cars off the road.

5. Conclusions

Tourism is an industry that maintains stable growth in recent years. Also, it is a sector that consumes large amounts of electricity and energy, the HVAC system has an important participation. However, in the tourism sector it is important to maintain a comforting concept and environment for its guests; for that reason, applying energy efficiency improvements in these facilities will reduce energy consumption toward guarantee environmental impact reduction such as Global Green House Emissions (GHGs). The hotel facilities are composed of three fundamental areas: room areas, public areas, and service areas; each one has different requirements for comfort according to international standards. The thermal loads in these areas vary and are in correspondence with the patterns of occupation which causes that the system of heating, ventilation, and air conditioning most of the time works in the partial load regime. It is suggested that during the design phase these particularities be considered so that the systems are installed and operate efficiently under these conditions through a correct sequence according to the demanded load.

To achieve the correct design of an HVAC system in a hotel installation, it is necessary to have extensive knowledge of the main characteristics of that sector which directly impact its operation. As a determining factor is the fluctuation of the occupancy patterns, it causes the HVAC system to work under the regime of the partial load, so it is suggested that systems are installed and operate efficiently under these conditions or a correct sequence in the function of the load variation.

Despite the advantages of the use of renewable sources in HVAC systems, in the tourism sector, its penetration is low, mainly because of its investment high cost and its low return on investment and maintenance schemes. The investments are focused mainly on the acquisition of more efficient technologies and in systems that allow continuous monitoring according to comfort requirements.

Declaration of competing interest

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

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