Control Energy Via Luxury Hotels: An investigation of the electricity consumption in luxury hotels in order to evaluate their potential to provide balancing energy, using Seychelles as an example

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Introduction

Electricity in Seychelles, as on other isolated islands, is largely generated by combustion generators using fossil fuel (heavy fuel oil, diesel). This results in relatively high carbon dioxide emissions from the power sector (cf. Public Utilities Corporation n.d.; Kojima and Fukuya, 2011, pp.125-126). In addition, fossil fuels are delivered by ship or even by air, adding to the relatively high electricity generation costs. Seychelles is responding to these challenges by setting a long-term goal of a completely renewable energy supply. Renewable energy should initially account for 15% of electricity generation by 2030 (see Brown et al., 2016, p.48; Kojima and Fukuya, 2011, pp.125-126f.; Vreden et al., 2010, p.9).

Although reducing fossil energy generation in favour of renewable energy generation will lead to a reduction in energy costs and energy-related greenhouse gas emissions, this development will also cause an increase in unpredictable generation fluctuations. In order to balance these fluctuations, flexible reserve capacities that can be used to react either spontaneously or in a planned manner to nature-related fluctuations (such as sunshine duration, air temperature and wind speeds) will be needed. *Control energy* (*Balancing power)* is the term used to describe the energy or power made available at short notice for the purpose of system or supply security (Gitte et al., 2011, p.6). Currently, diesel generators provide reserve capacity in Seychelles. However, the option of using diesel-based power plants to balance power in the short-term is limited by their intertia (cf. Brown et al., 2016, p.53ff.).

In Seychelles, the accommodation and food services sector accounted for 11.9% of local GDP in 2019, making it the largest local industry. The hotels in the accommodation industry could be used to provide balancing power via flexible adjustable or controllable loads. The luxury hotels, which provide their guests with a wide range of electrical equipment and devices, have a comparatively high level of electricity consumption. This could potentially enable them to provide balancing power (cf. National Bureau of Statistics, 2020; Bundesamt für Wirtschaft und Ausfuhrkontrolle, 2018, p.2; Priyadarsini et al., 2009, p.1319).

Objectives and structure of the study

The aim of this paper is to assess to what extent the electricity consumption of luxury hotels can be adjusted to provide balancing power. In order to do this, the paper will first provide a description of the luxury hotels' power supply and power consumption using Seychelles as an example. The aim is to clarify the loads and consumption which exist in luxury hotels, where the greatest electricity consumption occurs, and how variable these are. In the end, a first assessment of the potential of luxury hotels as controllable consumers can be made.

The article begins by introducing the topic and presenting the aim and the structure of the study. This is followed by sections covering the current state of research and practice, the methodology of the study, including the development of a guideline-based questionnaire, the selection of the interviewed hotels for the study, as well as the implementation of a guideline-based expert interview. The results of the interviews are then presented and interpreted in light of the current state of research, and the paper concludes with an outlook for the future.

Material, methods and implementation

The study is based on a survey of hotels in the luxury segment, an expert interview, and on literature research. A guideline-based questionnaire was created for the survey. This survey was intended to first provide information about the power supply, power consumption and storage possibilities of the luxury hotels in order to be able to examine the flexibility of electricity consumption.

Hotels for the survey were initially selected based on their status as luxury hotels. The term luxury is understood to be synonymous with splendour, lavish opulence and costliness. Accordingly, luxury hotels are described in the context of the survey as hotels that have exceedingly comfortable and elegant facilities (with corresponding electricity consumption). The luxury hotels are certified with a five-star rating, the highest classification level. Hotels without this certification can also consume similarly high amounts of electricity, but were not included in this study.

The selection was also based on the prominence of their public appearance. Three globally or locally distributed platforms served for the closer selection. Seychelles News Agency, a state-funded local news agency, includes a list of 'the best' four- and five-star hotels, restaurants in its *Best of Seychelles* section. Eleven of the fourteen hotels listed in the five-star category were contacted for the survey. *Five Star Alliance*, an international travel agency specializing in five-star accommodation, includes eleven hotels in Seychelles on their website. All of these hotels were contacted. The final platform used was the search engine of the *Google Limited Liability Company*. This search engine filtered the hotels according to the criteria 'luxury stays with five stars'. A total of 27 luxury hotels were identified in Seychelles through the aforementioned platforms. Nineteen of the 27 hotels that came up in this search were contacted for this study. These nineteen hotels represented 70% of the identified luxury hotels. The survey participation rate for the hotels was 33%. The response rate for the surveys was 47%. Table 1 shows the details of how the luxury hotels were contacted. The polled hotels are located on the islands Cousine, Eden, Félicité, Frégate, Mahé, North, Praslin, Round and Silhouette. Sensitive data that can be traced back to the hotels in the study was not published in this paper, but can be requested from the authors.

Table 1: Data from contacting the luxury hotels

Hotel-Abbreviation [1]	Type of Hotel [2]	Type of Contact	Contact Period	Number of Contact Attempts	Interview could be conducted (yes/no)
H1	Hotel with villas	In person	21 Feb and 24 Feb 2020	2	yes
H2	Hotel	In person	27 Feb 2020	1	yes
H3	Hotel with villas	In person	28 Feb 2020	1	yes
H4	Hotel	In person	6 March 2020	1	yes
H5	Hotel	In person	6 March 2020	1	yes
H6	Hotel with villas	Skype, by phone	26 May 2020	1	yes
H7	Hotel	Skype	27 May 2020	1	yes
H8	Hotel with villas	Skype	29 May - 17 June 2020	3	yes
H9	Hotel with villas	Skype, Email	29 May - 2 June 2020 via Email 17 June 2020 by phone	1	yes
HoT1	Hotel with villas	Skype, by phone	26 May - 17 June 2020	3	no
HoT2	Hotel	Skype, by phone, Whatsapp	26 May - 17 June 2020	3	no
HoT3	Hotel with villas	Skype, by phone, Whatsapp, Email	26 May - 17 June 2020	3	no
HoT4	Hotel	Contact form	30 May 2020	1	no
HoT5	Hotel with villas	Skype	26 May - 17 June 2020	3	no
HoT6	Hotel with villas	Skype	26 May - 17 June 2020	3	no
HoT7	Hotel	Skype	27 May - 17 June 2020	2	no
HoT8	Hotel with villas	Skype	26 May - 17 June 2020	3	no
HoT9	Hotel with villas	Skype	29 May - 17 June 2020	2	no
HoT10	Hotel with villas	Skype, Whats-app, Email	26 May - 17 June 2020	3	no

Notes:
[1] The abbreviation H indicates participating hotels, while the abbreviation HoT means hotels without participation.
[2] The type of hotel provides information about the distribution of accommodation. A 'Hotel' accommodates its guests predominantly in one building complex, while a 'Hotel with villas' also combines various residential buildings.

The interviews with the hotels were first conducted with face-to-face interviews on site and then, after the COVID 19 outbreak, were continued by telephone. Unfortunately, the pandemic – along with many additional negative effects – meant that the accessibility to the companies was reduced. Some of the hotels permitted the interviews to be conducted by phone, while other hotels preferred to be contacted in written form before or after the oral survey. A maximum of three attempts were made to contact each hotel. The contact attempts were stopped after hotels signalled that they did not wish to participate in a survey. The different methods used to contact the hotels were based on the accessibility, preferences, and common practices of the companies concerned. The interviews were carried out from 27 May to 17 June 2020.

In addition to these interviews, a guideline-based interview regarding balancing energy by luxury hotels was conducted on 5 March 2021, with an expert in the field. The selected expert has been advising public administrations and companies in tropical climates in Africa and Asia on the use of renewable energies for decades. After explaining the objectives and structure of the research, the interviewee was asked five guiding questions. The first questions were more general; the authors went into more detail during the interview. The expert interview was used to support the interpretation of the survey results.

Current state of research

This section presents the current state of research and practice relevant to the study. This includes the capability of controlling loads in off-grid systems, hotels and buildings.

Erdinc et al. (2015) evaluate island power systems and discuss potential challenges and solutions. In this study, the authors write that commercial areas, such as hotels, are increasingly coming into focus for demand response application, as islands usually have limited industrial facilities. The installation of smart meters could help to overcome the probable inertia of the generation system in island areas. The Caribbean islands are cited as an example (Erdinc et al., 2015, pp.334-344).

In his study on the optimal payment for demand bidding programme services in the context of hotels, Tarasak (2014) distinguishes load categories according to their occupancy rate and planning capability. The author claims that guest comfort would not allow for the scheduling of loads in guest rooms (Tarasak et al., 2014, p.824). This assessment is contrary to the findings of other authors.

Kirby (2008) investigated the use of air conditioning units in hotel rooms as a spinning reserve, citing a hotel in Tennessee as an example. A local (instantaneous frequency equalization) and a central load-shedding option, controlled by the grid operator, were implemented in the existing air conditioning control technology that the hotel used to save energy.

The study showed a possible reduction of the hotel load from 22% to 37% in 12 seconds to 60 seconds after the signal for load shedding by the air conditioning control. According to Kirby (2008), room air conditioning loads are capable of numerous short shutdowns and occasional extended shutdowns (Kirby et al., 2008, p.61).

Time delays are caused by the lack of limits regarding minimum switch-on, minimum switch-off or ramp times by the control signal alone. The authors argue for providing grid security services through air conditioning units, due to the reduced response time and response frequency in this case. Peak load reduction, on the other hand, requires longer operating periods and higher response frequencies. In comparison, peak load reduction often demands a deployment of several hours per day, which again also extends over several days. The use in peak load reduction significantly affects the operation of the equipment, while the provision of grid security services only requires short deployments, but otherwise does not disrupt normal operation. When the load was interrupted for 15 minutes, the authors' study showed an average increase in temperature of 1.7 degrees Fahrenheit (°F) and a 2% increase in humidity in rooms facing the sun with an outdoor temperature of 90°F (a temperature change of 1.7°F corresponds to a temperature change of approx. 0.9°C. 90°F corresponds to approx. 32°C.). Recovery of temperature and humidity was observed in the following 15 minutes. Temperature decreased by an average of 1.5°F (a temperature change of 1.5°F corresponds to a temperature change of approx. 0.8°C) and humidity by an average of 0.1%. There is a lack of information on the targeted room temperature and thus information on the temperature gradient from outdoor to indoor (Tarasak et al., 2014, p.824; Kirby et al., 2008, pp.61-66).

In this context, Kirby (2008) also discusses frequency balancing through responsive loads. Reaction to frequency deviations requires a response that is above the frequency of a rolling blackout. A response at high frequencies is not possible. In addition, a response characteristic similar to the frequency response of generators is required. This similarity can be achieved solely by aggregated load-frequency response with individual, minor adjustments of frequency trigger points of corresponding controllers. The frequency-response curve of the total load can then correspond to any generator response (Kirby et al., 2008, p.64ff.).

Mehta et al. (2014) developed safe, time-switching-based, protocols that can control groups of thermostatically controlled loads. The authors show that large and short upward and downward controls can be made that can quickly compensate for fluctuations in the minute range flexibly with a few aggregate parameters. In this context, Mehta et al. (2014) and Sinitsyn et al. (2013) also point out the delay of about 20 seconds in the change of state of air conditioning systems, which has a limiting effect on duration and accuracy. In addition, the study shows that the protocols are minimally invasive and not expensive. Thermostatic control is only possible with one-way communication, without collecting data from individual aggregates. Only the implementation of strategies to mitigate feedback effects requires the implementation of aggregated parameters. Moreover, a five-minute interruption remains unnoticed (Mehta et al., 2014, pp.785-790; Sinitsyn et al., 2013, p.306).

According to Mehta et al. (2014), for example, refrigerators, air conditioners and water heaters can be thermostatically controlled loads. Kansakar et al. (2018) examine fog-assisted architecture. Fog computing or edge computing describes the decentralized processing of data. In contrast to central processing in clouds, data is processed or collected in fog nodes at the edge of the network. Kansakar et al. (2019) explore the most advanced technologies in the hospitality industry in the context of smart cities. The authors point to the frequently used previously described smart thermostats in the hospitality industry, which could simplify the implementation of thermostatic control presented by Mehta et al. (2014). In addition, they point out the high energy-saving potential, which contributes to energy-cost reduction (Kansakar et al., 2018, p.62; Kansakar et al., 2019, p.4ff.; Mehta et al., 2014, p.785).

Pabst (2020) investigated the possibilities of the lead-acid and lithium-ion accumulators of golf carts in Seychelles hotels in the context of controllable electricity consumers in tropical tourist regions. The author concludes that both types of accumulators are suitable for participating in load-shifting programmes. Dominković et al. (2018) conducted an integrated energy modelling approach in a case study on the Caribbean island of Aruba. For the study, the two smart charging concepts for electric vehicles, Vehicle-to-Grid (V2G) and Smart Charging, were investigated comparatively. V2G differs from Smart Charging in the sense that the feed-in from the vehicle battery can be made into the grid in V2G. The study found no significant difference between the two charging concepts in the context of an optimal charging method from a system perspective. However, it points to the higher cycling of vehicle batteries, which is required for the V2G concept and could make manufacturers hesitant to react (Pabst, 2020, pp.13-25; Dominković et al., 2018, pp.5-14).

There is however a research gap when electric vehicles are considered as service providers for balancing energy in the context of hotels.

Tarasak et al. (2014) discusses the Demand Bidding Program (DBP) in the context of hotel energy management by formulating the optimization problem of the reward mathematically. They show that the DBP encourages hotels to manage their loads. It also proves that the DBP can provide them with an economic incentive.

Zizzo et al. (2017) come to similar conclusions by investigating the ‘control and communication system architecture’ for small islands through a feasibility study on the island of Lampedusa. The comfort level expected by hotel guests should correspond to the star category and room rate, which implies a limited flexibility offer for the network to prevent guests from experiencing any inconveniences. At the same time, according to Zizzo et al. (2017), demand response is possible for the studied hotel with an appropriate energy management system that maintains the minimum requirements of the hotel owners and guests (Zizzo et al., 2017, pp.1037-1044; Tarasak et al., 2014, pp.821-828).

In this context, Cui (2017) shows that existing in-building, load-management procedures can be integrated into the grid. Qi (2017) also proves that direct load control of heating, ventilation and cooling systems can improve grid frequency stability even while ensuring building comfort (Cui et al., 2017, pp.59-64; Qi et al., 2017, p.5 ff.).

Results of the survey

Grid connection, electricity generation and electrical storage

The evaluation of the survey shows that six out of nine polled hotels are connected to the public electricity grid and that electricity generation is partly supplied by it. One hotel indicated that generating their own power is more expensive than purchasing it externally. Another mentioned that it consumes more electricity than the electricity provider can provide. Another hotel indicated that it pays a fixed price depending on consumption for electricity purchase. Only two out of nine of the hotels interviewed indicated that they are equipped with renewable electricity generators. Only a few hotels are planning a project in this regard. However, fossil-fuel generators in the form of diesel generators are present in all hotels. Electric storage systems are used as part of back-up systems in two of the polled hotels, or in electric vehicles.

Identifying the largest electricity consumers

In terms of the potential for providing balancing energy in luxury hotels, it is relevant to first obtain a general overview of the electricity consumers in luxury hotels. The surveyed hotels were all in agreement about the fact that refrigerators and cooling rooms, electric vehicles, air conditioners and washing machines had the highest consumption. Air conditioners, in particular, were said to have the highest electricity consumption. They were reported to account for between 35% and 80% of the electricity demand. In addition, iceboxes and ice rooms (six out of nine), dishwashers (eight out of nine) and dryers (five out of nine) were also mentioned in this context by a majority of the interviewed hotels. Only rarely were ironing machines, desalination plants and swimming pools listed. These devices were listed by only one or two of the nine surveyed hotels as their biggest electricity consumers. Figure 1 shows the largest electricity consumers listed by the surveyed hotels.

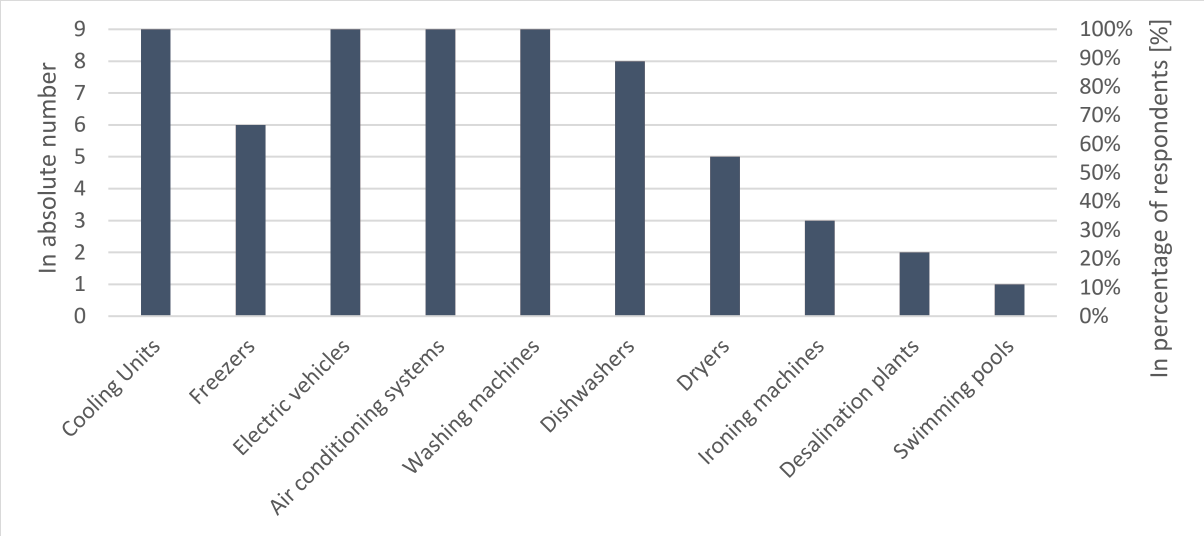

Figure 1: Identification of the devices with the highest electricity consumption by the polled hotels

Type and quantity of electrical consumers

The type of appliance does not differ among the refrigerators. Of the nine participants in the survey, all reported that cold-storage rooms were among their biggest consumers of electricity. While the number of cold-storage rooms used varies greatly, the size of the units is similar in all luxury hotels that provided this information. The number of units ranges from three to sixteen units and the room size of the units varies from $6m^2$ or $10m^3$ to $9m^2$. Looking at the freezers, it is also obvious that the number of units varies, but the information on the size of the room is similar. Between two and eleven appliances per luxury hotel are indicated. Only freezer rooms with a size between $6m^2$ and $9m^2$ were indicated.

The interviews further reveal that the luxury hotels are equipped with between twelve and 88 electric vehicles ('golf carts'), with between one and six batteries per vehicle. Two out of nine respondents provided information on the number of batteries per vehicle.

Furthermore, information was provided on the air-conditioning systems or the air-conditioned areas in luxury hotels. Of the nine participants in the survey, five specified the number of units they had. Among them, only two respondents stated that they have a central cooling system. One of them listed decentralized small systems in addition to the central system. According to the survey, some of the questioned luxury hotels are equipped with 34 to 150 small decentralized air-conditioning units, whereby one hotel also gave information about another nineteen air-conditioned villas in addition to the number of air-conditioning units for staff rooms and offices. Some of the other luxury hotels provided information on the number of air-conditioned rooms. Between 88 and 150 air-conditioned rooms were listed. One luxury hotel also added the air-conditioning of the conference rooms, restaurants, offices, gym and swimming pool.

The luxury hotels also identified washing machines, dryers and ironing machines as the largest consumers of electricity. With regard to washing machines, seven out of nine luxury hotels state that they use three to 75 industrial or large washing machines. One hotel uses two medium-sized washing machines, while four luxury hotels report having between two and twenty small or household washing machines. Two other hotels did not specify the type of washing machine they use, listing between four and 94 washing machines as equipment. There is less variation in the type of dryers listed. For example, only one hotel listed six large dryers as part of their equipment, while three others did not specify the type of dryer; only that they have between two and 35 dryers. Only two luxury hotels also identified one to two ironing machines as one of their largest electricity consumers.

The equipment of the surveyed luxury hotels with dishwashers differs according to type and size. While eight out of nine of the questioned hotels provide information about the number of dishwashers, six out of nine are more specific and supply details about the type, size or manufacturer of the dishwashers. Thus, three out of nine of the surveyed hotels use one or two dishwashers with conveyor belt systems. At the same time, two out of nine of the hotels surveyed report using up to four hood-type dishwashers. Another hotel quantifies six regular dishwashers. However, the surveys do not clarify what type or size these regular dishwashers are. Furthermore, three of the nine surveyed hotels indicate two to five large dishwashers. One out of nine respondents report using four medium-sized dishwashers, two small dishwashers or over twenty household-sized dishwashers. Another three surveyed hotels report the number of their dishwashers without any specification. They use between three and fifteen dishwashers. Two of the surveyed hotels also indicate desalination plants and another a swimming pool as the largest electricity consumers, whereby the number is limited to one facility in each case.

Table 1: Type and number of electricity consumers of surveyed hotels

Hotel		H1	H2	H3	H4	H5	H6	H7	H8	H9
Cooling units	Quantity	3	3	11	5	8	16	15	7	3
	Respective room size [m^2]	-	-	6	6	9	-	-	-	-
	Respective room size [m^3]	-	-	-	-	-	-	-	10	-
Freezers	Quantity	3	2	11	2	2	-	-	3	3
	Respective room size [m^2]	-	-	6	6	9	-	-	-	-
Electric vehicles	Quantity	42	70	88	13	12	60	14	25	36[1]
	Accumulators per vehicle	-	-	6	-	-	-	-	1	-
Air conditioning systems	Central facilities	-	-	-	-	1	-	-	1	-
	Decentralized small systems	-	-	150	86[2]	-	-	-	40	34[3]
	Air conditioned rooms	111	88	-	-	-	118[4]	150	-	-
	Air conditioned villas	-	-	-	-	-	-	-	-	19[5]
Washing machines	Industrial/large	75	3	4	3	6	-	-	5	3
	Medium-sized	-	-	2	-	-	-	-	-	-
	Small or household size	10 to 12	-	20	2	8	-	-	-	-
	Not specified	-	-	-	-	-	4	94	-	-
Dryer	Large	-	-	-	-	6	-	-	-	-
	Not specified	35	-	-	2[6]	-	-	4		2
Ironing machines	Quantity	1 to 2	1	-	1[7]	-	-	-	-	-
Dishwashers	Conveyor type	1	-	2	-	2	-	-	-	-
	Hood-type	4	Unknown	-	-	-	-	-	-	-
	Regular	-	-	-	-	6	-	-	-	-
	Large	-	-	5	3	-	2	-	-	-
	Medium-sized	-	-	-	-	-	4	-	-	-
	Small or household size	-	-	> 20	2	-	-	-	-	-
	Not specified	-	-	-	-	-	-	15	3	3 to 4
Desalination plants	Quantity	-	-	-	-	-	-	-	1	1
Swimming pool	Quantity	-	-	-	-	-	-	1	-	-

Notes:

[1] Eighteen villas each with one electric vehicle plus staff vehicles were specified. It is assumed that one employee vehicle is available per villa. This results in 36 electric vehicles.

[2] 60 air conditioners for the individual guest villas and 26 for the offices were indicated. This results in 86 air conditioning units.

[3] 24 air conditioning units in the staff rooms and ten in the offices were indicated. This results in 34 air conditioning units.

[4] 98 air-conditioned rooms and the offices with approx. 20 air-conditioned rooms were indicated. This results in 118 air-conditioned rooms.

[5] Eighteen air-conditioned villas and one air-conditioned Presidential Villa were indicated. This results in nineteen villas.

[6] The polled hotel indicates that they use dryers. A precise number is not given. It is assumed that the ratio of washing machines to dryers is similar for this hotel as for the other hotels. On average, there are about 0.38 dryers for every washing machine in the hotels surveyed. Thus, it can be assumed that there are two dryers for every five washing machines.

[7] The interviewed hotel uses ironing machines. A precise number is not given. It is assumed that the number of ironing machines in this hotel is similar to the number in other hotels. Other hotels indicated a number of ironing machines as one or one to two. Given the generally low number of ironing machines and the relatively low number of washing machines, it is assumed that no more than one ironing machine is used.

Technical data

In the course of the interviews, the surveyed hotels provided various technical data, such as the power, the electrical voltage, work, charge or even the flow rates of previously mentioned devices. This provides information about the level of electricity consumption and power of the individual devices. The daily power differs depending on the appliance and ranges from 13.95 to 2000 kW/d. The daily electrical power of individual electricity consumers is shown in Figure 2. If the daily power of the consumers is compared, the differences in electricity consumption are striking. The daily power of the central air conditioning system is by far the largest. It is followed by the cold storage rooms and the desalination plant. The daily power consumption of the small decentralized air conditioning units, swimming pools, dryers and industrial washing machines is considerably lower.

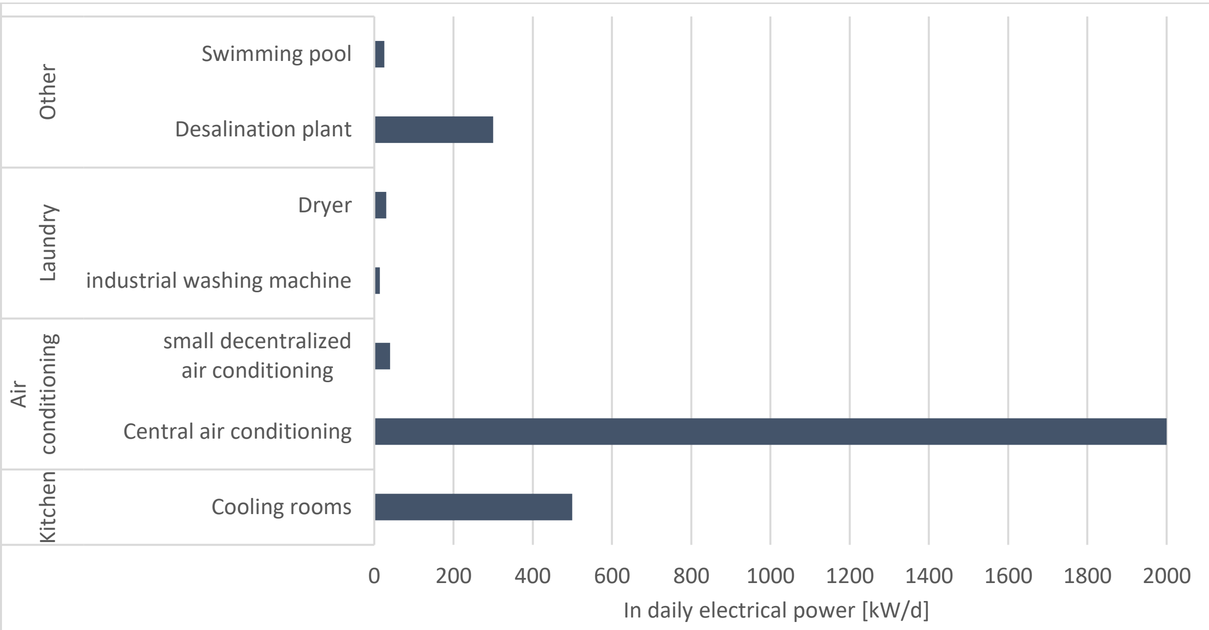

Figure 2: Daily electrical power of separate electricity consumers

Some information was also provided on the daily consumption of entire areas, such as the kitchen or the laundry. The daily power of the kitchen, for example, is indicated as 700 kW/d. The laundry, on the other hand, has a daily power of 200 kW/d. In addition, technical characteristics of the electric vehicles were given in the form of electrical voltage and electrical charge. Thus, an electrical voltage of 6 V and an electrical charge of 145 ampere hours were reported.

Time course of electricity consumption

In order to estimate the possibilities for having the electricity consumers of the luxury hotels provide balancing energy, it is necessary to have an overview electricity consumption over time. Depending on the electricity-consuming device, this can also be influenced by the consumption behaviour.

Electric vehicles consume electricity at the charging stations where their batteries are recharged. The charging stations are connected to a power supply system. When the electric vehicles are being used, the battery then discharges. The electricity consumed when the electric vehicles are being used is decoupled from the electricity consumption at the charging station and thus from the electricity supply system. The pattern of electricity consumption for electric vehicles at the hotels that participated in the survey is described by the charging behaviour which can be approximately described by the information provided by seven of the nine interviewed hotels. The charging behaviour of the electric vehicles of these hotels mainly includes charging at night. One hotel reported that it charges its electric vehicles after midnight. Four others indicated that they charge their vehicles at night and another one mainly at night. Only one of the participating hotels charges its electric vehicles directly after unloading.

Electric vehicles can only provide control energy if they are connected to the power supply system. As described above, a connection only exists when the electric cars are plugged into the charging station. Electric vehicles are used for transportation or mobility. When electric vehicles are used, they are removed from the charging station. They are then no longer available for providing control energy. In addition to charging behaviour, one hotel also provided information on usage behaviour. The hotel H6 described that the use is mainly between 8.00 a.m. and 5.00 p.m. Only half of the vehicle fleet is used during the day, while the rest of the fleet remains connected to the charging station.

Two of the nine hotels in the survey described the course of electricity consumption for the air conditioning systems. These two hotels characterized the electricity consumption of the air conditioning as similar or relatively constant throughout the day. One of them also reported that the highest electricity consumption at the hotel from air conditioning was between 9:00 a.m. and 5.00 p.m. Despite its continuity, the electricity consumption from air conditioning increases during this period compared to the night. This can be explained by the higher outdoor temperatures during the day. The luxury hotel H9 specified that the air conditioners in the occupied rooms should maintain a room temperature of 26°C for the guests. According to H9, if the rooms are not occupied, the indoor temperature corresponds to the outdoor temperature. If, on the other hand, the rooms are not occupied for a longer period of time, the systems should be switched off. H1 reported that they use a guestroom management system for the 111 guestrooms. The air conditioning systems automatically maintain a room temperature of 24°C in unoccupied rooms. H9 further indicated that they switch off the air conditioners in the office rooms at night.

Hotels H8 and H9 describe the course of electricity consumption for refrigerators/refrigerators and iceboxes/freezers as constant. The latter would maintain a temperature of -18 °C. The respondents did not provide any information about usage behaviour, such as the frequency in which the appliances are opened, temperatures adjusted or similar information.

While the electricity consumption of electric vehicles, air conditioners and cooling and ice systems is completely or partially decoupled from the periods of use due to their storage functions, washing machines, dryers and dishwashers are task-driven. Their electricity consumption cannot be decoupled from use without external storage and mainly takes place precisely when the devices are being used. The time course of electricity consumption can thus be approximately described by the utilization behaviour within the period of use for task-driven appliances.

According to eight out of the nine surveyed hotels, the electricity consumption for the washing machine occurs during the day. Only one hotel reported using the washing machines at night as well. Four hotels indicated a time frame for use during the day. According to them, electricity is only consumed between 6:00 a.m. and 10:00 p.m. Here, the use begins between 6.00 a.m. and 8.00 a.m. and ends between 5.00 p.m. and 10.00 p.m.

The timing of the electricity consumption of the task-driven dishwashers can also be approximately determined by the usage behaviour within the operating periods. Thus, the electricity consumption for dishwasher use mainly happens between 6.00 a.m. and 10.00 p.m. All luxury hotels that indicated a specific time period reported using the dishwashers during this time period, whereby the utilization for these hotels begins between 6:00 a.m. and 8:00 a.m. and ends between 6:00 p.m. and 10:00 p.m. Only one out of the nine hotels mentioned using the dishwashers 24 hours a day. Another hotel reported using the dishwashers three times a day, each time after meal service.

Change in electricity consumption

In response to the question whether the surveyed hotels see a possibility of changing the consumption level of the previously mentioned largest electricity-consuming devices, the luxury hotels predominantly answered ‘no’ or ‘currently not’. They listed various barriers that would impede them. Therefore, it is important to work out which obstacles the surveyed hotels see with regard to changing electricity consumption. In this way, it would be possible to find or work out specific solutions that enable overcoming or circumventing the obstacles.

For example, three hotels described the working hours of their employees as an impediment. Two of them agreed that a significant intervention in the course of electricity consumption is not possible due to the working hours of their staff. The other hotel mentioned the compatibility of the employees' working hours with the intervention (change of the temporal pattern of electricity consumption) as a precondition for the, in principle possible, change of electricity consumption.

Another barrier mentioned by two hotels is the present lack of interest or lack of incentive by the company to initiate the change in electricity consumption or even to consider it initially. However, the situation could be discussed if the interest of the company could be stimulated.

Two other hotels identified the price of electricity as a major barrier to changing electricity-consumption patterns. The price is always the same and so does not provide an incentive to modify electricity consumption patterns over time. Another obstacle is said to be the dependence of electricity consumption on guest occupancy. One hotel stated that changing electricity consumption is currently not possible due to this reason.

In addition to generally valid barriers, device-specific barriers were also mentioned. For example, one hotel described the fixed periods of washing machine use as an obstacle. At the same time, the temperature of the refrigerator and freezer rooms cannot be changed. The temperature of the refrigerator and freezer rooms is strongly dependent on their contents. In addition, another hotel reported that the operation of the refrigerators and freezers cannot be switched off during the day. The guests' meals would be prepared flexibly according to their wishes. Therefore, entering and opening the cold-storage and freezer rooms is not predictable in advance.

Even if the hotels mainly see barriers with regard to a possible change in electricity consumption, two hotels did indicate specific possibilities for implementation of change. One hotel admited that the laundry could, in principle, also run at night, assuming that the electricity price were cheaper during this time. Furthermore, it would be possible to check whether a washing machine is already full before it is switched on. One hotel also stated that the operation of the refrigerators and freezers could be interrupted during the night. This could already be practised during periods without guest occupancy and would in principle also work under normal conditions with occupancy. In addition, the hotel described the daytime operation of the refrigerators and freezers during the pandemic period without guests. For example, the refrigerators and freezers were only on from 6.00 a.m. to 1.00 p.m. and from 1.00 p.m. to 6.00 p.m. This is possible due to the fixed meal times, which are valid for the staff under the given circumstances. Another hotel claimed to be able to lower the temperature of freezer rooms to -20 °C.

Interpretation of the results

The interviews show that hotels have task-driven appliances and devices with thermal and electrical storage capabilities. Their equipment includes household appliances which, according to the literature, are suitable for participating in demand side management. The survey reveals that there is currently no incentive for hotels in Seychelles to provide balancing power. The hotels describe a current lack of interest due to the lack of incentive. The fixed electricity price, for example, does not offer any economic benefits for changing electricity consumption patterns.

The literature shows that the flexibility offered by hotels is limited by high guest comfort. The demand for guest comfort increases with the room price and the star category. Luxury hotels combine both, which goes hand-in-hand with particularly high expectations of guest comfort. Offering flexibility is nevertheless possible with energy management systems that take into account the requirements for guest comfort. Existing energy management systems can also be integrated into the electricity grid.

The literature also demonstrates that providing balancing power to hotels can also provide an economic benefit. However, the provision of balancing power requires a certain degree of automation and the implementation of an electronic information and communication system that can process large amounts of data. To what extent this already exists remains to be investigated.

However, it is known that smart meters for hotels have already been successfully tested on islands. A decisive factor in providing energy in the context of hotels is the dependence of electricity consumption on guest occupancy. This is considered a relevant factor both in the literature and in the context of the surveys. Thus, the interviewed hotels mentioned being dependent on guest occupancy as an obstacle to modifying electricity consumption patterns. The provision of control power requires fulfilling preconditions regarding incentives and technology. There is currently no economic motivation for the hotels in Seychelles to change their electricity consumption. The technology of the hotels in terms of communication and information systems remains to be clarified.

Loads with electrical storage capacity

In Seychelles, electrically powered golf carts in the hotel sector could be useful for the electricity grids as controllable loads. The state of research proves that grid-serving services, such as short and fast load changes, are possible for electric vehicles. Assuming a typical unidirectional energy flow, positive control power from discharging and feeding into the grid is currently excluded. Positive control power can still be applied by stopping the charging process. Negative control power would be provided by starting the charging of the vehicles.

Intelligent charging methods (smart charging and V2G) can, on the one hand, be used for grid-serving services and, on the other hand, already reduce the electricity costs of the luxury hotels at the current time by optimising charging processes. Considering the lower utilisation of 50% of electric vehicles, the V2G concept could provide luxury hotels with economic benefits. The low level of utilization opens time slots that allow recharging after grid-serving discharge. The electric storage predestines them for providing positive capacity and power through feed-in. However, this requires the possibility of a bi-directional power flow.

The surveys show that electric vehicles are mainly used during the day and charged at night. If the devices are fully charged at the beginning of the day, grid services would no longer be possible without a bi-directional energy flow and a V2G concept. Implementing smart charging procedures is considered grid-serving for both mentioned procedures. In contrast to smart charging, the economic benefit remains to be calculated against losses in battery life for V2G concepts.

Loads with thermal storage capacity

The interviews show that the polled hotels are equipped with loads with thermal storage capacity. Researchers are in agreement that the operation of cold-storage rooms, freezers and air-conditioned areas, loads with thermal storage capability, in hotels is not disturbed by short load shedding. The stored thermal energy allows the power to be interrupted or additional energy to be stored and the load to be shifted to another time. The literature also shows that a load delay is caused by the control signal alone. Different devices have different requirements. Refrigeration and freezer interruptions must ensure the shelf life and quality of the food, while air conditioning systems maintain a comfortable temperature in the building.

The thermal storage capacity of cold-storage rooms and freezer rooms results mainly from the heat capacity of the food and the room insulation. The thermal storage capacity of air-conditioning systems results predominantly from the heat capacity of the furniture and the room insulation in the air-conditioned area. If the room insulation is reduced by opening doors or windows, the storage capacity of the systems is reduced. In addition, heat sources in the room lead to a further reduction in the storage capacity.

After taking the coefficient of performance into account, the electrical power of the appliances corresponds to the added heat flow. The interviews show that the guests' meals are not always prepared at fixed times. The cooking is done according to the guests' wishes. This means that the insulation is interrupted regularly and unpredictably by the opening and closing of the refrigeration and freezer rooms, which increases the heat flow and thus the electrical power. This regular opening and closing affects the possible operating times of the control system. Positive control power from lowering the temperature can be shorter and smaller or even non-existent the more frequently an insulation interruption takes place. However, negative control power can also only occur if the nominal power of the devices has not yet been attained. It remains to be clarified to what extent the thermal loads reach their nominal power (based on how often the staff enter the cold-storage and freezer rooms).

The literature and the interviewed expert point out the difficulty in providing control energy through refrigeration and freezing systems, and this is caused by the mandatory preservation of food quality. In addition, the interviewed persons currently show a low willingness to change the operation of the cold-storage and freezing rooms. The temperature of these rooms is strongly dependent on their contents. At the same time, only a small reduction of the freezer temperature by 2°C is possible. Moreover, a longer shutdown only seems possible if there are fixed times for meals. However, this would also limit the period of use.

The literature shows that running air conditioners with thermostatic controllers for short periods can be used for both balancing the mains frequency and for load shifting. However, it remains to be clarified which temperature differences are acceptable for cooling food and rooms for hotels. The length of the possible temperature deviation determines the time period of possible control energy provision. A small permissible deviation also means a short possible application time as a controllable load. In the literature, using thermostatically controlled loads for brief periods is recommended for grid security measures. A short period of use, on the scale of minutes, could be possible for air conditioning, cooling and freezing rooms without changing the temperature of the rooms significantly.

The literature points out the frequent use of smart thermostats in building automation systems. To what extent this also applies to the luxury hotels in Seychelles is not clear from the interviews and also remains to be clarified. Existing smart thermostats could simplify the introduction and implementation of control energy provision. Existing building automation systems could also contribute to the implementation of control energy measures. Building automation systems already have a networking of the devices with central control of the devices, which contribute to providing control energy.

Task-driven devices

The persons interviewed for this study mentioned various task-driven devices as relevant electricity consumers. The task-driven devices differ significantly from the devices with thermal and electrical storage due to their dependence on guest occupancy and staff working hours. Thus, only the use of task-driven devices is limited by specific periods of use, whereby the running times are then more or less continuous and strongly depend on demand. Providing of balancing energy or balancing power is only possible here if the utilization is adapted. A load shift of task-driven devices would implicate a shift of the task. According to the current state of the survey, there is no willingness to change their use.

Discussion

This research is based on the evaluation of guideline-based questionnaires, which consist of five key questions. For the study, hotels were selected that are well represented in the media, are located within the studied area and can be classified as luxury hotels. The hotels in this study were five-star hotels. However, hotels with less than five stars and hotels without any rating can also be equivalent to the selected luxury hotels in terms of their facilities. Including these hotels would have increased the number of interviews and thus strengthened the validity of the survey. However, this would have required an individual classification of hotels in order to identify potential participants.

The chosen approach avoids the time-consuming consideration of the individual hotels. Data on power supply and power consumption should emerge from the surveys. The study shows that providing control power requires a certain degree of automation and equipment with information and communication technology. Key questions on existing energy building management systems, equipment with smart meters and smart thermostats could have been integrated. Nevertheless, it is essential for the study to find out the electricity consumption and power supply of the luxury hotels. Only with information about the type, size, and number of electricity-consuming devices makes it possible to identify potential for controlling. In order to clarify the extent to which this potential can be utilized, it will be necessary to additionally analyse the hotel equipment and devices containing smart systems.

Conclusion and outlook

Isolated islands, such as the Seychelles islands, often have high electricity generation costs and carbon dioxide emissions due to their dependence on diesel or heavy oil to generate electricity. Of course, the best energy is and remains the energy that is not needed at all. Therefore, the development and use of energy-efficient devices (especially those products that have a high electricity demand, such as air conditioning units) is very important.

Furthermore, it is essential to integrate as much renewable energy as possible into the electricity grid. Fluctuations in electricity generated from renewable sources require measures for balancing the resulting residual load. However, diesel power plants offer only delayed reactions to these fluctuations. In addition to electricity generation, controlling electricity consumption represents a possibility for flexibility, which helps to maintain or restore the stability of the system. For this purpose, luxury hotels in Seychelles were selected for this study.

The current state of research is discussed in the context of luxury hotels, island systems and buildings. Loads with thermal storage capability and task-driven devices are also being studied in research and practice in the context of hotels as controllable loads. Electric vehicles as controllable loads reveal a gap in research in this context. In order to explore the potential of luxury hotels to provide control energy, such hotels were surveyed using a guideline-based questionnaire regarding electricity consumption and generation. The luxury hotels in this study were selected for interviews based on their media presence and star category. In addition, an expert interview was conducted in order to complement the interpretation of the survey results.

According to the luxury hotel surveys, two-thirds of those who responded are connected to the public grid, although their electricity demand is only partially covered by the public electricity supplier. While all respondents generate electricity using diesel generators, only two generate renewable electricity. Electrical storage is provided solely by electric vehicles and back-up systems for IT infrastructure. The interviews clearly showed that air conditioning systems account for the largest electricity demand. Electric vehicles, refrigerators and freezers, washing machines and dryers also have electricity consumption.

The air conditioning in the luxury hotels is mainly decentralized. Electric vehicles are used in the form of golf carts. Task-driven appliances, such as washing machines and dryers, are available in varying sizes and types. In the context of the technical data mentioned above, the central air conditioning system has the highest electricity demand. This is followed by the cooling or freezing rooms and desalination plants. The electricity consumption of air-conditioning, cooling and freezing rooms is largely constant, while the electricity consumption of electric vehicles occurs mainly at night. Task-driven equipment is used at set times and throughout the day. The interviews showed that the fixed time periods restrict a change in electricity consumption. At the same time, due to fixed electricity prices in Seychelles, there is no incentive to modify electricity consumption patterns.

In addition, the proposed measures for the provision of control energy partly presuppose acceptance on behalf of the hotel guests (e.g. automatic switching off of the air conditioning when leaving the room). Especially in luxury hotels with correspondingly high room rates, guests expect that no savings are made in any area – and that includes energy resources as well. However, the measures presented in this paper are not focused on the certainly very important goal of saving electricity. They are rather about a spontaneous or planned fluctuation compensation (which is necessary due to the volatile electricity generation of the renewable energies) in an area that lies outside the perception of the guests.

Providing control energy requires equipment with an IT infrastructure that can process the resulting amount of data and still comply with the corresponding regulations on data protection. The reactivity of the consuming equipment requires smart meters or controllers. In addition to the required technology, it is also mandatory to provide incentives for providing control energy, with monetary benefits being mentioned by the interviewees. If smart charging or V2G concepts are implemented, electrically-powered golf carts can provide control energy. The low utilization rate of electric vehicles creates a potential for positive control power provision through V2G. However, charging at night limits the negative control power at the beginning of the day.

Thermostatically controlled loads, such as air conditioners, cold storage and freezer rooms, can be used for short load shedding without disturbing operation. The frequency and duration of use depends on the frequency in which cold-storage and freezer rooms are entered and opened and the rated output of the units. If the room insulation is frequently interrupted and the units are frequently operated up to their rated output, the duration and frequency of use will be reduced. Task-driven units require a change in usage behaviour to provide control energy. Their use is dependent on the working hours of the staff and guest occupancy. The surveyed hotels currently see no relevant possibility to change the use of these devices.

The study shows that there is a need for research on existing IT infrastructures such as smart metering, energy management systems and in-house load management systems. While cooling systems are discussed in the context of hotels by the academic community, electric vehicles represent a research gap in this regard. In general, the impact of hotel occupancy on individual electricity consumers needs to be explored. In the area of cooling systems, there is a need to examine permissible temperature differences, usage frequency and utilization.

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