Detailed Analysis of Energy Demand and COVID-19 Impacts on Hotel Buildings

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ABSTRACT

The energy demand of buildings within the hospitality sector, notably hotels, is high and diversely distributed. Furthermore, it is rising due to growing needs of convenience per guest. Determination and analysis of electrical and thermal energy is necessary to achieve reduced energy loads. This is hindered by missing concrete data on loads.

Therefore, 24 buildings linked to the hospitality sector are equipped with devices for gathering electrical and thermal energy load data in detail from January 2019 to January 2021, a period markedly affected by the COVID-19 pandemic. The data is used for identifying possible energy enhancements and developing a model predictive control (MPC) algorithm for adapting efficiency improvements. A new methodology is introduced by a classification system for categorizing the hotel buildings in terms of utilization and energy efficiency. The buildings are further differentiated into the four application categories conference, journey, event and wellness. This study also explores the integration of renewable energy sources, including photovoltaic (PV) and block-type thermal power stations (BTTP), combined by district heating (DH), besides conventional oil/gas boilers. A specific concept for collecting data in every category is developed and instrumentation is installed to measure energy demand spatially and temporally resolved for a period of two years.

The unique context of the pandemic provides insights into the resilience and adaptability of energy demand patterns in the hospitality sector. By analyzing the collected data, key energy improvement opportunities are identified in relation to the acquired data for base loads, typical peaks and mid-term impacts like holidays.

1. INTRODUCTION

The tourism sector in Germany accounts for a substantial energy footprint, with an annual consumption of approximately 64.7 TWh, translating to around 5 million tons of carbon dioxide (CO2) emissions [1]. Notably, 4% of these emissions come from non-residential buildings, specifically hotel buildings. Enhancing the energy efficiency of these buildings has a great impact on the total energy demand of Germany. Until now, there is a lack of research focusing on the pathways of energy flow within German hotel buildings. To bridge this gap, a comprehensive study is initiated to explore the distribution and temporal fluctuations of energy usage across these buildings. The initial phase of the research involves categorizing 24 hotel buildings based on their primary usage, size, and thermal/electrical energy source. From these, four buildings -one from each category- are chosen for in-depth analysis using an expanded set of monitoring equipment. This equipment comprises of 40 devices for tracking electrical power and 80 for monitoring thermal power, highlighting the study's emphasis on high temporal resolution with data recorded every minute. A unique aspect of this research is its contribution to the optimization of the MPC algorithm. This advanced algorithm is designed to forecast a system's future performance based on input data [2], with the potential to significantly lower energy requirements through refined control strategies.

2. METHODOLOGY

This study involves the participation of 24 hotel businesses, which exhibit a broad range of energy usage profiles and building standards, particularly in terms of energy efficiency. To ensure comparability among these buildings, key performance indicators for characterizing hotels in terms of their energy needs are identified, and a categorization based on the hotel use case is performed. The Energy Efficiency Number K

$$K = \frac{Total\ Thermal\ Energy\ Consumption + Total\ Electrical\ Energy\ Consumption}{Number\ of\ guest\ nights} \quad (2.1)$$

is introduced. This efficiency indicator offers insight into the energy and power efficiency of a facility relative to its occupancy and duration of stay. In addition, the buildings are partitioned to categories, which depend on the usage. These main categories are ‘vacation’, ‘wellness’, ‘conference’ and ‘business’. The considered characteristic is the floor area allocation of the usage area, as seen in Figure 1.

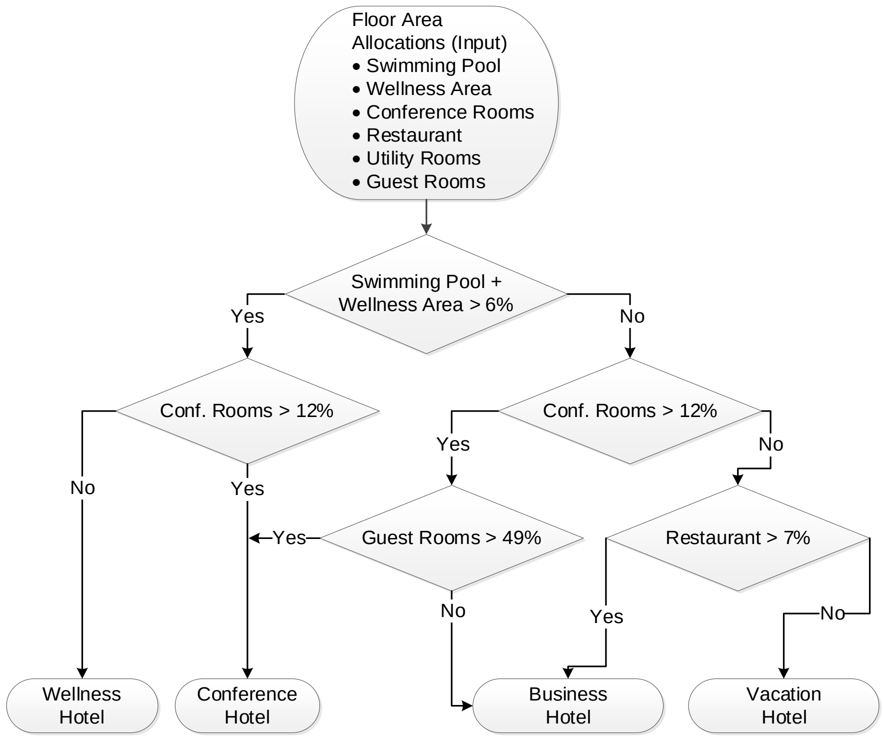

Figure 1: Flow diagram of the algorithm for determining the hotel category according to the floor area allocation.

A threshold value for the K-value is defined for each category to evaluate the building in terms of energy efficiency. For values above the threshold, the term K^+ is used, and for values below, K^- is applied, see Table 1. The value for conference hotels is 70, and for vacation hotels 60. As expected, wellness hotels have a higher energy demand, which is why their threshold value is set at 75.

Table 1: Threshold values for the K-Value based on Hotel Category

	Conference	**Wellness**	**Business**	**Vacation**
$K_{Threshold}$	70	75	60	60

Furthermore, the buildings are categorized based on their number of rooms. In this study, a hotel is classified as large (Z^+) if it has more than 50 rooms, and small (Z^-) if it has fewer than 50 rooms. In summary, the combination of described characteristics results in four subcategories as shown Table 2.

Table 2: Subcategories based on size and efficiency

Rating	**Description**
Z^-K^-	small and less efficient
Z^+K^-	large and less efficient
Z^-K^+	small and more efficient
Z^+K^+	large and more efficient

2.1 Hotel Buildings

The 24 hotel buildings get their thermal and electrical energy from conventional sources like gas/oil boilers and from the national grid. Renewable and local sources encompass PV systems, DH systems which distribute heat generated at a centralized location, and BTTPs. A BTTP is a piston engine running with gas or petrol, whose thermal power is used to feed the heating system of the building and the kinetic energy converted to electrical power.

11 buildings, as seen in Table 3, are equipped with one or more BTTP which deliver thermal and electrical power, 4 have a photovoltaic system and two are connected to a district heating source. All buildings are connected to the national electrical grid and have an oil or gas heating. For a more detailed analysis four buildings are chosen to enable a comparison between the sub-categories and technologies. These are marked in and have a bold font, see Table 3.

Table 3: List of considered buildings

Building	**category**	**rooms**	**Heat Source**			**Electrical Source**			**rating**
			Gas / oil heating	**BTTP**	**DHP**	**Grid**	**PV**	**BTTP**	
	vacation	12	X			X			Z^-K^+
	vacation	15	X			X	X		Z^-K^+
	vacation	17	X			X			Z^-K^+
	vacation	22	X			X			Z^-K^-
	vacation	51	X	X		X		X	Z^+K^-
	vacation	107	X			X			Z^+K^-
	business	13	X			X			Z^-K^+
	business	15	X	X		X		X	Z^-K^+
	business	18	X	X		X		X	Z^-K^+
	business	23	X			X			Z^-K^-
	business	25	X	X		X		X	Z^-K^+
	wellness	14	X			X	X		Z^-K^-
	wellness	28	X			X			Z^-K^-
	wellness	35	X	X		X		X	Z^-K^+
	wellness	73	X	X		X		X	Z^+K^-
	wellness	102	X	X		X		X	Z^+K^-
	conference	18	X			X			Z^-K^+
	conference	60	X	X		X		X	Z^+K^-
	conference	96	X	X		X		X	Z^+K^+
	conference	515	X		X	X			Z^+K^-
V-131	**vacation**	**131**	**X**			**X**			$\boldsymbol{Z^+K^-}$
B-36	**business**	**36**	**X**	**X**		**X**	**X**	**X**	$\boldsymbol{Z^-K^-}$
W-53	**wellness**	**53**	**X**	**X**		**X**	**X**	**X**	$\boldsymbol{Z^+K^-}$
C-96	**conference**	**96**	**X**			**X**			$\boldsymbol{Z^+K^+}$
			Σ 24	Σ 11	Σ 1	Σ 24	Σ 4	Σ 11	

2.2 Energy Monitoring

Monitoring the energy consumption of the 24 hotel buildings represents the primary objective of this study. To facilitate this, watt meters and heat meters are installed in each building. The selected watt meters are IoTaWatt™ devices, featuring 14 input ports to accommodate measurements across multiple phases. These meters utilize passive sensors that clip onto a single wire of a circuit, measuring the magnetic field to quantify current usage. Furthermore, the watt meters are integrated into the hotel management system's controllers, enabling the transfer of data to cloud storage for analysis. Typically, these meters are connected to the main grid inlet and the BTTPs, PV systems or other renewable energy systems.

The measurement of thermal energy demand is conducted using an advanced ultrasonic flow meter, supplemented by temperature probes that are securely attached to the heating system's pipes. This setup facilitates the precise monitoring of the volumetric flow rate $\dot{V}$ and the differential in temperatures between the inlet T_1 as well as the outlet T_2. The calculation of the heat flux $\dot{Q}$ is derived through the formula

$$\dot{Q} = \rho * \dot{V} * c_p * (T_2 - T_1) \tag{2.2}$$

where ρ represents the refrigerant density and c_p the isobaric mass heat capacity. The installation of heat meters is strategically executed, typically positioning them downstream of the central heating boilers or BTTP systems, as applicable. Additional heat meters are deployed across various heating circuits within the structure for comprehensive analysis of the selected buildings. This setup enables the precise quantification of heat demand across distinct sections of the hotel, including guest rooms, conference rooms, the wellness area, kitchen, and laundry facilities. To ensure a comprehensive evaluation, the monitoring period extends over two years, capturing data at one-minute intervals. This rigorous data collection framework supports a detailed assessment of energy usage patterns, facilitating the identification of optimization opportunities for enhanced energy efficiency.

3. ANALYSIS

3.1 Energy Demand Pattern Analysis: Sector-wide Perspectives and COVID-19 Impact on the Hotel Buildings

The global COVID-19 pandemic has profoundly affected various sectors, especially including the hospitality industry. The recorded overnight stays as well as the occupancy capacity of the 24 hotel businesses over the period from January 1, 2019 to December 31, 2020 are shown in Figures 2 and 3, highlighting significant fluctuations due to governmental restrictions and public health measures.

Two critical periods are identified: the first lockdown, starting in the first quarter of 2020, and the second lockdown later in the same year in the fourth quarter. The data reveal a stark decline in overnight stays corresponding to these lockdown periods, underscoring the severe impact of the pandemic on hotel occupancy rates. This analysis provides the extent of disruption caused by the COVID-19 pandemic.

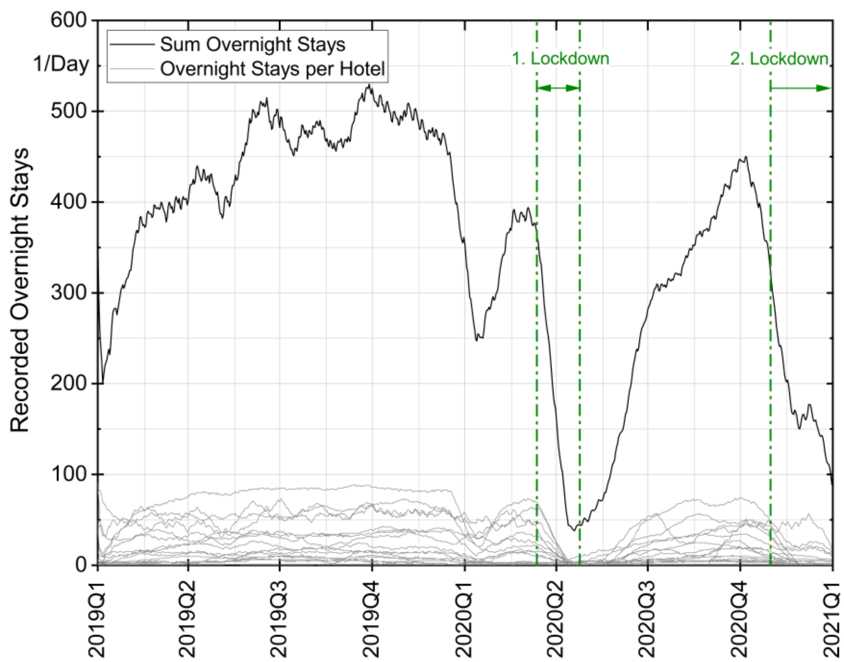

Figure 2: Total number of recorded overnight stays from January 1, 2019 to December 31, 2020

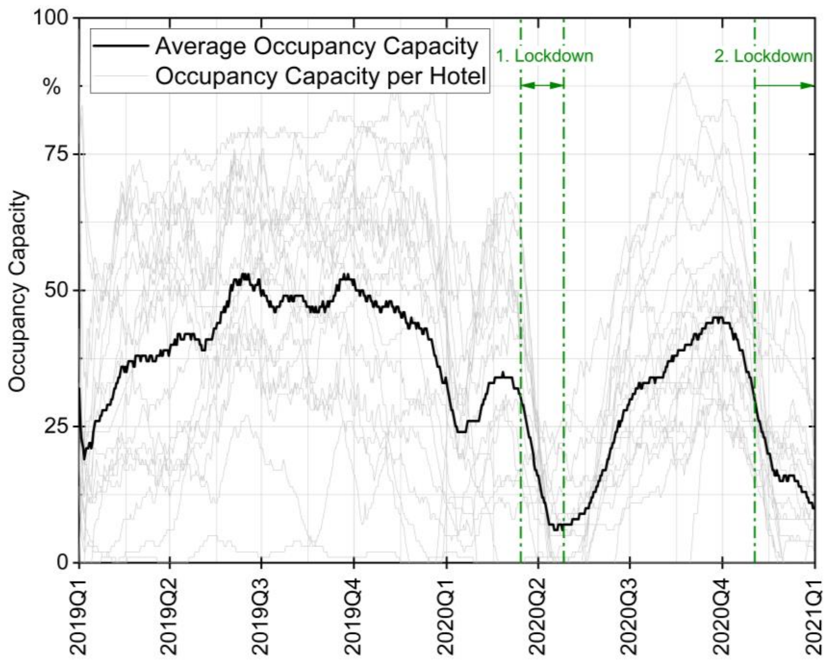

Figure 3: Occupancy Capacity from January 1, 2019 to December 31, 2020

Figures 4 and 5 present the thermal and electrical energy load by type of generation and the average occupancy capacity over the entire measurement period for the 24 selected hotels. In both figures a significant fluctuation are observed in energy loads that correlate closely with changes in occupancy rates.

The data for thermal energy includes contributions from oil/gas boilers, block-type thermal power stations and district heating sources, while the data for electrical energy comprises contributions from the electrical grid, block-type thermal power stations, and photovoltaic sources.

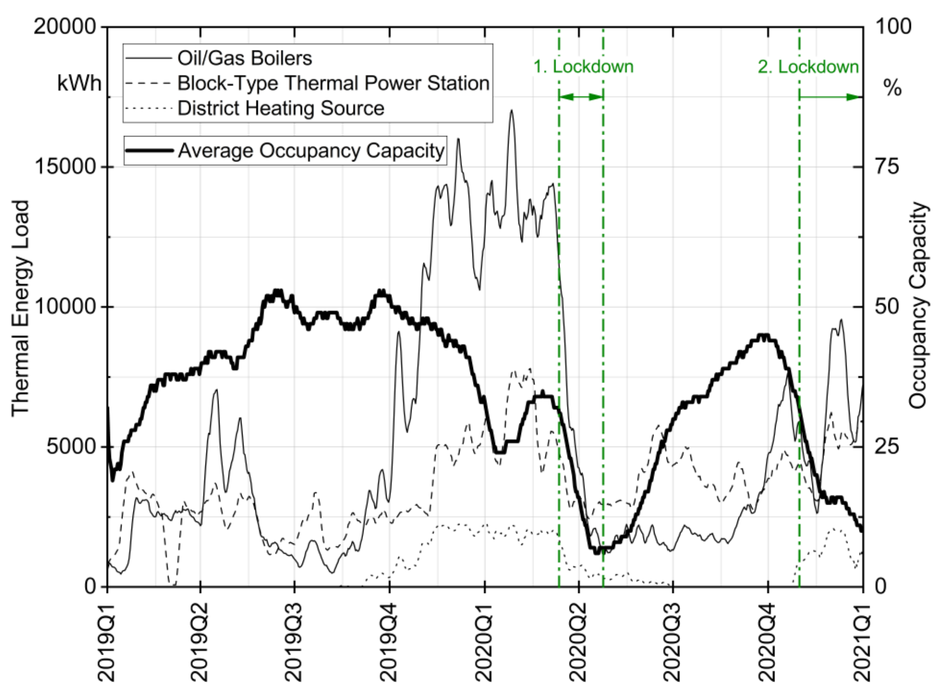

Figure 4: Thermal energy by generation type and average occupancy capacity over the entire measurement period

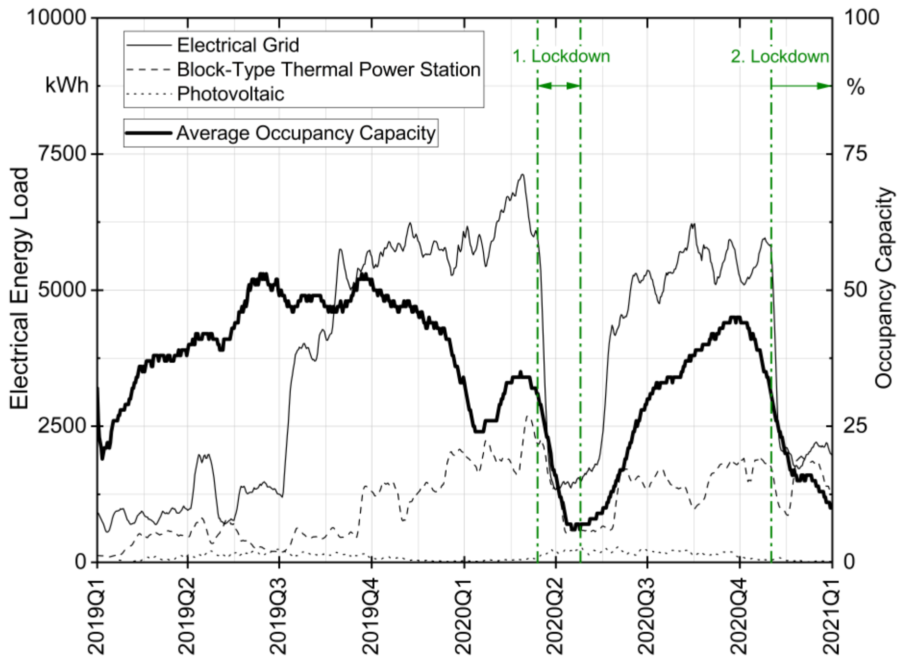

Figure 5: Electrical energy by generation type and average occupancy capacity over the entire measurement period

Similar trends are evident in both figures. Energy loads from all sources exhibit peaks and troughs in response to occupancy variations, with notable declines during the first and second quarters of 2020, corresponding to the COVID-19 pandemic lockdowns. These findings highlight the necessity for adaptable and efficient energy management strategies in the hospitality sector, particularly during periods of fluctuating demand.

The distribution of the 24 hotel businesses across the K-Value, number of rooms (size) and the four main categories is illustrated in Figure 6. This metric serves as an indicator of energy efficiency, allowing for a comparative analysis across different types of hotels. It is observed that hotels above the threshold of 50 rooms are more widely dispersed in terms of room numbers. Fourteen hotels are classified as 'small' (Z^-) and ten as 'large' (Z^+).

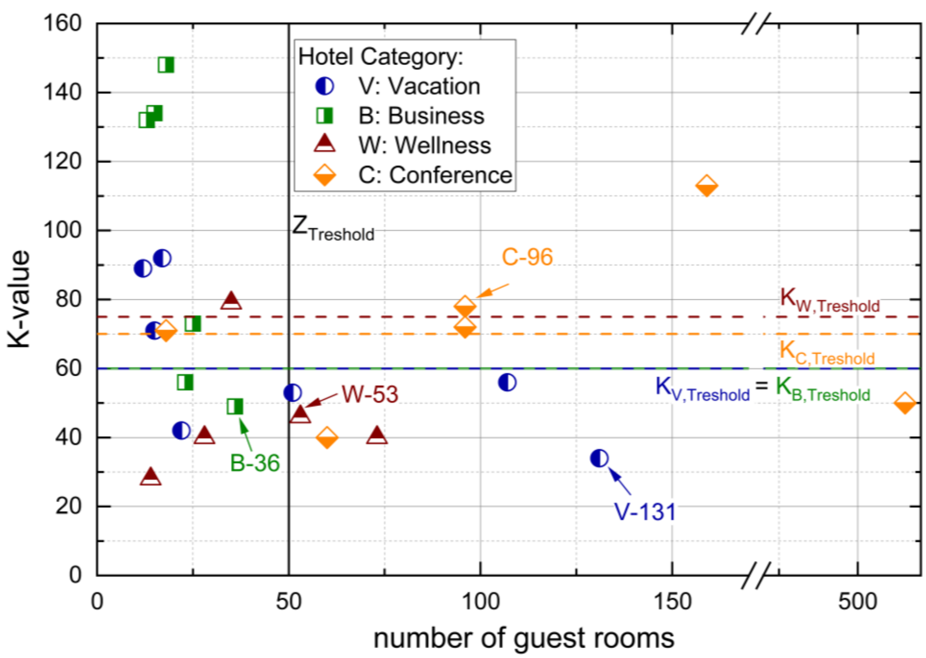

Figure 6: Distribution of participating hotels across the rating categories according to Table 2.

The threshold values from Table 1 have been strategically selected to facilitate an equitable distribution of these hotels across the defined subcategories in Table 2. Hotels with higher K-Values are indicative of higher energy consumption per guest room, highlighting a greater potential for energy-saving interventions. By examining the K-Values, one can prioritize hotels for efficiency improvements based on their energy consumption patterns.

3.2 Focused Case Study: Energy Demand Insights

The analysis of the energy consumption is done for the selected buildings B-36 and W-53 in Germany. The heating period is from September 1st until May 31st. In the following only a fraction of the data could be shown in order to get a short impression of patterns and trends in energy consumption.

The Thermal and electrical energy consumption for B-36 are shown in Figures 7 and 8. Thermal power demand shows a significant correlation to the season, weather summer or winter in regards to outdoor temperature, as seen in Figure 7. The highest thermal energy demand is during winter in the first and fourth quarter, and a lower demand during summer in the second and third quarter. A strong decrease after the first lockdown is evident, too. All tourist related travels were closed by the government during the shutdown in Germany from March to June 2020 and from November to the end of 2020. A decrease in thermal energy for the second lockdown is still visible, but not as significant as in the first lockdown. The thermal power demand is about 2x higher than the electrical.

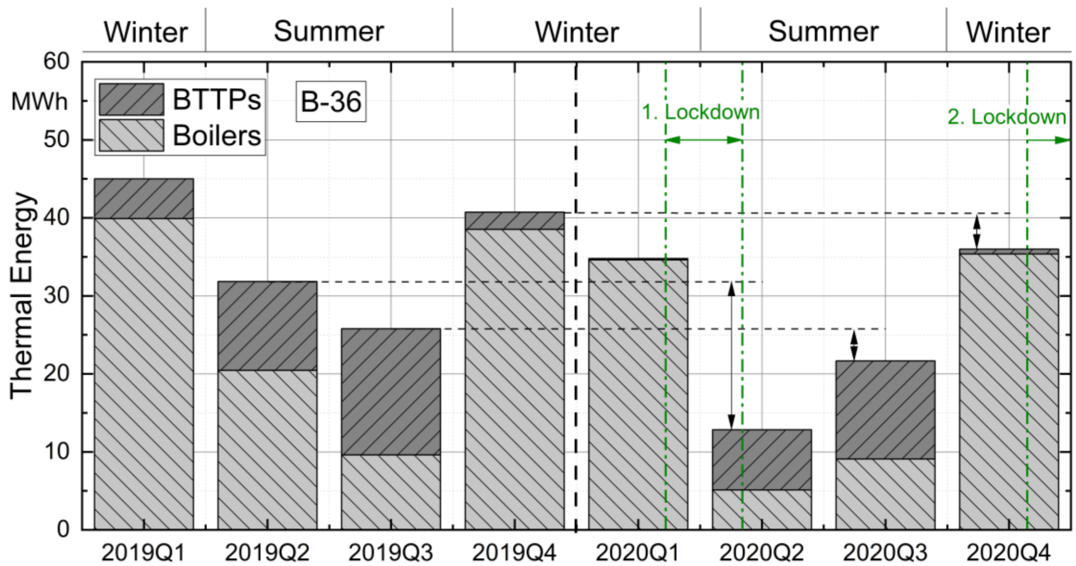

Figure 7: Comparison of Thermal Energy generation type for Hotel B-36

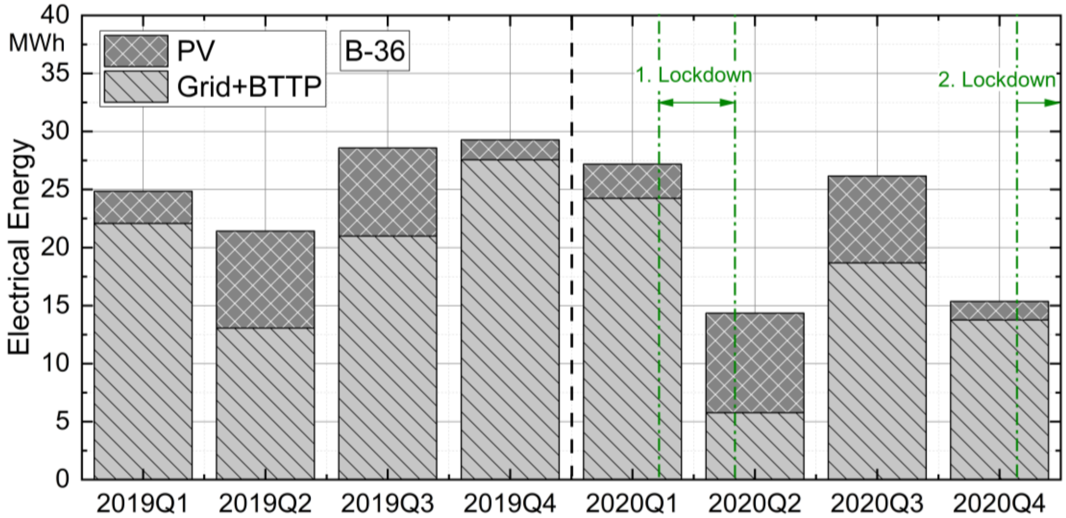

Figure 8: Comparison of Electrical Energy generation type for Hotel B-36

The Thermal and electrical energy consumption for W-53 are illustrated in Figures 9 and 10. This hotel business was closed due to renovation until the end of October 2019. The thermal energy sensors were disconnected during renovation. Therefore, the thermal energy for the first and second quarter of 2019 wasn't recorded. It is assumed to be significantly less than the Thermal Energy during the third quarter. Hotel W-53 offers a large wellness area which needs a lot more heating power than regular guest rooms.

The gap between electrical and thermal energy demand is noticeable in Figures 9 and 10. The much higher demand of thermal energy for Hotel W-53 compared to electrical energy is significant. In buildings B-36 and W-53 additional generators for electrical energy like PV-systems or BTTPs are installed. These local sources decrease the amount of energy taken from the grid and provide thermal power. Concluded, an optimization of the thermal energy production has a much greater impact on the total consumption because of its higher amount.

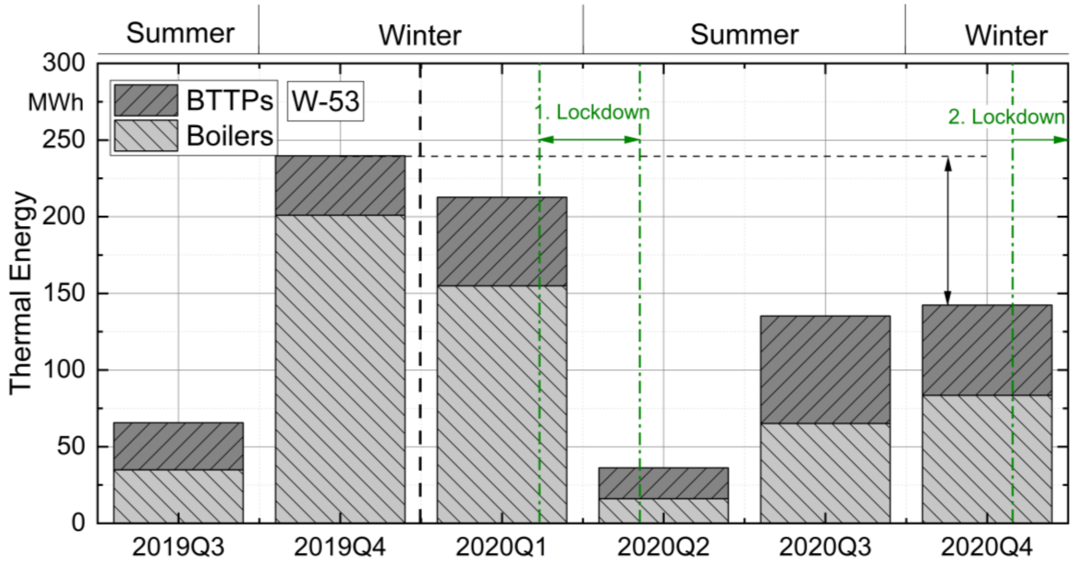

Figure 9: Comparison of Thermal Energy generation type for Hotel W-53

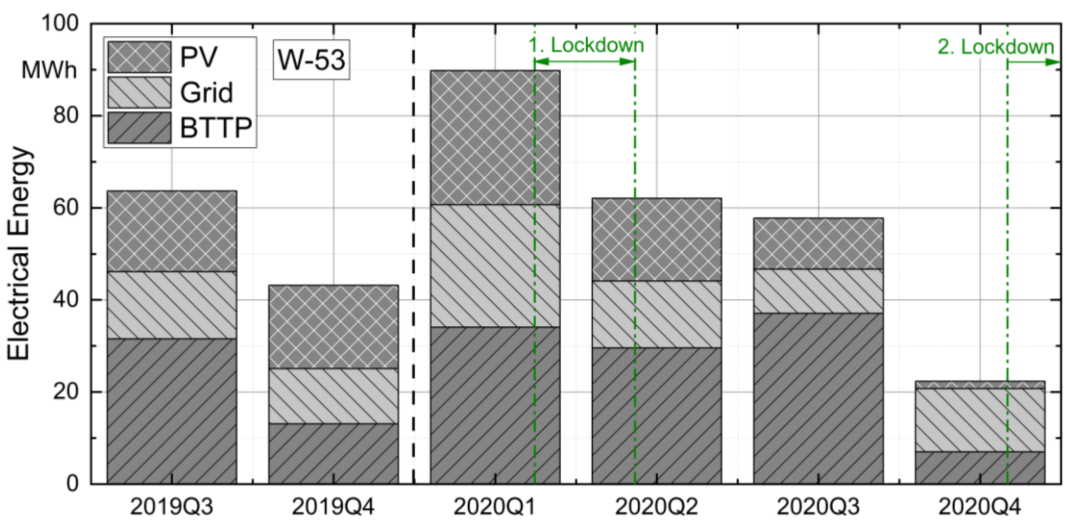

Figure 10: Comparison of Electrical Energy generation type for Hotel W-53Power of Four Selected Buildings

In addition to the consideration of the complete heating period, the analysis for each a week in summer and fall is shown for the building B-36 in Figure 11. The electrical energy consumption of B-36 in a weekly resolution shows a constant basic load which is interrupted by the inducted current of the PV system. The power of the PV-system correlates to the daytime respectively the sunlight as seen in Figure 12. The impact of the PV System is much greater for a week in the summer days. The PV System inducts a peak power of 20kW which is enough to supply the whole building. In this case the power consumption from the grid drops below zero.

Thermal energy production of one of the boilers for the specific week in autumn 2019 is shown in Figure 12 (left). A pattern repeated daily is evident. To further analysis the thermal power demand per hour of several sections is shown in Figure 12 (right). The heating power drops significantly during the night while the heating of the tap water remains constant until morning. It is supposed that the energy consumption for the tap water increases when guests are waking up and using the bathroom facilities. The heating of the main building increases at the beginning of the day, too. There is a daily pattern which is an appropriate starting point for optimization.

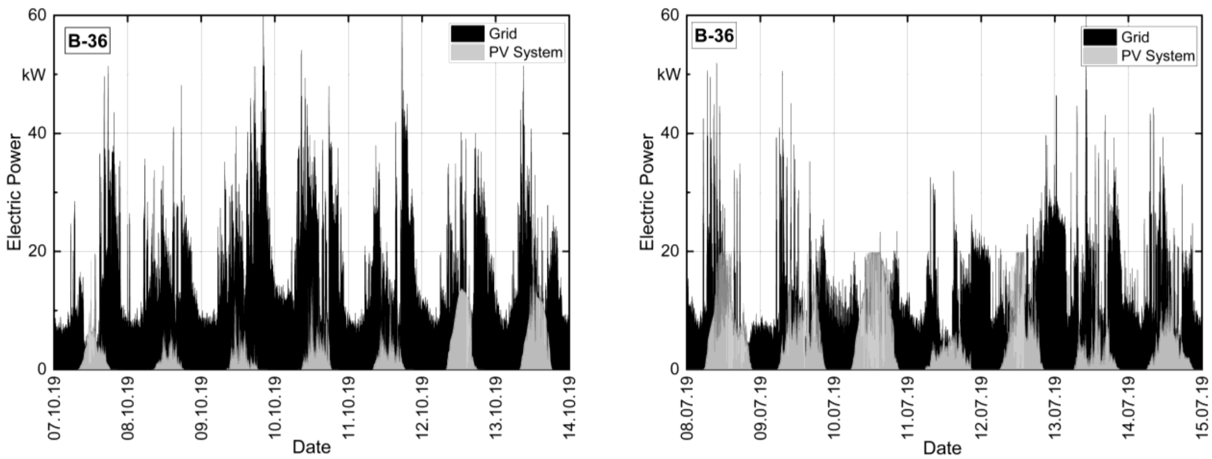

Figure 11: Electric Power Supply and Production for One Week in October (left) and July (right).

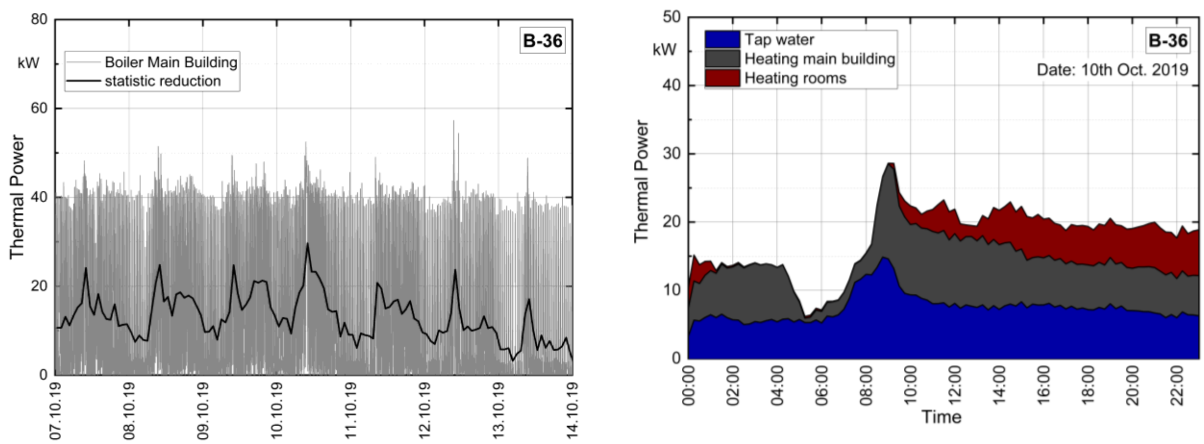

Figure 11: Thermal power demand for a week in October (left) and a day in October (right)

4. CONCLUSIONS

In this study a comprehensive methodology aimed at observing and evaluating the energy utilization within hotel buildings across Germany are devised. This approach entailed the meticulous monitoring of both electrical and thermal energy in 24 hotel establishments over an extensive two-year timeframe. The accumulated data has been instrumental in refining a MPC algorithm tailored to each building's controllable units. This sophisticated algorithm is designed to regulate various power generation and consumption devices, considering a multitude of impact factors detailed in Section 3 of the manuscript.

Although the implementation of the control algorithm is still pending, the preliminary data analysis reveals significant opportunities. The algorithm, developed by an industry partner, evaluates the integration and performance of replacing conventional electrical grid source and oil/gas boilers by BTTPs or Heat Pump Systems (HPS) as well as combined PV+BTTPs or PV+HPSs [3]. It highlights the use case for identifying energy consumption patterns and peak demand periods, thereby paving the way for the formulation of targeted optimization strategies. These strategies are expected to play a crucial role in diminishing the overall energy footprint of the hotel industry. This endeavor not only contributes to the environmental sustainability goals but also offers a blueprint for energy efficiency enhancements across the sector, underscoring the vital importance of predictive control systems in achieving substantial energy conservation.

NOMENCLATURE

Latin Letters

K	Energy Efficiency Number	
$\dot{Q}$	Heat Flux	[kW]
T	Temperature	[K]
$\dot{V}$	Volumetric Flow Rate	[m³/s]
$\dot{W}$	Power Consumption	[kW]

Greek Letters

ρ	Density	[m³/kg]

Abbreviations

BTTP	Block-Type Thermal Power Station
CO_2	Carbon Dioxide
DHP	District Heating Power Station
MPC	Model Predictive Control
PV	Photovoltaic
HPS	Heat Pump Systems

Subscript

1	Inlet
2	Outlet
Ons	Overnight Stay
t	Technical
tot	Total

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