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► **To cite this version:**

Alaa Krayem, Al Bitar Ahmad, Ahmad Al Bitar, Ghaleb Faour, Ali Ahmad, et al.. BEIRUT AS A SMART CITY: REDEFINING URBAN ENERGY. AUB Issam Fares Institut. 2019. hal-04528332

**HAL Id: hal-04528332**

**<https://hal.science/hal-04528332>**

Submitted on 1 Apr 2024

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# BEIRUT AS A SMART CITY: REDEFINING URBAN ENERGY

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## Summary

Global efforts are exerted to improve energy supply-demand balance in urban environments which are characterized by higher population density and levels of energy consumption. Beirut, Lebanon's capital, is no exception in facing such urban challenges, which are compounded by the regular power outages. As such, developing an urban scale energy model for energy management is essential to achieve this goal. This policy brief presents a model developed for the Bachoura area to determine its buildings energy performance. The results are integrated to report the hourly energy use profile spatially distributed over the city, which leads to identifying hotspots and peak hours of energy demands. The model can be used to estimate the potential savings from rooftop solar energy production and recommend targeted energy-use policies to alleviate peaks and ensure an optimal and efficient distribution of resources.

## MAIN RECOMMENDATIONS

- ▶ Predicting electricity consumption patterns in Beirut's urban environment could ultimately help inform smart rationing of the electricity by the power utility company EDL, when the grid is strained. Additionally, it could match local demand to supply from solar energy through smart distribution and optimization of demand management.
- ▶ The developed model could be utilized to test various policy instruments that promote energy savings such as the implementation of building efficiency codes, installation of water heaters, etc.

## Introduction

The expansion of cities worldwide is accompanied by socio-economic problems that range from challenges in providing services to compounding the impact of climate change. One major issue cities face is soaring demand for energy. Consequently, designing energy efficient cities will go a long way in reducing demand for power while also reducing emissions and air pollution. As such, energy modeling has been adopted to simulate buildings' energy consumption at early design stage, evaluate the efficacy of various design options, and optimize the overall performance of building systems in Beirut.

When extending the scope of the energy performance simulation to the urban scale, two main categories of urban energy models can be found: top-down models and bottom-up models. Top-down models are mainly used to explore the interrelations between the energy sector and variables like socio-economic indicators, energy price, and climate. However, they lack technical details and hence fail to study the impacts of new technologies and intervention. Bottom-up models, on the other hand, estimate individual end-uses then aggregate results to get the urban energy consumption.

They are suitable for improvement and technological intervention studies. They can be further subdivided into statistical and engineering models. The former relies on a large amount of historical dataset to estimate energy consumption at the metered data scale. Engineering models apply thermodynamic and heat transfer equations at the building level, leading to high accurate results, and offer the maximum flexibility to test end-use energy conservation measures.

The work presented in this policy brief has been extended from the individual building scale to the urban scale, allowing for the assessment of building to building interactions as well as of buildings to other urban forms interactions.

### **Methods**

Urban Building Energy Model UBEM, which has been utilized in this study, combines the bottom-up statistical and engineering models and communicates results with GIS platform for energy maps generation, used for results analysis and comparison with measured data or surveys to help designers and policy makers.

#### Data collection and processing

The conducted analysis utilized data collected from a range of sources to create the model's dataset, namely:

- Hourly weather data from Beirut International Airport.
- Topographic map to create the digital elevation profile.
- GIS data incorporating buildings' footprints, area, number of floors, year of construction, function.

Cleaning the data was a crucial step to ensure model's consistency and accuracy. Buildings with the following drawbacks were removed from the data set:

- Mismatch of buildings' footprints with their corresponding position in the satellite image.
- Missing entries such as the number of floors, function or EDL electricity consumption.

**Buildings' segmentation:** Beirut buildings were grouped based on two parameters, the building function and the year of construction based on a historical architectural study of the buildings. Building's function helps in setting a building's occupancy patterns and determining internal heat loads, while its year of construction informs about construction materials and methods.

For the specific case of Beirut, five distinguished construction periods were identified based on Georges Arbid's study: 1900 to 1923, 1924 to 1940, 1941 to 1960, 1961 to 1990, and after 1991. Regarding the function, the buildings were grouped into six classes (residential, mixed, hospitals, schools and governmental buildings). In total, 30 archetypes were generated.

**Buildings' Characterization:** Thermal properties were obtained from the Technical Guide for the application of the Thermal Standard for Buildings in Lebanon published in 2005, the simulation software's default library and online libraries.

A priori, non-geometrical properties such as the occupancy and use schedules were set by referring to The American Society of Heating, Refrigerating and Air-Conditioning Engineers (ASHRAE) standards and previous studies. The a priori values were then modified to take into consideration the Beirut context (working hours, occupancy, and heating/cooling systems)

#### Thermal model generation and calibration

Each building was represented by a 3D thermal model, divided into floors, with windows on facades and balconies if residential.

When simulating the energy consumption of each building, discrepancies between the predicted model outputs and the actual metered data from EDL were found. They can be attributed to three categorical errors as follows:

- Systematic errors resulted from the daily 3 hours of blackouts not accounted for during simulations, and from the constraints on indoor temperature and humidity that need to be met despite them being behaviorally unrealistic, such as keeping indoor temperature at 21°C in winter.
- Heating, Ventilation, and Air Conditioning (HVAC) systems operating when they are not supposed to, for example covering all floor's area and operating even under 20°C for cooling.
- Variation of equipment use and occupancy profiles.

### **A Case Study: The City of Beirut**

Beirut city, the capital of Lebanon, holds with its suburbs 50 percent of the urban population. It consumes 12 percent of the total national energy produced while it only covers 0.2 percent of the country's total area. Its building sector accounts for almost all of its electricity consumption. The city and its residents suffer from a minimum of 3 hours of blackouts per day. These key indicators demonstrate that Beirut is an energy-starved city.

In 2015, during the 2015 United Nations Climate Change Conference (COP21), Lebanon pledged to reduce its emissions by 30 percent by 2030 within a conditional commitment. Four years later, the country is still facing a significant challenge to manage its energy sector and integrate renewable energy. Therefore, developing an urban scale energy model could prove to be a very useful tool to assess Beirut's energy resources and provide insights for the management of its energy supply. The developed model could serve as a decision support system by estimating energy consumption patterns and identifying grid peak demands with a spatiotemporal distribution. The latter, integrated with the potential solar production findings, will offer a great potential in estimating the savings and recommending targeted energy-use policies to alleviate peaks and ensure an efficient and optimal resources distribution.

Another feature of the energy model for Beirut is its capability to project energy consumption under normal conditions. Currently, estimates of demand do not account for the suppressed amount of electricity, since during outages, occupants modify their behaviors and alter their energy consumption patterns and preferences.

Therefore, one of the major advantages of the developed model is to provide projected estimates for demand, which are currently underestimated.

**Results**

Data for buildings in the Bachoura area was obtained. After the cleaning process and removal of outliers (buildings with abnormal EDL electricity consumption), 1830 residential and mixed buildings were represented by thermal models. Most of these buildings were built between 1940 and 1990. The difference between the metered data and the predicted data was of 203534 MWh, representing an overestimation of 200 percent. After eliminating the impacts of the systematic errors and the HVAC systems related errors, we found that the remaining disparity was independent of the buildings position and archetype.

More than 70 percent of mixed buildings' floors are residential. Therefore, the majority of the floors in the Bachoura area are residential, sharing similar occupancy schedules.

Accordingly, we could think about energy use and occupancy profiles as the main reason behind the disparities and mismatch between actual and predicted consumption. More specifically, maximum occupancy corresponds to buildings whose electricity consumption is the highest compared to their counterparts with the same number of floors. Therefore, the ratio of the latter consumptions is an indicator of the occupancy level and should explain the aforementioned mismatch. Results showed a strong correlation between this indicator and the ratio of the model's predictions to the actual consumptions, which validates our hypothesis.

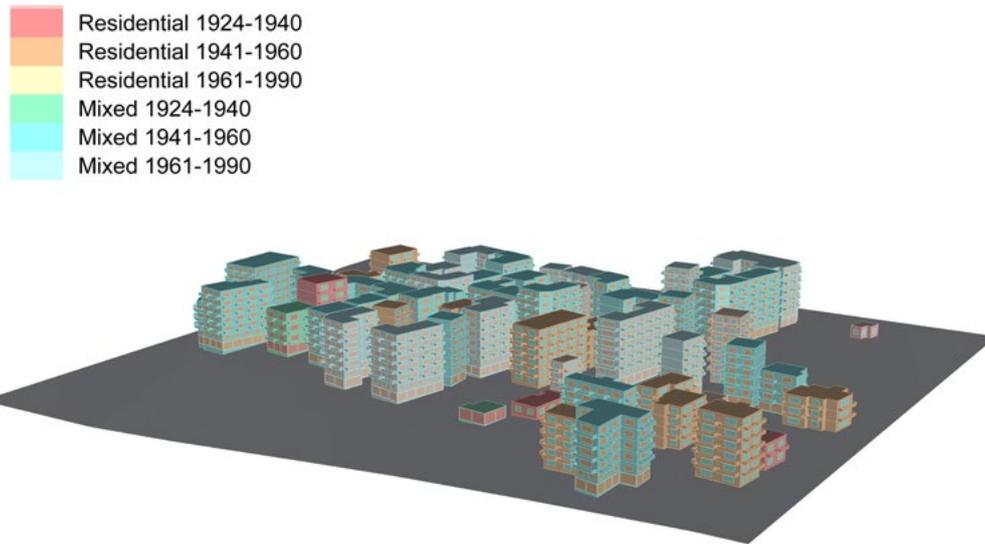


Figure 1: Sample of the generated 3D model of Buildings in the Bachoura area, Beirut, Lebanon

*“The developed model could serve as a decision support system by estimating energy consumption patterns and identifying grid peak demands”*

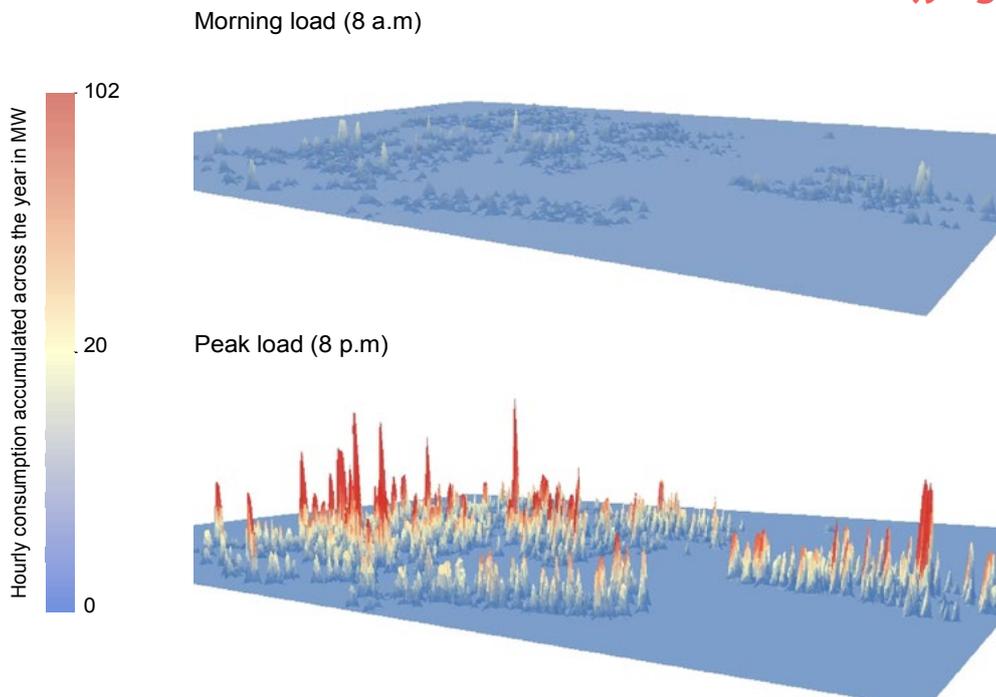


Figure 2: Hourly electricity consumption accumulated across the year during the morning (at the top) and at peak time (at the bottom) for the buildings in the Bachoura area

In terms of load profiles, the model could replicate the overall bimonthly electricity consumption of the buildings. March and April are the least consumption-intensive months while July and August are the highest. The equipment and hot water in residential buildings shared around a third of the total annual electricity consumption, while cooling's share has been estimated to be around 20 percent. Mixed buildings, on the other hand, had 39 percent of their electricity consumption for appliances, followed by 31 percent for cooling.

The electricity consumption results also showed similar spatial clustering as the metered data from EDL with the strongest correlation at 40 meters, i.e. the energy consumption of two buildings is most similar when they are 40 meters apart. Hence, the energy model can be employed to relate the observations of electricity consumption at one location to those at other locations.

#### Model Applicability

The model multi-scalability is recognized spatially when ranging from building to the city level, and temporally when ranging from hourly to yearly resolution. This allows for spatiotemporal energy patterns analysis to allocate hot spots and peak times of energy demands, as shown in Figure 2. Therefore, energy measures can be optimized to specified buildings with high energy demands. Figure 2 shows peak consumptions across the study area in residential and mixed buildings constructed between 1941 and 1990.

#### **Acknowledgement**

We acknowledge the Lebanese University's support through which we were granted access to Microsoft Azure cloud computing.

#### **The Energy Policy and Security Program**

The Energy Policy and Security Program at the Issam Fares Institute for Public Policy and International Affairs at AUB was launched in 2016 as a Middle East-based, interdisciplinary platform to examine, inform and impact energy and security policies, regionally and globally. The Program closely monitors the challenges and opportunities of the shift towards alternative energy sources with focus on nuclear power and the Middle East. The Program has been established with a seed grant support from the John D. and Catherine T. MacArthur Foundation to investigate the prospects of nuclear power in the Middle East and its potential to promote regional cooperation as a way to address the security concerns associated with the spread of nuclear power.

#### **Issam Fares Institute for Public Policy and International Affairs at the American University of Beirut**

The Issam Fares Institute for Public Policy and International Affairs at the American University of Beirut (AUB Policy Institute) is an independent, research-based, policy-oriented institute. Inaugurated in 2006, the Institute aims to harness, develop, and initiate policy-relevant research in the Arab region.

We are committed to expanding and deepening policy-relevant knowledge production in and about the Arab region; and to creating a space for the interdisciplinary exchange of ideas among researchers, civil society and policy-makers.

We thank Prof. Haitham Zaraket for his assistance all throughout, Prof. Jocelyne Gerard for sharing the surveyed data of Beirut, and the technical team at the National Center for Remote sensing.

Special thanks to Prof. Aram Yeretian for his major assistance in archetype generation.

*This work was funded by the CNRS-L.*

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