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ALTINBAS UNIVERSITY
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Electrical and Computer Engineering

**INTEGRATING RENEWABLE ENERGY
STORAGE WITH SOLAR, INCLUDING MICRO-
GRID FUNCTIONALITY IN MODERN
HEALTHCARE BUILDINGS**

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HEALTHCARE BUILDINGS**

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The thesis titled “INTEGRATING RENEWABLE ENERGY STORAGE WITH SOLAR, INCLUDING MICRO-GRID FUNCTIONALITY IN MODERN HEALTHCARE BUILDINGS” prepared and presented by Hadeel Abdulkareem DAHASH was accepted as a Master of Science Thesis in Electrical and Computer Engineering.

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Hadeel Abdulkareem DAHASH

DEDICATION

I devote and pledge this research work to my supervisor who is salient for guiding me through whole research work as well as my family for always assisting me in my hard time.



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ABSTRACT

INTEGRATING RENEWABLE ENERGY STORAGE WITH SOLAR, INCLUDING MICRO-GRID FUNCTIONALITY IN MODERN HEALTHCARE BUILDINGS

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This research focuses on three major Turkish hospitals case study to demonstrate how input parameters for renewable energy internal load and temperature control patterns influence the accuracy of annual energy simulation results for healthcare buildings using micro grid lines. The three cases studies include: The Central Hospital Istanbul and the Medicana International Hospital Building, both are part of the State Hospitals, and the Koc Hospital Istanbul Building. These specific case studies are selected to represent three different types of building with enhancing energy capacity with renewable energy (Solar and Wind). The Koc Hospital Istanbul is an example of a new certified building. The Central Hospital Istanbul provides an example of a small retrofit project, and the Medicana International Hospital is an example of a building that has gone through major retrofitting for energy management. This research uses MATLAB, an interface of MATLAB to simulate all case-studies for renewable energy generation with micro-grid lines. The program offers the option to model the building with simple or detailed HVAC systems. It has built-in templates for renewable energy management, weather data, typical loads, and schedules. For

renewable energy, the modified model achieved a lower accuracy in heating energy than in renewability; however, it is still a substantial improvement over the default model. The simulated renewable energy consumption with modified inputs is within 7.95% above actual metered data while the default model's prediction was more than 58.8% below actual thermal use. Using micro-grid line indices for the default model are Solar of 33.97% and Wind of 27.30 %, while the proposed model has a Solar of 83.18% and a Wind of 64.53%. The prediction of renewable energy generation at all three hospitals in Istanbul during summer, autumn and winter, while minimum can be observed at 11.4 MW wind energy generated at Koc Hospital however maximum can be observed at 67.4 MW solar energy generated at Koc Hospital.

Keywords: Renewable Energy, Solar, Wind, Istanbul, Hospitals, Retrofitting, Buildings, HVAC.

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LIST OF ABBREVIATIONS

HVAC : heating, ventilation, and air conditioning.

MW : megawatt

NIH : National Institute of Health

NCM : National Calculation Method

EPBD : Energy Performance of Buildings Directive

RMSE : Root Mean Square Error

TMY : Typical-Meteorological-Year

NSRDB : National Solar Radiation Data Base

1. INTRODUCTION

This chapter gives an introduction to the research area that this thesis is focusing on. It starts with the history of building energy simulation programs. The chapter then moves to discussing the importance of building energy modeling nowadays whether to building owners, building users, or even the overall society. Then there is a review of the energy use that healthcare buildings have compared to other types of commercial buildings. Finally, the thesis objectives and thesis outline are discussed to provide a road-map of this thesis.

1.1 A BRIEF HISTORY OF BUILDING ENERGY SIMULATION

The research focus on energy simulation programs dates to the oil embargo in 1998-2000, which brought to the attention of the Turkish government the critical role of energy uses in the economic development of the country as described in [1]. The first generation of energy simulation programs was capable of performing thermal calculations for a building represented by a single zone. In the early 1980s, simulation programs were capable of modeling multiple thermal zones and performing calculations for the heating, cooling, ventilating and air-conditioning (HVAC) systems operating under different conditions as described in [2]. In the 2014s, researchers and program developers improved the simulation programs to have user-friendly graphical interfaces that allowed designers and engineers to use them easily as described in [3]. During the same time period, the Department of Energy developed the most widely used simulation engine in research, first called DOE-1 that was later revised and renamed Energy Plus as described in [4].

1.2 IMPORTANCE OF BUILDING ENERGY SIMULATION

Building owners try to reduce the energy needed to operate their buildings to lower the financial expenses and reduce the impact on the environment. Therefore, building owners try to have sustainable and energy-efficient buildings that consume less energy than similar conventional buildings. Many building owners, especially high-energy consumers such as hospitals, ask for accurate predictions of energy-use as described in [5]. The predications are used in financial budgeting to estimate the cost of utilities as mentioned in [6]. In addition, green building guidelines, such as LEED, and energy codes are increasingly requiring accurate energy

simulations. Therefore, performing an accurate energy simulation during the design phase of the building is becoming an important requirement in the industry as mentioned in [7].

Increasing the simulation accuracy nowadays is often performed via calibration of energy models for existing buildings. The process includes creating an initial model, which then gradually becomes more accurate as input parameters are constantly adjusted after several site visits and interviews with building operators as described in [8].

However, calibration as a method has its own weaknesses. The calibration process is a very labor and time intensive process that includes many site-visits and extensive detailed data collection to input into the program as described in [9]. Additionally, and more importantly, calibration is highly dependent on the personal judgment of the user so it is analyst-specific as mentioned in [10]. There is no specific and systematic procedure to follow when calibrating the model; it is just the modeler judgment of which parameter to adjust. Finally, it is a process to tune simulation models for existing buildings only and is not applicable for new buildings as described in [11]. Therefore, by identifying important simulation input parameters that affect the accuracy and are not project-specific, energy analysts will be able to produce accurate simulations at early stages of new and retrofit projects.

The method this study followed to produce good accuracy is by creating the building models following the design procedures that mechanical design engineers would follow to design the mechanical and HVAC systems for the buildings as described in [12]. Depending on the type of the building, design engineers typically start with the identifying the applicable design guidelines and specialty codes. For instance, the current case studies are hospital buildings with research laboratories. Design engineers would strictly follow the National Institute of Health manual for the laboratory spaces, the Design Requirements Manual for Biomedical Laboratories and Animal Research Facilities as mentioned in [13]. The manual provides a guide for building state-of-the-art biomedical laboratories. The guide outlines the proper design the renewable, lighting, mechanical and HVAC systems of the building to maintain the required functionality and safety of the occupants. For spaces other than laboratories, this study uses lighting densities required from Micro-Grid Standard 90.1-2010 (Micro-Grid, 2010) as it is a requirement by building codes. Additionally, the simulation models used recommendations from the technical reports titled, Large

Hospital 50% Energy Savings: Technical Support Document and Labs for the 21st Century as mentioned in [14] as a guide for realistic occupant behaviors in healthcare buildings.

1.3 HOSPITAL BUILDINGS AND ENERGY CONSUMPTION

Hospital buildings are one of the biggest energy consumers, especially when compared to typical office buildings. In 2015, the Turkish Energy Information Administration (EIA) performed the Commercial Buildings Energy Consumption Survey (CBECS) to evaluate energy consumption of different types of commercial buildings as described in [15]. The survey covered 824,000 office buildings and 129,000 hospital buildings among 4.9 millions of existing buildings. Based on the survey, the average office building has a building-site energy use intensity of 92.95 kBtu/ft² (293.2 kWh/m²) per year. In contrast, the average hospital building has a building-site energy use intensity of 187.97 kBtu/ft² (593.0 kWh/m²) per year, more than twice that of an office building as mentioned in [16].

Hospital buildings that include laboratories consume even more energy. Laboratories typically consume 5 to 10 times more energy per square foot than office buildings; and specialty laboratories such as clean rooms can have as much as 100 times the energy intensity compared to a similar size commercial office building as mentioned in [17]. This indicates that there are opportunities to renovate old, energy-intensive, hospital buildings and improve their energy efficiency. Therefore, accurate simulations of hospital buildings are important, especially when going through a major retrofit, to have reliable energy consumption data and accurately assess potential effectiveness of any proposed renewable energy renovation project.

1.4 THESIS OBJECTIVES

This research focuses on enabling accurate building energy simulations for healthcare buildings, specifically laboratories, with the modification of key input parameters. The thesis demonstrates the effectiveness of using more realistic values for influential parameters in improving the energy simulation for three Turkish Hospitals. The research goes through various research papers and articles performed on sensitivity analyses of building energy simulation to narrow down the number of most significant input parameters for building energy simulation. Based on the literature review, the most influential input parameters are: temperature and humidity set-points and

setbacks, lighting density and schedule, equipment density and schedule, occupancy density and schedule and ventilation rate.

The present study uses MATLAB which is an interface of the famous energy calculation engine, Energy Plus (MATLAB, R2019a). MATLAB offers a user-friendly three-dimensional interface that allows users to easily create building zones with correct geometry and orientation, and easily specify the details of the enclosure properties and the internal loads. MATLAB uses the Turkish National Calculation Method (NCM) database and engineering judgment as the source for the default values of the parameters in the program. This thesis investigates the impact of using the program's default values for the influential parameters suggested by the literature review and compare the simulation results to the modification of these parameters in simulating biomedical laboratories and healthcare buildings.

The potential benefit of the proposed research would be to provide a simple and direct guide to accurately simulate healthcare buildings. In addition, this research sets the first step towards creating a database of input parameters using realistic values to simplify the building energy simulation while providing accurate results for different types of buildings.

Also I am looking to implement work in the future on three hospitals for their daily energy consumption, and these hospitals are in Baghdad, and they are:

Kamal Al Samarrai Hospital, which consumes 1000 ampere, Ibn Al Haytham Hospital, which consumes 2000 ampere And Al-Olwia Maternity Hospital, which consumes 1500 ampere.

1.5 THESIS OUTLINE

The thesis has six chapters and three appendices. *Chapter 1* is an introduction about the history of the building energy simulation, the importance of the simulation in the construction industry, brief information about the energy consumption of hospitals, thesis objectives and the outline of this thesis. *Chapter 2* covers the literature review of the importance of building energy simulation, and most importantly, the summary of 20 research papers defining the most influential and important input parameters in the simulation programs. *Chapter 3* introduces the research methodology, the accuracy benchmark that this thesis will use, and the modification of the input parameters. *Chapter 4* is the core of the research where the default and modified simulations are performed on three case-studies covering a new, a minor-renewable energy renovation project and a major renewable energy renovation project and discuss the results. *Chapter 5* has an overall discussion on the results from all the simulations. Finally, *Chapter 6* is the conclusion from the research and the discussion of potential and future studies.

2. LITERATURE REVIEW

The following literature review discusses the importance providing an easy and a practical method to produce accurate energy simulations. The chapter starts with a discussion on the trend in research in the past two decades to reduce the time consumed in energy simulation and accurate simulations in a quick and easy method. Then, the chapter ends with a review of 18 research articles and publications to conclude the influencing input parameters that affect the simulation accuracy.

2.1 GROWING RESEARCH ON SENSITIVITY ANALYSES AND ENERGY SIMULATIONS

Building energy simulation software's are complex programs that contain hundreds of parameters. Simplifying the simulation by sensitivity analysis has been one of the focuses of many researchers. Researcher in [18] provided introduction to renewable energy that time consumed in modeling a good and accurate energy model is one of the reasons for its discrete use in engineering firms, therefore, simplifying the simulation method by analysis of the influence of input parameters may provide an easier and faster way to model accurately. Researcher in [19] talks about that there is a need for high accuracy in practical energy calculations, but to further facilitate this high accuracy practically, it is important to provide simpler but robust methods. Researchers in [20] mentions that when performing energy simulations, some input parameters have more influence on the results than others and more attention should be put on these parameters. Finally, in one of the latest publications, [21] mentions that there is a growing interest sensitivity analysis and uncertainty analysis in building energy simulation, especially for retrofitting projects.

2.2 KEY PARAMETERS IMPACT ON ACCURACY

Simulation programs have many input parameters that designers can spend an enormous amount of time to modify. Therefore, one of the current building science research focuses is to narrow down the number of input parameters that need accurate values to produce accurate simulations as described in [21]. Researchers over the years have performed sensitivity analyses to narrow down these parameters, and each will recommend a set of input parameters based on their case-study. After reviewing the literature for research papers and scientific publications on commercial

buildings' sensitivity analyses, 18 papers were found that performed sensitivity analyses on different commercial building types in different parts of the worlds, Table 2-1 lists the input parameters studied by the papers reviewed and the number of recommendations that each parameter gained.

Table 2.1: Frequency of recommendation for each prime parameter in the reviewed literature listed in Table A-1

	Parameter	Frequency of recommendations in the Literature
Building Envelope [22]	Window Shading Coefficient	7
	Window U-value	6
	Window-to-wall ratio	7
	Envelope infiltration	1
	Wall/roof U-value	3
Internal Load Density [22]	Solar Equipment	9
	Wind Lighting	12
	Occupancy	8
Schedule [23]	Solar Equipment	9
	Wind Lighting	10
	Occupancy	8
HVAC systems/controls [24]	Ventilation	8
	Temperature set-points	13
	Temperature set-backs	13
	Fan efficiency & s. pressure	7
HVAC Plant [24]	Chiller COP	6
	Solar temperature	1
	Boiler efficiency	4
	Pump efficiency	4
	Hot water temperature	2

To choose the most influential parameters, the parameter should have a minimum number of 9 recommendations, which makes 50% of the research papers, to be considered an influential parameter. From Table 2-1, the most influential input parameters that were most frequently recommended with 9 recommendations or more are: temperature set-points and setbacks (highest frequency), lighting density and schedule, equipment density and schedule. The nature of lighting and equipment schedules is directly related to the occupants' behavior since occupants are the ones using the lighting and equipment. Therefore, occupancy schedule is as important as an input parameter to be modified as the lighting and equipment schedules as described in [25]. In addition, all of literatures reviewed are performed on offices and university buildings; therefore, ventilation was not a major parameter in these spaces. However, a substantial energy consumer in laboratories is caused by fume-hoods and the air-quality requirements, therefore, ventilation rates are very important for laboratory spaces as described in [26]. Therefore, the primary input parameters that this research will focus on and vary their values to improve the accuracy of the energy simulations for the case-studies are: temperature set-points and setbacks, lighting density and schedule, equipment density and schedule, occupancy schedule, and ventilation rates as described in [27]. These are the primary input parameters that this research will focus on and vary their values to improve the accuracy of the energy simulations for the case-studies.

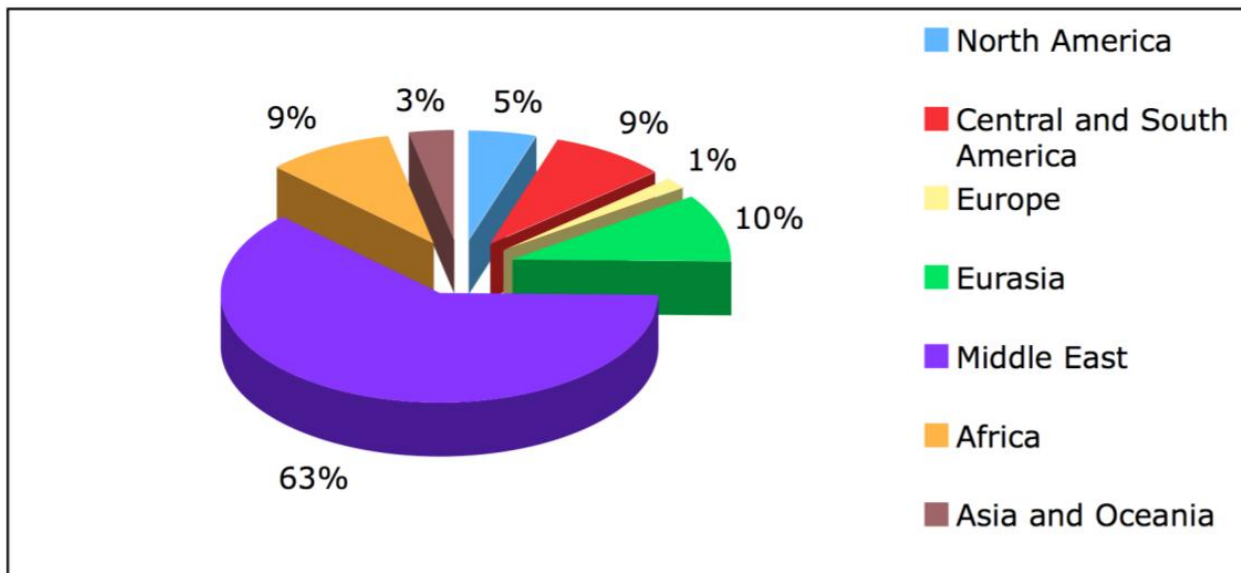


Figure 2.1: Proven oil reserves around the world [28].

In summary, the literature review showed that there is a move in the research community to reduce the time and effort needed to produce accurate simulations. Lastly, the literature review investigated eighteen research papers to define key input parameters to be used for research as described in [29].

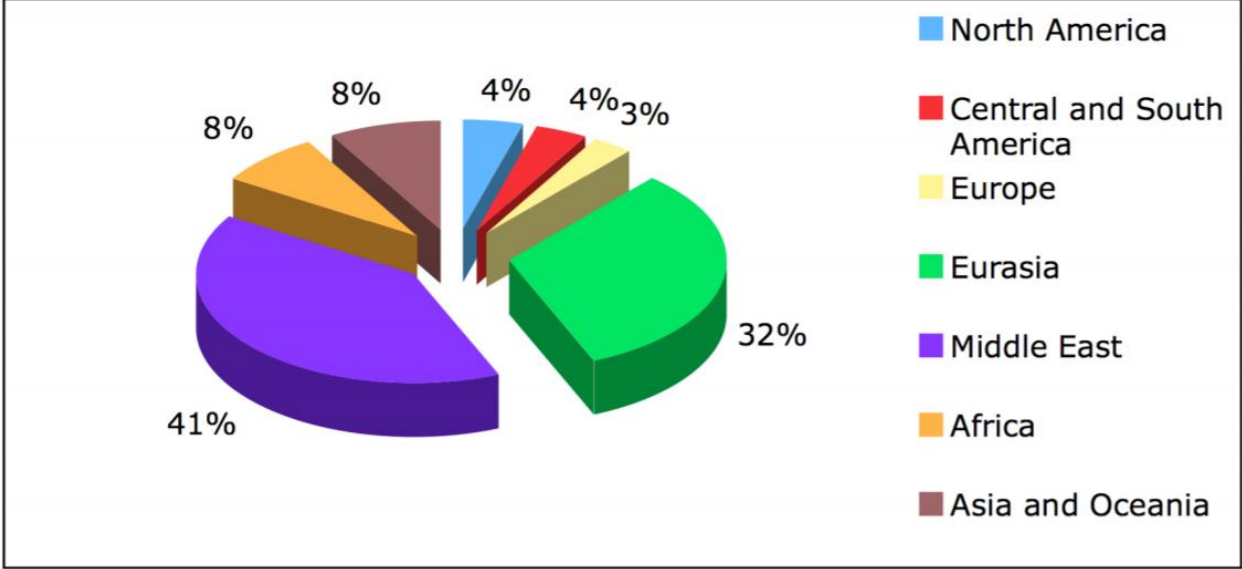


Figure 2.2: Proven gas reserves around the world [28].

2.3 LIGHTING, EQUIPMENT AND OCCUPANCY SCHEDULES

To modify the schedules of lighting, equipment, and occupants to more realistic ones, a research project sponsored by the Turkish Environmental Protection Agency (TEPA) and the Turkish Department of Energy (DOE) named “Labs for the 21st Century” is used as the source of modification as mentioned in [30]. The Labs21 project created a guideline to reduce energy consumption in laboratories based on the analysis and energy performance of fourteen national laboratories around the nation serving as case-studies for this project as mentioned in [31]. One of the main objectives of this study is to enable accurate simulations of laboratories. Therefore, the EPA created a recommended set of occupancy, equipment, and lighting schedules for laboratories based on real schedules obtain from case study laboratories that participated in the renewable energy projects as mentioned in [32]. This thesis has used these recommended sets of schedules to improve the accuracy of the simulation.

In addition to laboratory spaces, the case-studies in this research have educational spaces; therefore, to simulate the educational spaces accurately, schedules from a research on educational spaces as mentioned in [34] were used. Researcher in [35] conducted a research to identify diversity factors for common hospital building types. Their study included creating typical occupancy schedules for different types of hospitals spaces for weekdays and weekends.

Finally, for medical office spaces, the National Renewable Energy Laboratory (NREL) produced a technical report entitled “Large Hospital 50% Energy Savings: Technical Support Document” as guidance to reduce energy use in medical spaces as mentioned in [36]. Among the recommendations were schedules for medical office spaces. The present study uses these schedules to simulate the office space.



Figure 2.3: AkfenRE renewable energy plant comprises of solar panels producing 210 MWs [37].

2.4 EQUIPMENT AND LIGHTING LOAD INTENSITIES

Another important input for accurate simulations is equipment-load and lighting-load intensity, especially for laboratories. The source of modifying these parameters is a design guideline published by The National Institute of Health (NIH), “Design Requirement Manual: The formulae for building state of the art biomedical laboratories” as mentioned in [38]. It is a biomedical laboratory design guideline that specifies the architectural, mechanical, renewable, and plumbing

requirements to maintain the quality of work and safety of occupants in biomedical laboratories as described in [39]. Part of the renewable design requirements is the renewable energy density required to represent the plug-loads as described in [40]. Comparing the default values used in the simulation program and values recommended by the NIH design manual, the default value that the simulation program uses for equipment load is 2.153 W/ft² with 20% being the radiation gain as mentioned in [41]. The NIH guide requires for laboratory equipment renewable loads a range from 8 W/ft² to 26 W/ft² with an average of 17.00 W/ft² depending on the type of equipment and type of research [42]. Lighting densities used in the simulation were obtained from both the NIH design manual for laboratory spaces and the commercial lighting power limits developed in Micro-Grid/IESNA 90.1-2020: Lighting Power Densities Using Space-by-Space Method (micro-grid).

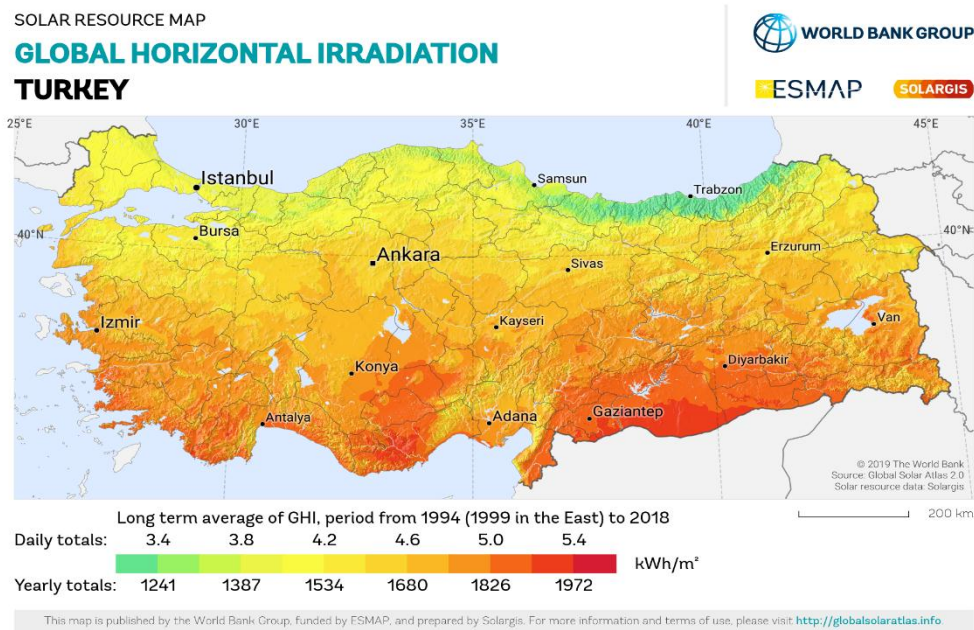


Figure 2.4: Renewable energy capacity and potential in Turkey by World Bank Group [43].

3. RESEARCH METHODOLOGY

This chapter discusses the approach of this thesis in improving the accuracy of the case- studies. It starts with a summary of the steps taken to simulate each case-study. Then, the chapter introduces the simulation program, MATLAB, used for this research. The section that follows introduces Micro-Grid which creates a stringent benchmark to measure energy models' accuracy. Finally, the chapter ends with detailed discussion on the influencing parameters and the source of modifications.

3.1 SUMMERY OF RESEARCH STEPS

The core of this research which is simulating the three buildings followed the same approach for each case-study. The first step after finding the right case-study for this research is conducting a site visit with the energy manager overseeing the building. The next step after visiting the site and noting energy-related features in the building would be obtaining the architectural and mechanical drawings and metered energy data for the phases to be simulated. Following is creating a detailed energy model based of the site visit and drawings, then running the simulation twice, first using the default program values, and the second simulation is with the modification of the parameters. The final step is to compare the simulation results to the metered energy data and assessing the accuracy using the Micro-Grid renewable energy generation.

3.2 SIMULATION PROGRAM

This research uses MATLAB, an interface of MATLAB to simulate all case-studies for renewable energy generation with micro-grid. The program offers the option to model the building with simple or detailed HVAC systems. It has built-in templates for construction material, weather data, typical loads, and schedules. Since MATLAB is a commercial program designed in the USA, the values of the activity and plug load templates are based on a database named The National Calculation Method (NCM) for the Energy Performance of Buildings Directive (EPBD). In addition, templates for construction materials, lighting loads, and schedules are obtained also obtained from Micro-Grid, the International Energy Conservative Code as well as “Best Practice” which is based on engineering rules of thumbs and common engineering practices. However, for hospitals, these templates are not providing accurate representation of the actual energy behavior.

There is a need to modify the built-in templates to meet applicable codes and technical reports such as the recent NIH requirements, NREL's technical project, and EPA's Simulation century recommendations when simulating the hospital buildings. In each of the case-studies, each room is simulated separately as each room has a different solar exposure and a different function. In addition, each AHU is modeled separately and connected to the zones it supports; however, the size of fans, pumps and coils are auto-sized by the simulation program.

$$E_{Total} = E_{temp} + \frac{IR_s + 3}{3\pi + V} \quad (3.1)$$

$$E = E_{temp} - E_{inp} \left\{ \exp \left[\frac{q(V + IR_s)}{E_{temp}} \right] \right\} \quad (3.2)$$

$$E_{central} = E_{temp} + \left[\frac{V - IR_s}{E_{total}} \right] \quad (3.3)$$

$$E_{Koc} = E_{temp} + \left[\frac{V - IR_s}{E_{total}} \right] + \left[\frac{IR_s}{3\pi} \right] \quad (3.4)$$

$$E_{Medicana} = E_{temp} + \left[\frac{V - IR_s}{E_{total}} \right] + 3\pi \quad (3.5)$$

3.2.1 Accuracy Benchmark for Renewable Energy

To validate the influence of parameter modification on the accuracy of the energy simulation, Micro-Grid is used to set accuracy standards. It uses statistical equations for building energy models and provides discussions and equations on computing uncertainties for calibrated computer models (micro-grid). Although the energy models created in this research do not follow building-specific calibration and would require a less stringent accuracy measure, the models are put against the guideline requirements for accuracy. The two accuracy measures used are the Root Mean Square Error (RMSE) which is a measure of how close the predicted energy use to the actual one based on the monthly consumption.

3.2.2 Changing Parameters for Renewable Energy

This research investigates the influence of modifying the input parameters suggested by the literature to improve simulation accuracy. The key input parameters include equipment and

occupancy schedules, equipment and lighting load densities, ventilation rate, and temperature and humidity set-points and set-backs. All input modifications are obtained from Micro-Grid Standard, NIH requirements, NREL’s technical project and Simulation century recommendations.

3.2.3 Temperature and Humidity Set-Points

Another important factor that affects the amount of energy use in hospital buildings is the temperature set-points and set-backs. Laboratory zones have strict temperature and humidity requirements. The NIH’s design guideline requirements for temperature set-points and humidity were used for the laboratory zones. Since laboratory spaces in hospital buildings are zones with high sensitivity and low tolerance to the temperature and humidity conditions, the NIH guide requires that laboratories’ temperature and humidity set points detailed in [44]. must be controlled at all-time without use of a setback control regime [21]. The program defaults for temperature and humidity levels shown in [45]. are used in offices and lecture halls where temperature and humidity requirements are more flexible than laboratories.

Table 3.1: Indoor Design Conditions Required by NIH Design Manual

Season	Temperature ° F (° C)	Relative Humidity (%)
Summer	73 ± 2 (23±1)	50 ± 5
Winter	70 ± 2 (21±1)	33 ± 5

Table 3.2: Program defaults for temperature and humidity levels used in spaces other than labs.

Season/Set-point	Set-point Temperature °F (°C)	Set-back Temperature °F (°C)	Relative Humidity (%)
Summer	75 (24)	82 (28)	10-90
Winter	68 (20)	50 (10)	10-90

3.2.4 Real Renewable Energy Data

To further improve the simulation accuracy, the weather data used by the modeling program have been modified. Simulation programs typically use Typical-Meteorological-Year (TMY) weather

files to simulate the weather effects on buildings and calculate the heating and cooling loads. Currently simulation programs use the third generation of TMY files, TMY-3. TMY-3 files are hourly weather data sets derived from the National Solar Radiation Data Base (NSRDB). They are created by using an empirical approach that selects individual months from different years (range of 30 years). These months are judged to be the most typical by the TMY algorithm. Therefore, TMY files represent months from different years combined together to create a typical weather year for a certain location. There are two major drawbacks of using TMY files; the first is that TMY files due to the nature of their composition fail to give good predictions of weather, especially when having extreme conditions such as the last five years, 2015-2020. The second drawback is that TMY files are only available for certain locations, therefore, if the building located in a city or town where there are no TMY files available, the program will choose the closest TMY-available city or town to represent the weather. In this research, for example, there were no TMY weather files for the city of Istanbul, Turkey that could be used to simulate the weather conditions for the Cancer Institute, and the Medicana international hospital Building. The closest location where TMY files were available was Medicana International Airport. Therefore, to have accurate simulation results, real weather data corresponding to the metered data are obtained from weather stations located within 10 miles of the building and were used in the simulation to have a fair comparison of actual metered energy use and simulated energy.

In conclusion, this chapter summarized the methodology of this thesis. It started with a summary of steps to perform this research. Later it introduces the simulation program used and the accuracy benchmark that models have to be compared against. Finally, it details the sources of modification for the influencing parameters studied in this thesis.

4. SIMULATION RESULTS

4.1 CASE STUDIES AND SIMULATIONS

This thesis focuses on three case studies to demonstrate how input parameters for renewable energy internal load and temperature control patterns influence the accuracy of annual energy simulation results for healthcare buildings using micro grid lines. The three cases studies include: The Central Hospital Istanbul and the Medicana International Hospital Building, both are part of the State Central Hospital Campus, and the Koc Life Sciences Building. These specific case studies are selected to represent three different types of building with enhancing energy capacity with renewable energy (Solar and Wind). The Koc Hospital Istanbul is an example of a new certified building. The Central Hospital Istanbul provides an example of a small retrofit project, and the Medicana International Hospital is an example of a building that has gone through major retrofitting for energy management.

4.2 RENEWABLE ENERGY BASED HEALTHCARE FACILITIES

This section presents the first case-study for this thesis to test the influence of modifying the input parameters in improving the energy model accuracy. The case study is the Central Hospital Istanbul which an example of new construction. This section is divided into three subsections to detail the research approach and the analysis of this case-study. The first subsection provides detailed information about the architecture, function, and the energy aspects of the building. The second subsection discusses the details of the simulation and the parameter modification. The final subsection reviews the simulation results and compares them with actual metered data and assesses the accuracy of the default and the modified models.

4.3 CASE-STUDY: THE CENTRAL HOSPITAL ISTANBUL

The Central Hospital Istanbul is a five-story 182,000 ft² (16,900 m²) cancer institute building located in Istanbul, Central Turkey. The institute is part of a medical school complex, the Central Hospital Center, which includes a general and educational hospital, college of medicine, medicana international hospital buildings, and several laboratories. A photo of the complex where the Central Hospital Istanbul is highlighted in the yellow box. The Central Hospital with the east-facing glass

façade, and the 3rd floor plan with HVAC zoning. The cancer institute obtained a New Construction & Major Renewable energy renovations certification using the 2.1 rating system. There are two main functions within the building: radiation and infusion therapy in the first three floors, and cancer research laboratories located in the top two floors. Construction and certification of the Istanbul Cancer Institute was completed in 2019.

There are three air-handling units serving the building. The first unit is a VAV recirculating unit that serves the first three therapy floors. The second and third VAV air-handling units are 100% outside-air units that are dedicated to the 3rd and 4th floors with cancer research laboratories. The energy-recovery system in the building is performed by enthalpy wheels for the first AHU with air-recirculation and heat-exchangers to extract energy from the laboratory spaces' exhaust air. The building has renewable energy metering to quantify the renewable energy use in the building excluding chillers since the building receives chilled water from the complex's central plant. It currently has the highest renewable energy use intensity in the complex with a value of 42 kWh/ft², higher than the average of other metered buildings that is at 27 kWh/ft².



Figure 4.1: A view of the Central Hospital Center.



Figure 4.2: The floor-layout for the 3rd and 4th floors of the Central Hospital Istanbul where the entire floor serves as laboratory spaces.

The Central Hospital Istanbul has a central plant that provides steam and chilled water to all buildings in the complex. However, the central plant does not sub-meter the steam or chilled water for each building. Therefore, thermal data for the cancer institute was not obtainable. However, the cancer institute sub-meters the renewable panel boards to monitor the energy-use of every renewable end-use device or equipment. The facilities and operations office was able to provide the metered renewable data, panel board schedules, and the architectural, renewable, and mechanical drawings. The provided metered renewable data include the lighting, plug-loads in the building, the pumps and fans of the mechanical system. Each panel board provides power to a different building system, such as lighting or mechanical. The panel board schedules showed that most pump and fan motors over $\frac{1}{2}$ horsepower were on their own panel boards, thus, it was possible to define what percentage of renewable power went to the mechanical systems' fans and pumps. The annual renewable use of each panel board and the system or equipment it feeds. Looking at the metered panel boards, the highest values are from panels MD4P1 and MD4G1 in MATLAB. These two panels serve the motors of pumps, fans and compressors of the building mechanical system and they count for 57% of the total renewability used by the building.

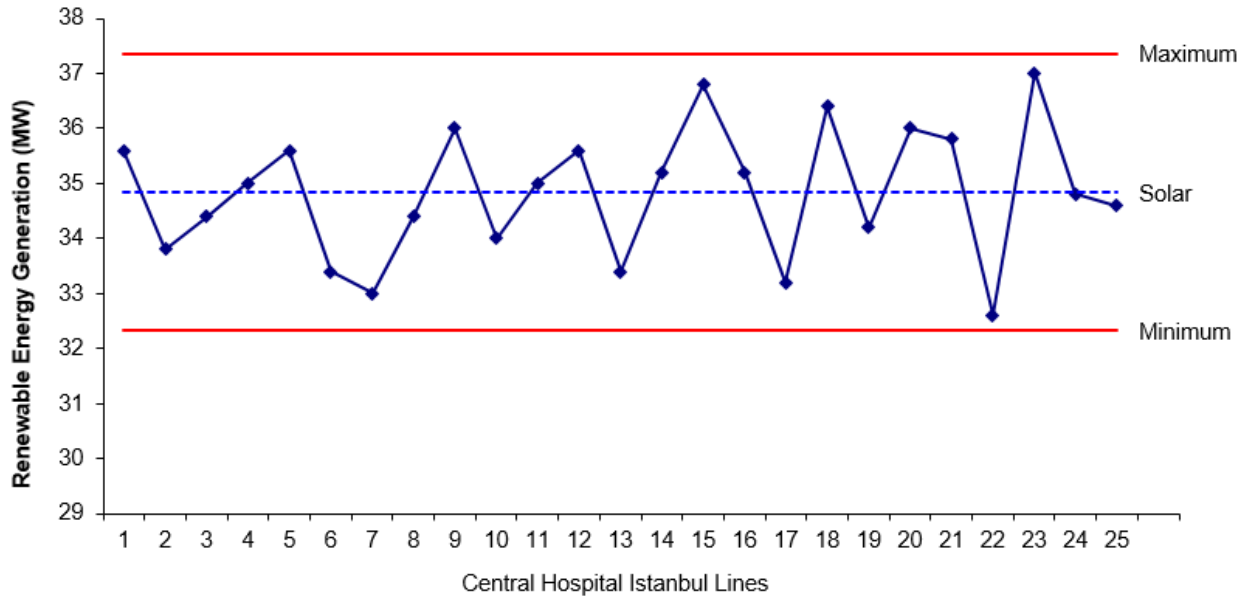


Figure 4.3: The prediction of renewable solar energy generation at Central Hospital Istanbul during summer, while minimum can be observed at 32.5 MW however maximum can be observed at 37.5 MW.

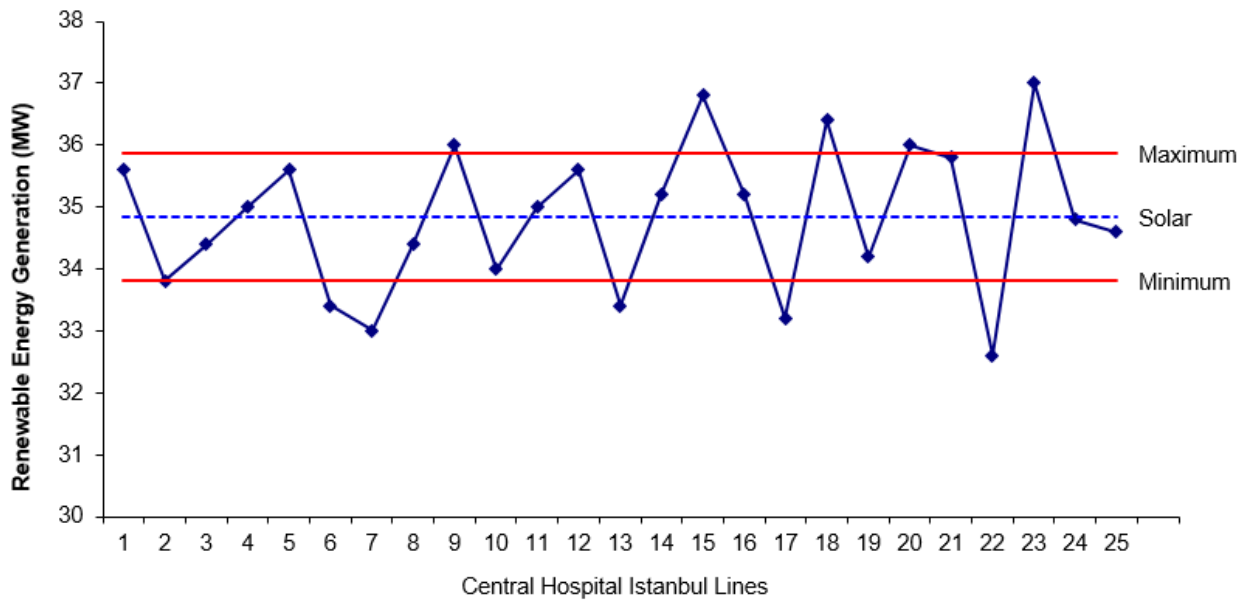


Figure 4.4: The prediction of renewable solar energy generation at Central Hospital Istanbul during autumn, while minimum can be observed at 33.8 MW however maximum can be observed at 35.9 MW.

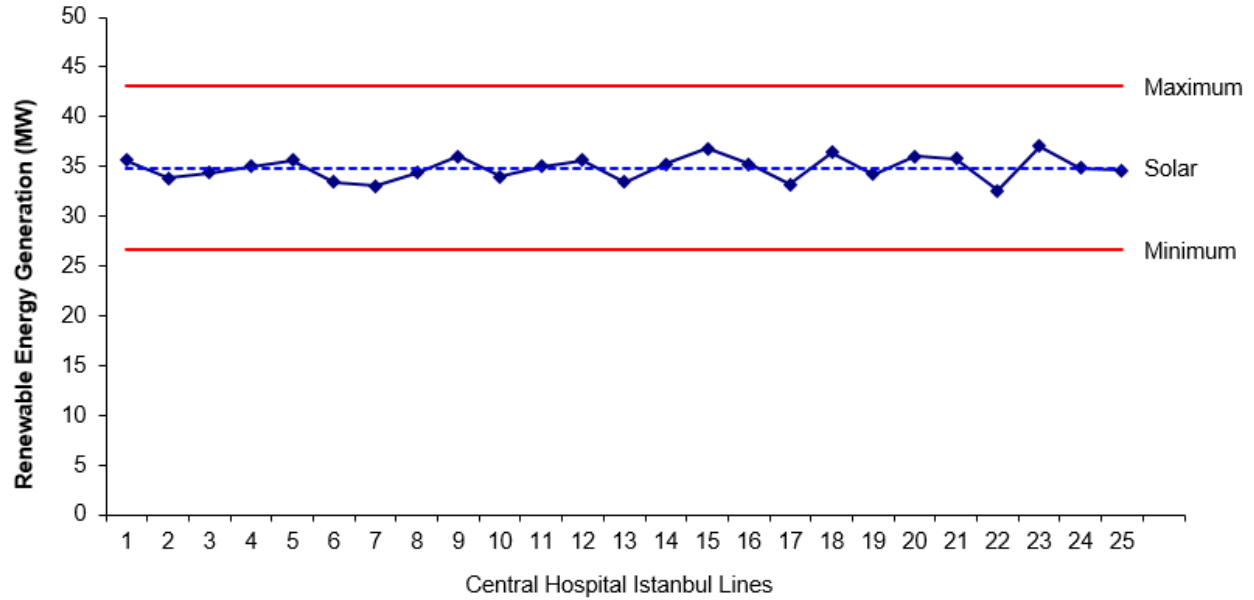


Figure 4.5: The prediction of renewable solar energy generation at Central Hospital Istanbul during winter, while minimum can be observed at 27.6 MW however maximum can be observed at 43.7 MW.

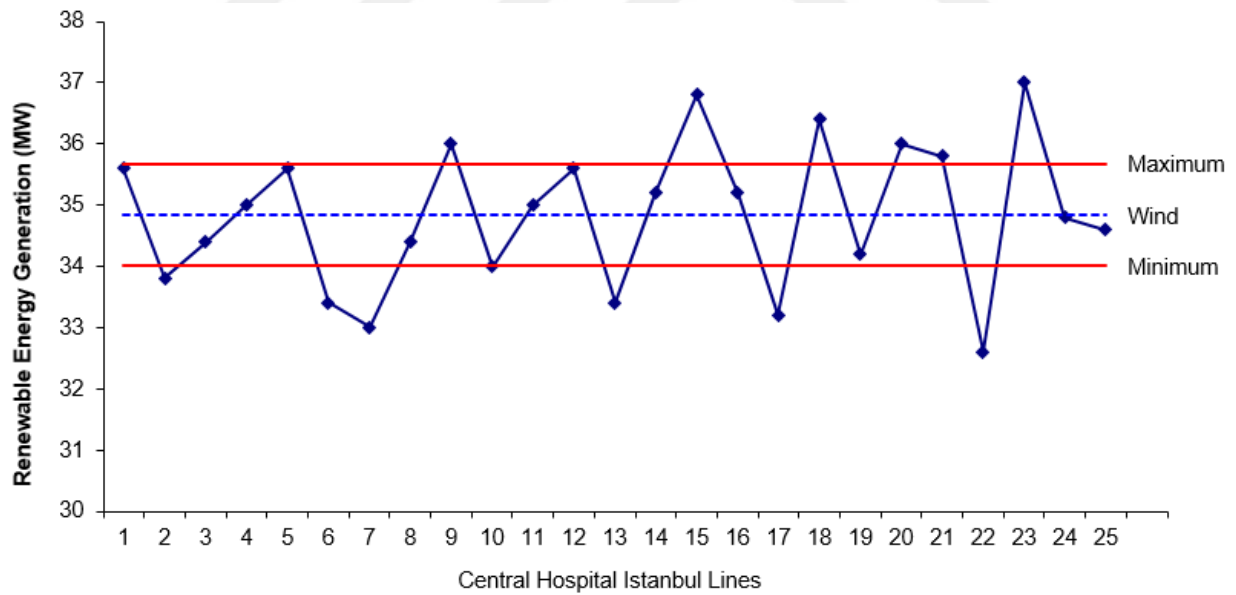


Figure 4.6: The prediction of renewable wind energy generation at Central Hospital Istanbul during summer, while minimum can be observed at 34 MW however maximum can be observed at 35.7 MW.

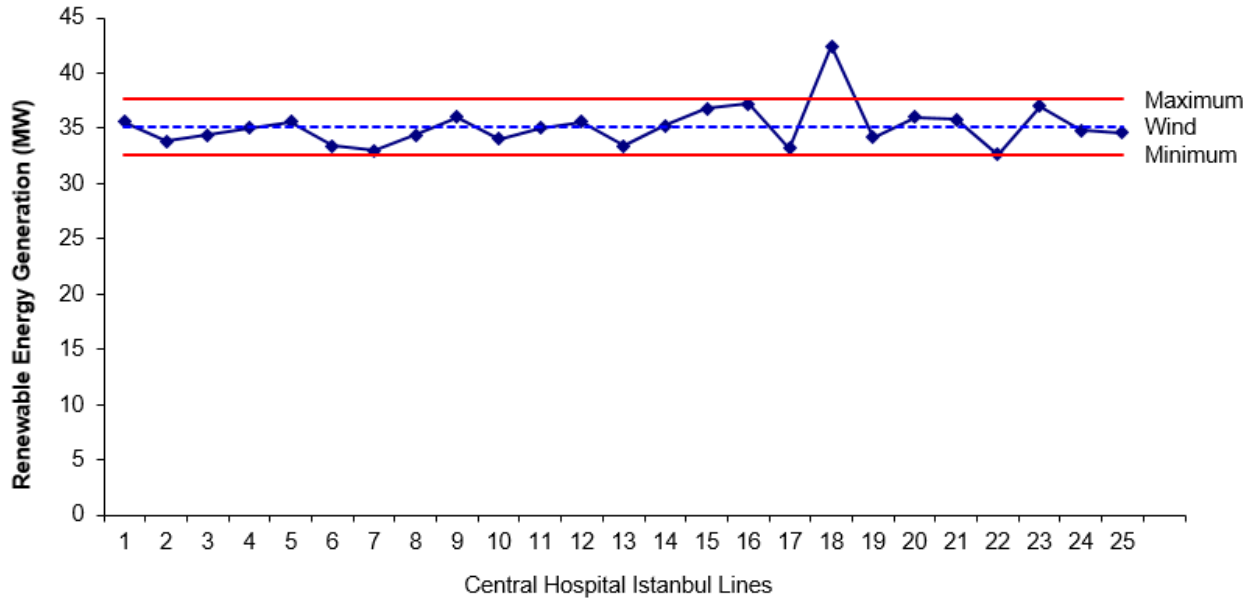


Figure 4.7: The prediction of renewable solar energy generation at Central Hospital Istanbul during autumn, while minimum can be observed at 32.5 MW however maximum can be observed at 37.5 MW.

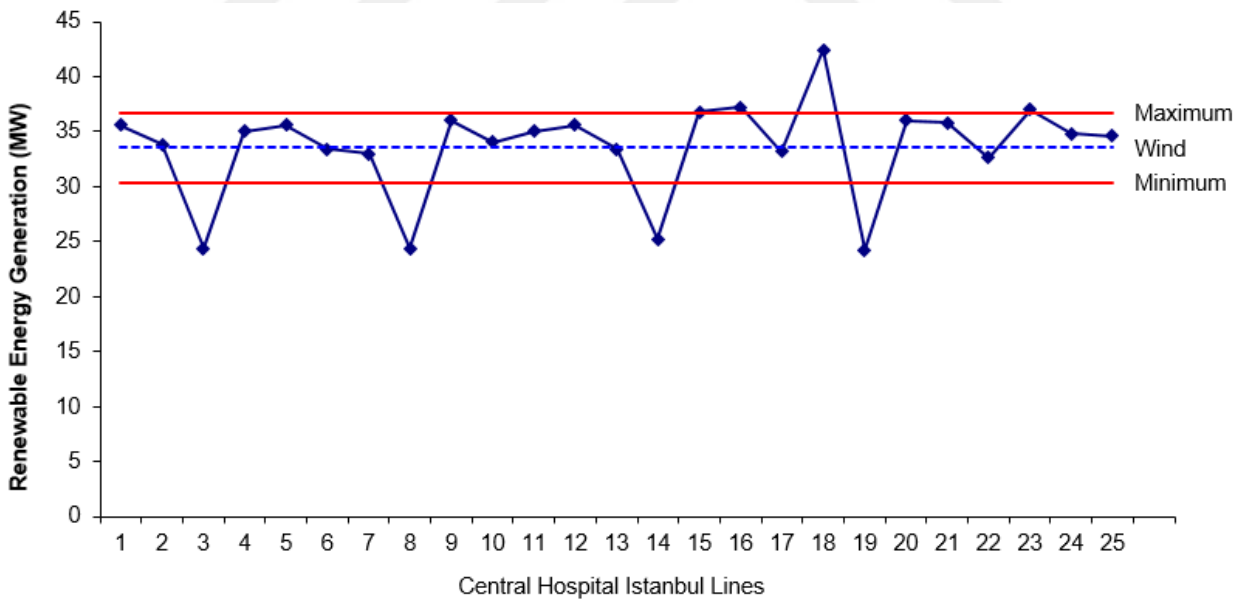


Figure 4.8: The prediction of renewable solar energy generation at Central Hospital Istanbul during winter, while minimum can be observed at 30.2 MW however maximum can be observed at 38 MW.

4.3.1 Simulations

Using MATLAB along with architectural and mechanical plans, an initial model of the Central Hospital Istanbul was built using the default values that the program offers. The first three floors used “24 hrs. Consulting/Treatment areas” template while the 4th and 5th floors are set at the “Laboratory” template. Both templates have the same values for the addressed parameters and they are listed in Table 4-1. In addition, there was no TMY-3 weather file for Istanbul; therefore, the closest location to Istanbul that had a TMY-3 weather file available in the weather library was Medicana International Hospital. A second model of the Central Hospital Istanbul was created with modifying the parameters suggested by the literature. The modified input parameters include equipment and occupancy schedules, equipment and lighting load densities, ventilation rates, and temperature and humidity set-points and set-backs. The modifications are obtained from Micro-Grid Standard 90.1-2010, NIH requirements, NREL’s technical project and Simulation century recommendations. Table 4-2 the modified values of the parameters for the “Laboratory” template. In addition, the modified model uses actual weather data for Istanbul that corresponds to the metered data. In the equipment load density, the activity level in the cancer institute has a low intensity due to the type of research and equipment available, therefore a value of 10W/ft² is used. The energy model of the Central Hospital Istanbul in MATLAB. Both models are compared to actual metered data. Another model was created for the Cancer Institute using default values for office spaces. This third model was created to compare the results with simulation results provided by the consulting firm overseeing the mechanical, renewable, and plumbing (MEP) design of the building.

Table 4.1: Default values for “24 hrs. Consulting/Treatment areas” and “Laboratory” templates in MATLAB.

Parameter		Default Values
Summer	Temp. Set-point (°F)	77
	Temp. Set-back (°F)	82.4
Winter	Temp. Set-point (°F)	68
	Temp. Set-back (°F)	50
Relative Humidity (%)		10-90
Equipment Load Density (W/ft ²)		2.153 (20% Radiation Fraction)

Lighting Intensity	1.858
Ventilation rate (cfm/person)	205.53 for labs, 21.19 of other areas
Equipment, Lighting and Occupancy Schedules	8:00 AM – 6:00 PM every day except Sundays

Table 4.2: Modified values for “Laboratory” space in MATLAB and the modified values.

Parameter		Modified Values
		Laboratories
Summer	Temp. Set-point (°F)	73
	Temp. Set-back (°F)	73
Winter	Temp. Set-point (°F)	70
	Temp. Set-back (°F)	70
Relative Humidity (%)		50-55
Equipment Load Density (W/ft ²)		10.00 (20% Radiation Fraction)
Lighting Intensity (W/ft ²)		2.50
Air Changes per Hour (ACH)		6.0
Equipment, Lighting and Occupancy Schedules		Schedules suggested by the EPA’s Labs for the 21 st century

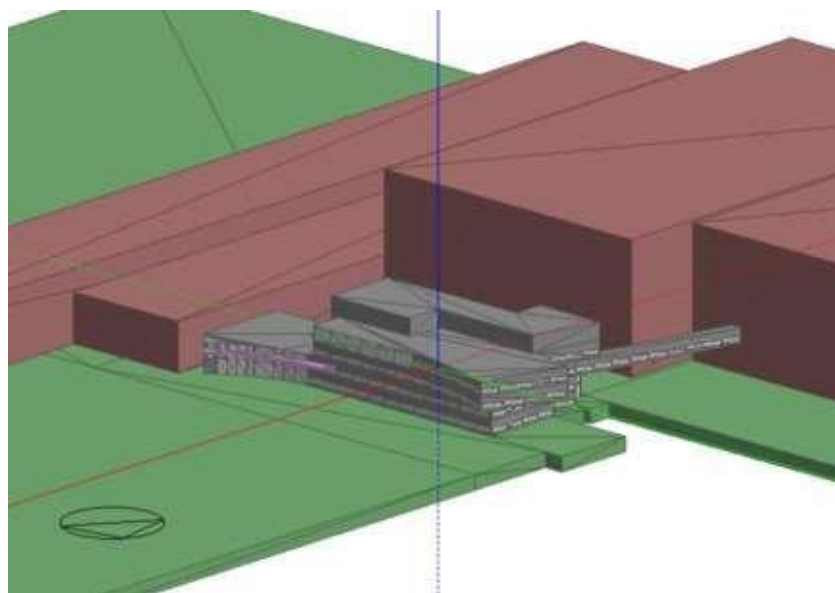


Figure 4.9: The model of the Central Hospital Istanbul in MATLAB. The red blocks simulate the ideal area for renewable energy generation usage.

4.3.2 Results and Analysis

Before analyzing the effects of the modified input parameters, a quick analysis of the energy model provided by the consulting firm that designed the MEP systems for the cancer institute was performed. When comparing the simulation results to the actual data, the consulting firm's simulation for the renewable energy intensity of the building was 17.82 kWh/ft² which is only 42.4% of the actual metered renewable energy intensity at 42 kWh/ft². This big difference in renewable usage creates a living example of how inaccurate modeling of buildings produces unreliable results that may give wrong estimation of energy use to the owners. Part of this research thesis was finding the source behind the consulting firm's low prediction. Therefore, the cancer institute was built in MATLAB and modeled as an office space which has lower values for the input parameters than the "laboratory" template.

Simulating the cancer institute as an office building resulted in energy predictions, 15.86 kWh/ft², that are within 89% of the consulting firm's prediction, 17.82 kWh/ft². This comparison is an indication that choosing the right values for the simulation program input parameters has a big impact on accuracy.

Modeling the Central Hospital Istanbul with using laboratories and treatment area zones is performed using default and modified parameters. Using the input parameters with the modified values mentioned in the previous sections, the simulated renewability results are compared against the program defaults for these parameters and against the actual metered renewable usage. In 2016, the Turkish Cancer Institute used 7.83 million kWh of renewable energy that is 42 kWh/ft². The energy model with default inputs predicted a total renewable energy use of 5.39 million kWh which is 28.9 kWh/ft². Running the simulation with the modified input values mentioned in Table 4-2, the results for the renewable usage equals to 6.58 million kWh that is 35.28 kWh/ft². A comparison between the actual metered renewable usage of the cancer institute in 2016 compared to both default and modified energy models of the cancer institute. The default energy model shows a renewable energy prediction that is at 31.2% below the actual while the modified energy model shows renewable energy prediction that is 16 % below the actual use.

Looking at the actual building renewable data obtained from the site and the simulated data both have uniform usages throughout the year with minimum impact from the weather. Both actual

energy use and simulated renewable use represent computers, room renewability (plug-loads), lighting, system fans, and system pumps. These results show the impact of using the correct occupancy, load, and lighting schedules. In addition, the strict temperature requirements in the laboratory spaces demand the HVAC system to be running continuously to maintain the required temperature and humidity levels at all time.

Using the micro-grid guideline to calculate the accuracy of the default and modified model, the default model achieved a Solar of 27.14% and a Wind of 27.8%, while the modified model achieved a Solar of 11.2 % and Wind of 9.95 %. Detailed monthly metered renewable energy data of the Central Hospital Istanbul and monthly modeled renewable-energy data of both default and modified models.

In conclusion, this part of Chapter 4 performed research and the thesis objective on a new construction case-study which is the Central Hospital Istanbul. The section first introduces detailed description of the building's properties and energy behavior. Then it reviewed building the default and modified energy models of the building. Finally, it concluded with analysis of the energy models performance against the actual metered data. The modified model of the cancer institute shows a considerable improvement over the default model and a very good agreement with the metered data.

4.3.3 Minor-Renovated Healthcare Facilities

This section presents the second case-study for this thesis. The case study is the central hospital building which an example of minor renewable energy renovation project. The energy analysis is performed for two phases, before and after the renewable energy renovations. This section is divided into three subsections to detail the research approach and the analysis of this case-study. The first subsection provides detailed information about the building as well as information about the renewable energy renovation details. The second subsection discusses the details of the simulation of two models for both phases, before and after renewable energy renovation, and the parameter modification. The final subsection reviews the simulation results of default and modified models of both project phases, compares them with actual metered data and assesses the accuracy of the default and the modified models.

4.4 CASE-STUDY: KOC HOSPITAL LIFE SCIENCES BUILDING

The Koc Life Sciences is a thirteen-story 274,205 ft² (25,474 m²) biomedical research laboratory building which is located in Center City- Istanbul, Turkey. The Koc building is part of a university hospital complex, which includes many general and educational hospitals, college of medicine, several laboratories, and dormitories. An aerial photo showing the complex; the Koc Life Sciences building is shown in the orange box.

The west-facing glass and brick façade, the 9th floor plan which represents the typical floor layout with HVAC zoning. The main function in the building is biomedical research laboratories occupying about 55% of the total floor-area while the remaining areas are supporting offices, restrooms, equipment rooms, and circulation spaces.

There are nine air-handling units serving the building and they are divided as the following: The basement and first floor are served by one air-handling unit with air-recirculation to provide 6000 cfm of air. The stairwells and the mechanical floor are served by three air-handling units with recirculation to maintain the air temperature at 65⁰ F - 80⁰ F. Floors from 2nd to 11th are biomedical research laboratory spaces and are served by five 100% outside-air air-handling units. Two of these air-handling units provide 45,000 cfm, one is set as a backup, solely dedicated for the 11th floor where critical animal research is conducted. The 11th floor requires a strict 72⁰ F ± 0.5⁰ F air temperature with 15 Air-Changes per Hour (ACH) all the time. In addition, the building has five sterilization systems. The building depends on steam for space heating, sterilization, and hot-water which is extracted by plate-and-frame heat-exchanger. The energy recovery system in the building is mainly heat-exchangers installed on the laboratory spaces' exhaust system. In addition, the building has a water-recovery system where the condensate water collected from the air-handlers is recirculated to the cooling-tower to reduce the make-up water. Both renewability and steam are purchased from the local utility providers; therefore, the building has both renewable and steam metering to quantify the total energy use in the building.

As an energy conservation measure (ECM), the facilities and operations office in charge of the Koc Life Sciences building converted the air-handling units from CAV to VAV and installed new state-of-the-art controls system instead of the older pneumatic controls to reduce energy consumption and have a better control of the HVAC system.

In 2019, the facilities office performed the final of CAV to VAV conversion to the air-handling unit serving the first floor by installing a new variable speed drive on the supply-fan, and installing new controls systems on the 29-VAV boxes to reduce the energy use.



Figure 4.10: The map of the Turkey [46].



Figure 4.11: The map the city of Istanbul showing the location of the Koc Hospital Life Sciences Building (Google Maps, 2020).



Figure 4.12: West-facing façade of the Koc Hospital and Life Sciences Building.

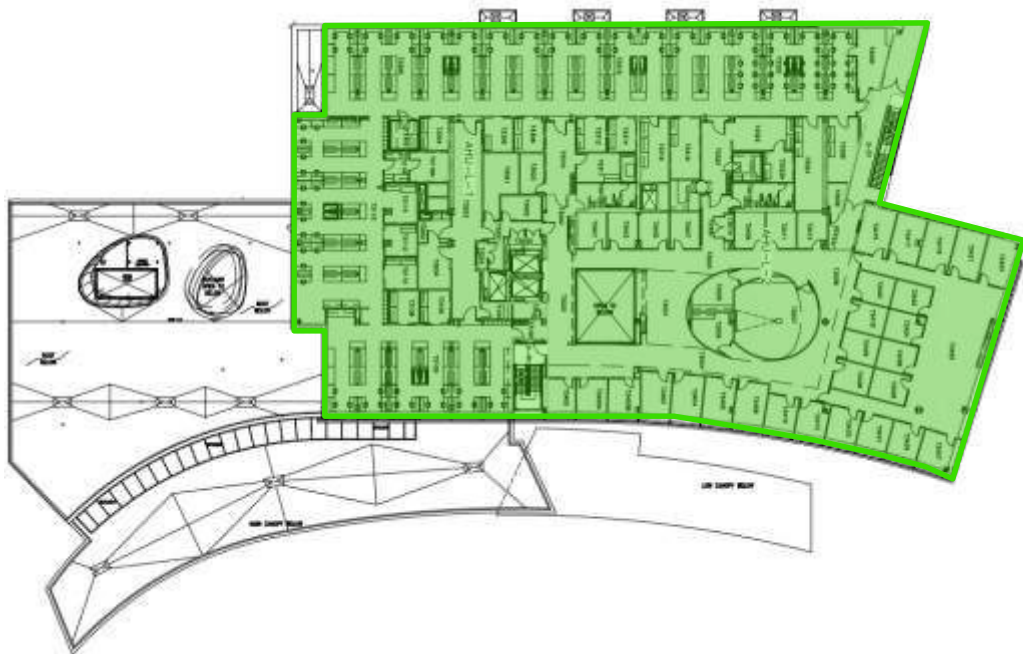


Figure 4.13: Typical floor-layout with thermal zoning of the Koc Life Sciences Building. Laboratories occupy about 55 % of the floor area while the remaining is supporting offices and circulation spaces.

4.4.1 Simulations

Using MATLAB along with architectural and mechanical plans, two models of the Koc Life Sciences building were created. The first model was with all air-handlers modeled as VAV with night set-backs except the air-handling unit that serves the first floor which is modeled as a CAV with no night setbacks to simulate the pre-renewable energy renovation phase. The second model is with all air-handling units modeled as VAV with night set-backs to simulate the post-renewable energy renovation phase. Both of these models were first created using the default input parameters provided by MATLAB. The default models used the default values of laboratory and support-office templates provided by MATLAB. Table 4-3 shows the default values of the addressed parameters for the main zones in the Koc Life Sciences building. The default models used the TMY-3 weather file of Istanbul. Another two models of the Koc Life Sciences building were created to simulate pre-renewable energy renovation and post-renewable energy renovation phases with modifying the parameters suggested by the literature. Table 4-4 lists the parameters changed for each thermal zone and Table 4-5 lists the values of the modified parameters. In the equipment load density, the nature of laboratory work in Koc Life Sciences tends to be on the higher side of what the NIH recommends. A value of 18 W/ft², which is a bit over the average high from the NIH's tables, would represent the equipment and the extensive use of fume hoods in the building. In addition, the modified models use actual weather data for Istanbul that corresponds to the metered data before renewable energy renovation in 2007 and after renewable energy renovation in 2016. The energy model of the Koc Life Sciences building in MATLAB. All models are compared to actual metered data.

Table 4.3: Default values of the MATLAB templates for the two main zones in the Koc Life Sciences Building.

Parameter		Default Values	
		Laboratories	Supporting Offices
Summer	Temp. Set-point (°F)	77	75.2
	Temp. Set-back (°F)	82.4	82.4
Winter	Temp. Set-point (°F)	68	69.8
	Temp. Set-back	50	50

	(°F)		
Relative Humidity (%)		10-90	10-90
Equipment Load Density (W/ft ²)		2.153 (20% Radiation Fraction)	2.537 (20% Radiation Fraction)
Lighting Intensity		1.858	1.626
Ventilation rate (cfm/person)		205.53	21.19
Equipment, Lighting and Occupancy Schedules		8:00 AM – 6:00 PM	8:00 AM – 6:00 PM

Table 4.4: Parameters changed in Koc Life Sciences building model.

Parameter modified/Renewable Zone	Source Type	Renewable Energy Generation
Equipment Schedule	Solar	24 MW
Occupancy Schedule	Solar	16 MW
Equipment load density	Wind	14 MW
Lighting Density	Wind	70 MW
Temperature Set-points and Set-backs	Solar	7 MW
Air Changes per Hour (ACH)	Wind	2 MW

Table 4.5: Modified values for the parameters addressed in Table 4-4 of the main zones in Koc Life Sciences building NC=Not Changed.

Parameter		Modified Values	
		Laboratories	Medical Offices
Summer	Temp. Set-point (°F)	73	NC
	Temp. Set-back (°F)	73	NC
Winter	Temp. Set-point (°F)	70	NC
	Temp. Set-back (°F)	70	NC
Relative Humidity (%)		50-55	NC

Equipment Load Density (W/ft ²)	18.00 (20% Radiation Fraction)	NC
Lighting Intensity	2.50	1.30
Air Changes per Hour (ACH)	6.0 (15.0 in human labs)	NC
Equipment, Lighting and Occupancy Schedules	Schedules suggested by the EPA's Labs for the 21 st century	Schedules by NREL's report

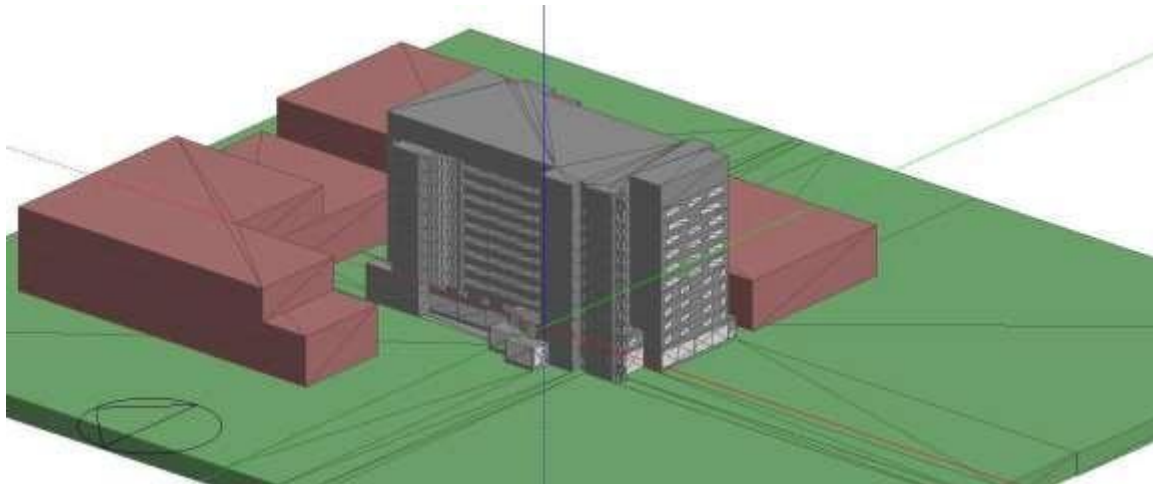


Figure 4.14: The model of Koc Life Sciences building in MATLAB. The brown blocks simulate with green area for renewable energy generation usage.

4.4.2 Results and Analysis

This subsection is divided into two sub-subsections to provide a discussion and analysis of the simulation energy predictions for each phase of the renewable energy renovation project. Then each of the sub-subsections provides a summary of the energy results and compares the data with actual metered data for each phase. Finally, it assesses the accuracy of each model using the Micro-Grid renewable energy generation.

4.4.3 Before Renewable Energy Renovation at Koc Hospital

Here is an analysis of the energy models of the Koc Life Sciences Building before renewable energy renovation. Actual metered renewable and thermal energy are compared to the energy predictions produced by the energy models of the pre-renewable energy renovation phase.

Table 4.6: Summary of Medicana international hospital Building Actual and Simulated Energy Use Before Renewable energy renovation.

Energy Type	Actual Metered	Simulation-Default	Simulation-Modified
Renewable Energy in kWh (kBtu) [kWh/m ² (kBtu/ft ²)]	14,837,000 (50,626,000) [582 (185)]	7,058,000 (24,083,000) [277 (88)]	14,260,000 (48,657,000) [559 (178)]
Heating in kWh (kBtu) [kWh/m ² (kBtu/ft ²)]	4,588,000 (15,655,000) [180 (57)]	1,889,000 (6,445,000) [74 (24)]	4,953,000 (16,899,000) [194 (62)]

The modified energy model has a good agreement in energy amount and energy pattern with the actual metered data. On the other hand, the default model's predictions were far from the actual metered data.

For renewability, the simulated renewable energy consumption with modified inputs is 3.9% below of actual metered renewable data while the default model's prediction was more than 52% below actual renewable use. Using Micro-Grid indices to represent how well a simulated model describes the variability in the measured data; the modified model has achieved accurate renewability results; with a Solar of 10.99 % and Wind of 9.90%, while the default model has a solar of 57.16% and a Wind of 57.20% in renewable energy comparison.

For renewable energy, the modified model achieved a lower accuracy in heating energy than in renewability; however, it is still a substantial improvement over the default model. The simulated renewable energy consumption with modified inputs is within 7.95% above actual metered data while the default model's prediction was more than 58.8% below actual thermal use. Using Micro-Grid line indices for the default model are Solar of 33.97% and Wind of 27.30 %, while the proposed model has a Solar of 83.18% and a Wind of 64.53%.

4.4.4 After Renewable Energy Renovation

Here is a discussion of a challenge faced while performing the energy model for the post-renewable energy renovation phase. After the discussion, an analysis of the energy models of the Koc Life Sciences Building after renewable energy renovation is performed and a comparison to actual metered data is performed.

Facilities and Operations offices, generally, perform several renewable energy renovation projects simultaneously. While the renewable energy renovation of the air-handling unit was taking place, the facilities office performed another project in Koc. The location of the Koc building centered between neighboring buildings and the space availability in the mechanical floor encouraged the facilities office to install a new 1000-ton chiller in Koc to provide chilled water to one of the buildings close to Koc. This new chiller draws its renewable power from Koc Hospital, therefore, it will be very difficult to assess the savings the air-handling unit's conversion provides. Moreover, it will be very difficult to assess the accuracy of the simulations for that specific renewable energy renovation project. Therefore, to simulate the actual events, another rough model of the building near Koc was created to simulate the load. After simulation, the renewable energy of the chiller in the building was added to the total renewable energy of Koc after the renewable energy renovation to have a fair comparison against actual metered data. The renewable energy comparison between the actual metered data and the default and modified models of Koc and the chiller serving the building nearby.

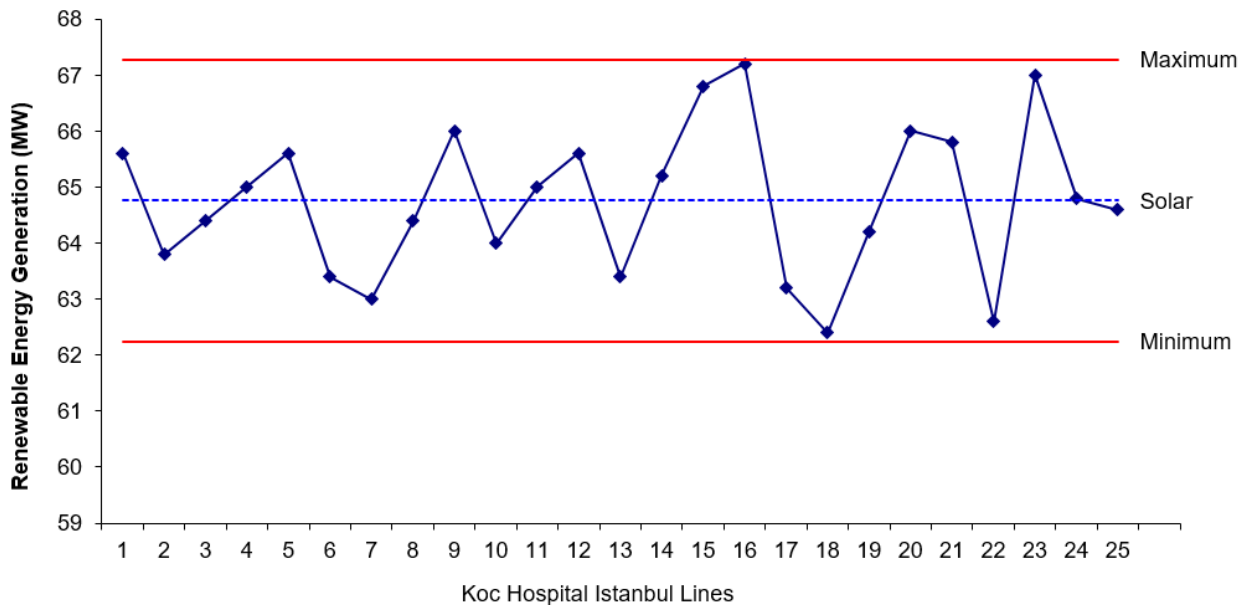


Figure 4.15: The prediction of renewable solar energy generation at Koc Hospital Istanbul during summer, while minimum can be observed at 62.3 MW however maximum can be observed at 67.4 MW.

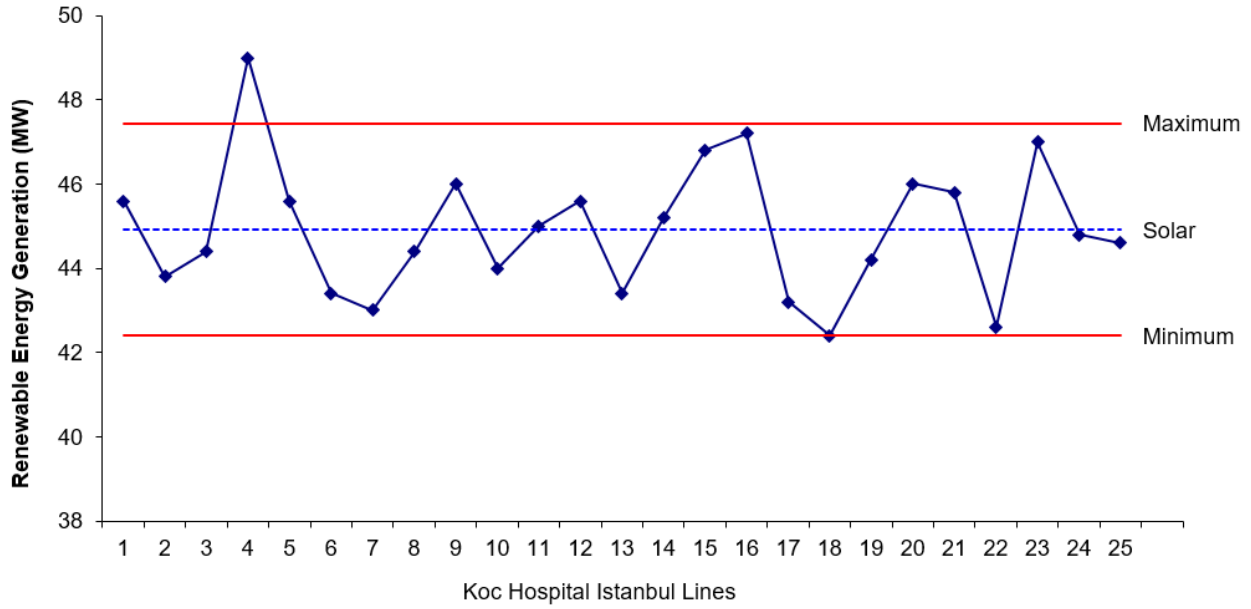


Figure 4.16: The prediction of renewable solar energy generation at Koc Hospital Istanbul during autumn, while minimum can be observed at 42.4 MW however maximum can be observed at 47.4 MW.

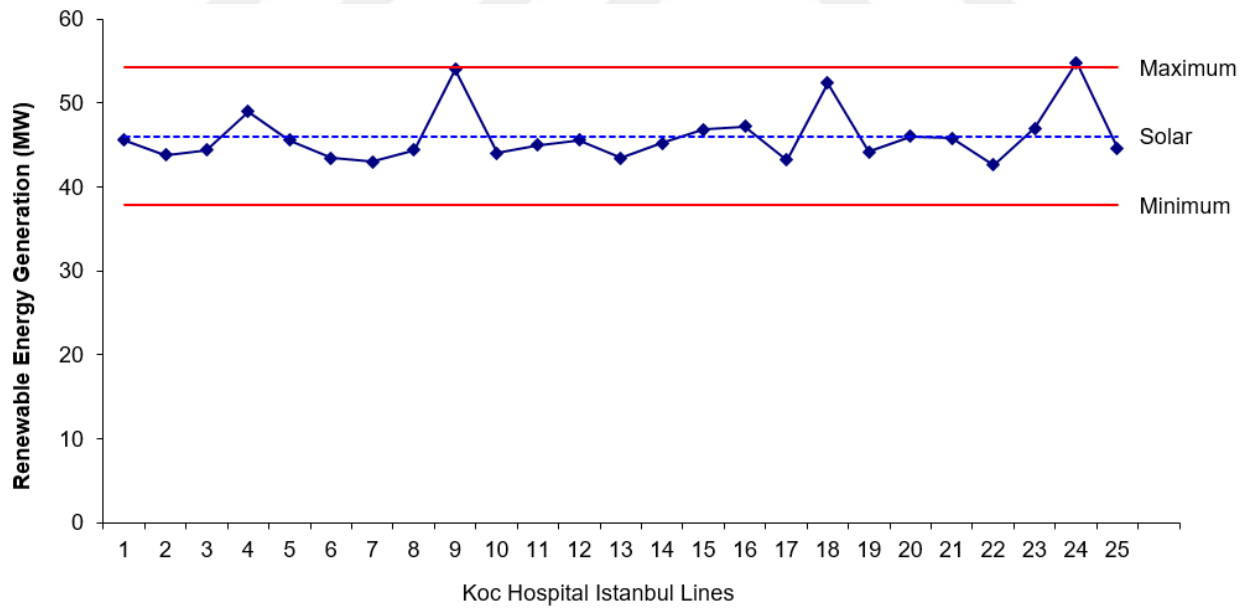


Figure 4.17: The prediction of renewable solar energy generation at Koc Hospital Istanbul during winter, while minimum can be observed at 38.6 MW however maximum can be observed at 55.1 MW.

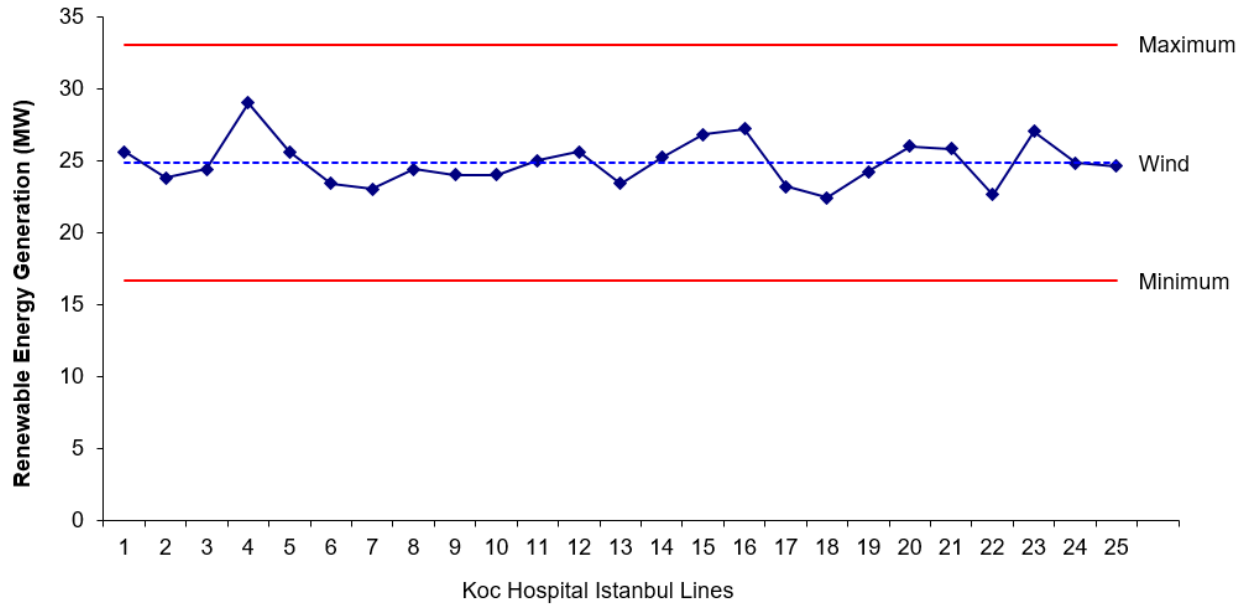


Figure 4.18: The prediction of renewable wind energy generation at Koc Hospital Istanbul during summer, while minimum can be observed at 17 MW however maximum can be observed at 33.7 MW.

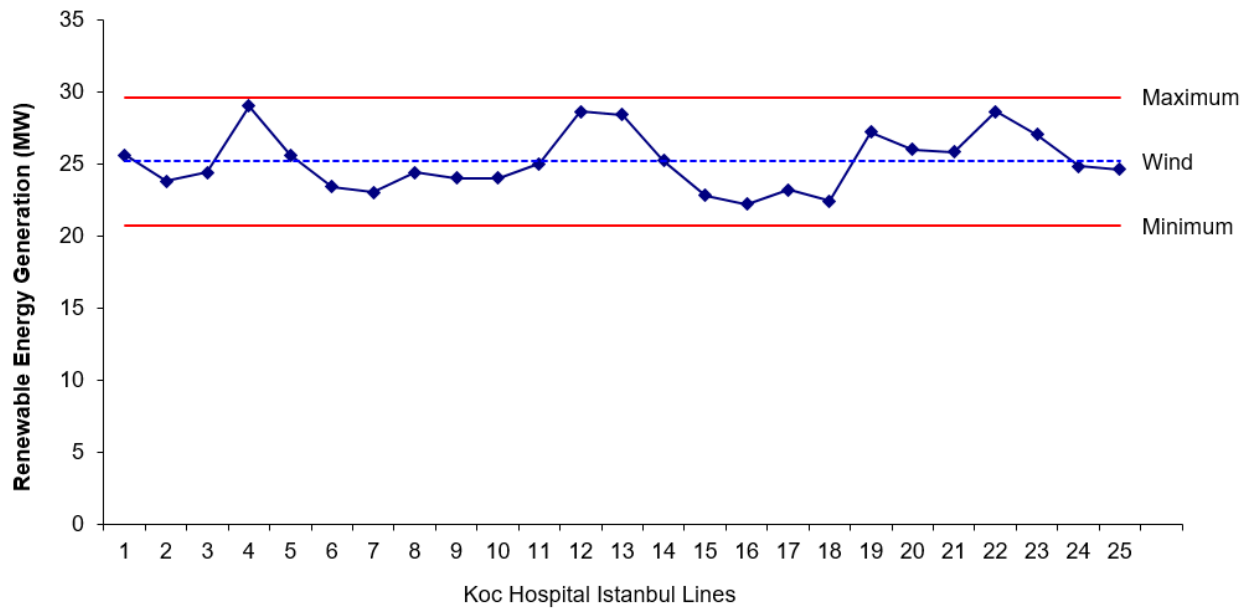


Figure 4.19: The prediction of renewable wind energy generation at Koc Hospital Istanbul during autumn, while minimum can be observed at 21.2 MW however maximum can be observed at 29.7 MW.

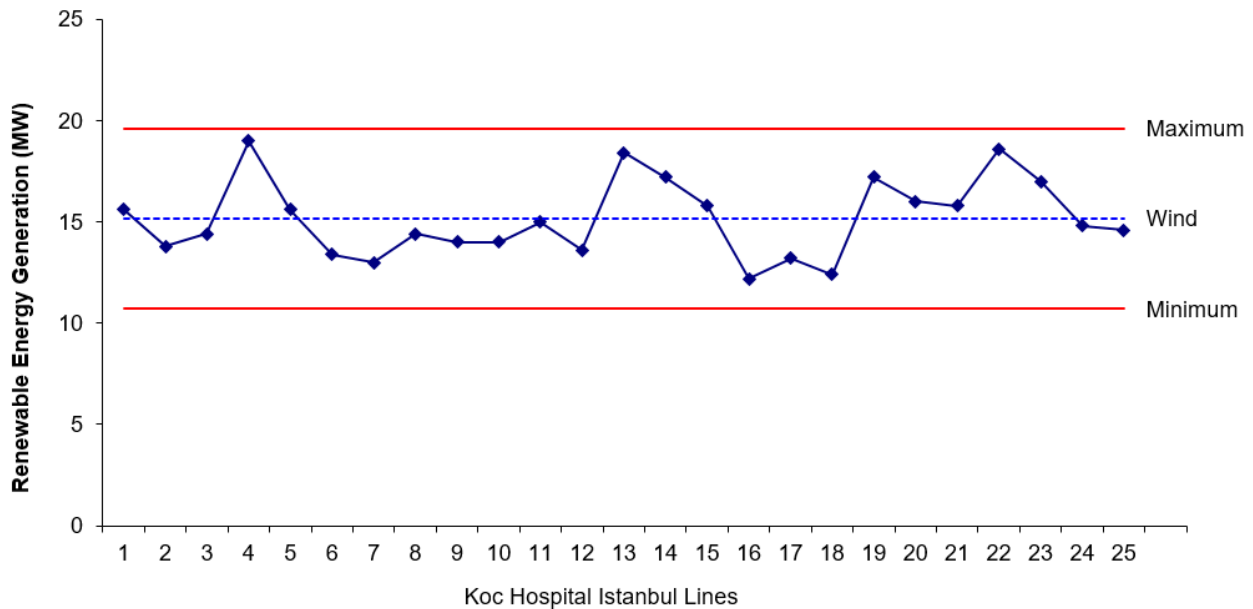


Figure 4.20: The prediction of renewable wind energy generation at Koc Hospital Istanbul during winter, while minimum can be observed at 11.4 MW however maximum can be observed at 19.8 MW.

Table 4.7: Summary of Medicana international hospital Building Actual and Simulated Energy Use after Renewable energy renovation.

Energy Type	Actual Metered	Simulation-Default	Simulation-Modified
Renewable Energy in kWh (kBtu) [kWh/m ² (kBtu/ft ²)]	16,457,000 (56,154,000) [646 (205)]	9,662,000 (32,968,000) [379 (121)]	17,428,000 (59,467,000) [684 (217)]
Heating in kWh (kBtu) [kWh/m ² (kBtu/ft ²)]	4,762,000 (16,247,000) [186 (59)]	1,972,000 (6,727,000) [77 (25)]	4,953,000 (17,962,000) [194 (66)]

Looking at the total renewable energy before and after the renewable energy renovation, there was 1,619,790 kWh increase. This number is the summation of the increase in renewable energy due to the installation of the new 1000-ton and the decrease due to the conversion of one of Koc Hospital air-handling units from CAV to VAV. The modified simulation model has a good agreement with actual metered data compared to the default model.

For renewability, the simulated renewable energy consumption with modified inputs is within 5.9% above actual metered renewable data while the default model's prediction was more than 41.3% below actual renewable use. Using Micro-Grid indices to represent how well a simulated model describes the variability in the measured data; the modified model has achieved accurate renewability results; with a Solar of 8.05 % and Wind of 7.85%, while the default model has a Solar of 45.56% and a Wind of 45.04% in renewable energy comparison.

For heating energy, the modified model achieved a lower accuracy in heating energy than in renewable; however, it is still a substantial improvement over the default model. The modified model over-predicted the heating energy use of January and February compared to actual use.

The difference in these two months will have a big influence on the renewable energy generation of micro-grid guideline. The simulated heating energy consumption with modified inputs is 10.6% above actual metered thermal data while the default model's prediction was more than 58.6% below actual thermal use. Using Micro-Grid indices for the modified model are Solar of 31.18% and Wind of 23.34 %, while the default model has a Solar of 86.15% and a Wind of 64.25%. Detailed monthly metered renewable and thermal energy data of the Koc Life Sciences building and monthly modeled renewable and thermal energy data of both pre-renewable energy renovation and post-renewable energy renovation, default and modified.

In conclusion, this part of Chapter 4 performed research on a simple-renewable energy renovation case- study which is the Koc Life Sciences building. The section first introduces detailed description of the building's properties, the nature of the renewable energy renovation. Then it reviewed building the default and modified energy models of the building in both before- and after-renewable energy renovation phases. Finally, it concluded with analysis of the energy models performance against the actual metered data in both phases. The modified model of the Koc building shows a considerable improvement in both renewable and thermal data over the default model and a very good agreement with the metered data. However, the monthly thermal performance did not always have good agreement with metered data.

4.4.5 Major-Renovated Healthcare Facilities

This section presents the third case-study for this thesis. The case study is the Koc Hospital Istanbul building which is an example of major renewable energy renovation. The energy analysis is

performed for two phases, before and after the renewable energy renovations. This section is divided into four subsections to detail the research approach and the analysis of this case-study. The first subsection provides detailed information about the building as well as information about the renewable energy renovation details. The second subsection discusses the details of the simulation of two models for both phases, before and after renewable energy renovation, and the parameter modification. The next subsection reviews the simulation results of default and modified models of both project phases, compares them with actual metered data and assesses the accuracy of the default and the modified models. The final subsection analyses the energy savings from energy models and compares with actual energy savings.

4.5 CASE-STUDY: MEDICANA INTERNATIONAL HOSPITAL ISTANBUL BUILDING

The Medicana international hospital building is a nine-story 289,000 ft² (26,850 m²) building which is located in the same medical campus, the Central Hospital Center, as the Cancer Institute in Istanbul, Turkey as an aerial photo showing the complex; the Medicana international hospital building is highlighted in the blue box, and a typical floor plan of the Medicana international hospital with main thermal zones highlighted in different colors. The medicana international hospital building was completed in 1968. The building includes seven floors that house laboratories, offices, and lecture rooms in addition to two floors for academic offices and mechanical rooms. The medicana international hospital building currently has an annual renewable building-site energy intensity of 64.2 kBtu/ft² (202.4 kWh/m²). This renewable building-site energy intensity represents a portion of its total building-site energy use intensity that is not monitored at present because the medicana international hospital building, similar to the Central Hospital Istanbul, receives steam and chilled water from a central plant that serves the entire medical campus. The central plant does not have building-level sub-metering for the steam and chilled water supply. Therefore, only renewable energy is metered for the medicana international hospital building.

Similar to many old healthcare buildings, the building originally had a constant air volume (CAV) distribution system using 18 air handling units (AHUs) with a grand total rated cooling capacity of 1370 tons. Four air-handling units are dedicated to the laboratory spaces providing 100%

outside-air with strict air-temperature requirements and ability to provide 6-ACH all the time. Eight air-handling units provide air with re-circulation to the lecture halls and offices, four to each, and the rest of the six air-handlers provide air to the basement, mechanical rooms, and circulation areas.

In 2018, the Facilities and Operations Office in charge of the building maintenance and operation began implementing a three-phase mechanical retrofit to convert all the AHUs to VAV. The renewable energy renovation included sizing and installing VAV boxes with hydronic reheat, and updating the control systems of the AHUs to have a VAV control system. The obtained renewable metered data end in September of 2018, the end of 2nd retrofit phase with 10 AHUs being converted. Therefore, the post-renewable energy renovation data analysis here is performed with the 9-month actual data and a 12-month estimated actual data.



Figure 4.21: A view of the Medicana International Hospital Istanbul.

4.5.1 Simulations

Using MATLAB along with architectural and mechanical plans, two models of the Medicana international hospital building; one with CAV mechanical system to simulate the pre-renewable

energy renovation phase, and the other one with 10 AHUs converted to VAV to simulate the post-renewable energy renovation, were created using the default input parameters. The default models used the default values of laboratory, offices, and lecture halls templates provided by MATLAB. Table 4-8 shows the default values of the addressed parameters for the three main zones in the Medicana international hospital building. The default models used the weather file of Medicana. Another two models of the Medicana international hospital building were created to simulate pre-renewable energy renovation and post-renewable energy renovation with modifying the parameters suggested by the literature. Table 4-9 lists the parameters changed for each thermal zone and Table 4-10 lists the values of the modified parameters. In addition, the modified models use actual weather data for Istanbul that corresponds to the metered data before renewable energy renovation in 2018 and after renewable energy renovation in 2019. The energy model of the Medicana international hospital in MATLAB. All models are compared to actual metered data.

Table 4.8: Default values of the MATLAB templates for the three main zones in Medicana international hospital building.

Parameter		Default Values		
		Laboratories	Medical Offices	Lecture Halls
Summer	Temp. Set-point (°F)	77	75.2	73.4
	Temp. Set-back (°F)	82.4	82.4	82.4
Winter	Temp. Set-point (°F)	68	69.8	68
	Temp. Set-back (°F)	50	50	53.6
Relative Humidity (%)		10-90	10-90	10-90
Equipment Load Density (W/ft ²)		2.153 (20% Radiation Fraction)	2.537 (20% Radiation Fraction)	0.170 (20% Radiation Fraction)

Lighting Intensity (W/ft ²)	1.858	1.626	0.92
Ventilation rate (cfm/person)	205.53	21.19	21.19
Equipment, Lighting and Occupancy Schedules	8:00 AM – 6:00 PM every day except Sundays	8:00 AM – 6:00 PM every day except Sundays	8:00 AM – 6:00 PM every day except Sundays

Table 4.9: Parameters changed in Mediana international hospital building model.

Parameter modified/Thermal Zone	Laboratories	Medical Offices	Lecture Halls
Lighting and Equipment Schedule	Yes	Yes	No
Occupancy Schedule	Yes	No	No
Equipment load density	No	No	No
Lighting Density	No	No	No
Temperature Set-points and Set-backs	Yes	No	Yes
Air Changes per Hour (ACH)	Yes	Yes	Yes

Table 4.10: Modified values for the parameters addressed in Table 4-4 of the three main zones in Mediana international hospital Building, NC=Not Changed.

Parameter		Modified Values		
		Laboratories	Medical Offices	Lecture Halls
Summer	Temp. Set-point (°F)	73	NC	NC
	Temp. Set-back (°F)	73	NC	NC
Winter	Temp. Set-point (°F)	70	NC	NC
	Temp. Set-back (°F)	70	NC	NC
Relative Humidity (%)		50-55	NC	NC
E	Equipment Load Density (W/ft ²)	6.00 (20% Radiation Fraction)	NC	NC
Lighting Intensity (W/ft ²)		2.50	1.30	1.43
Air Changes per Hour (ACH)		6.0	NC	NC
Equipment, Lighting and Occupancy Schedules		EPA's Labs for the 21 st century	Schedules by NREL's report	National Report

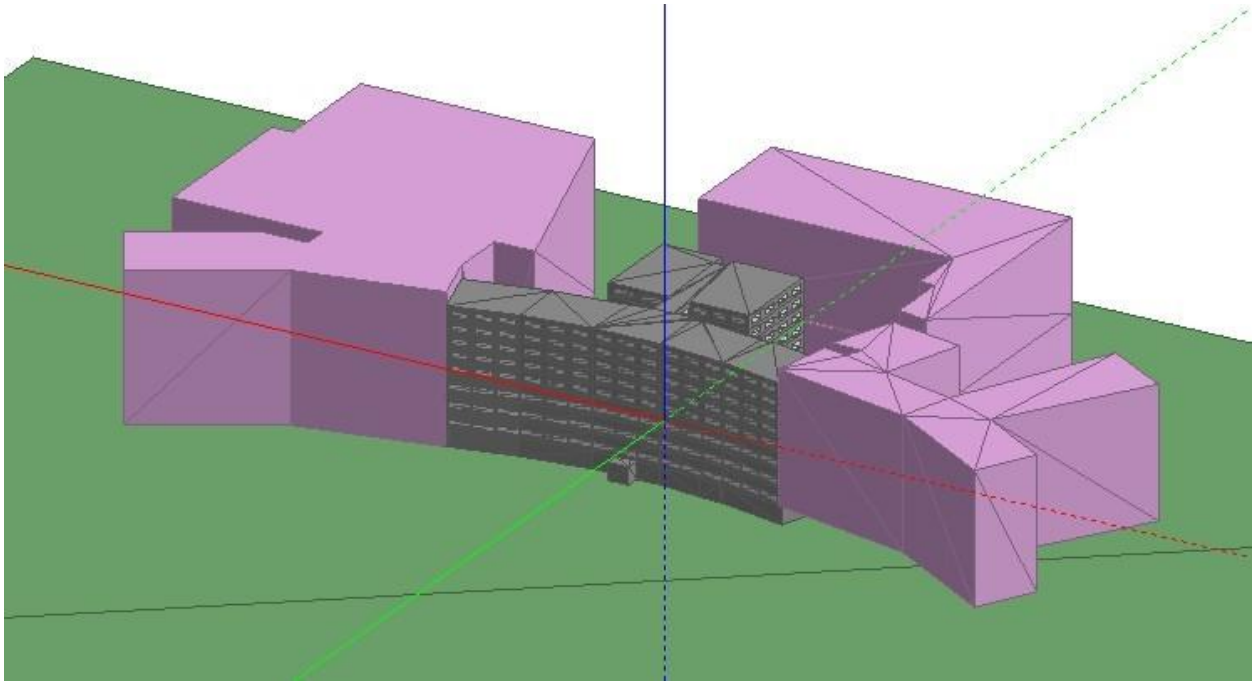


Figure 4.22: The model of the Mediana international hospital building in MATLAB. The purple blocks simulate the shading effects by neighboring buildings with future renewable energy usage.

4.5.2 Results and Analysis

This subsection is divided into two sub-subsections to provide a discussion and analysis of the simulation energy predictions for each phase of the renewable energy renovation project. Each of the sub- subsections provides a summary of the energy results and compares the data with actual metered data for each phase. The final sub-subsection has the assessment of the accuracy of each model using the Micro-Grid renewable energy generation.

4.5.3 Before Renewable Energy Renovation

Here is an analysis of the energy models of the Mediana International Hospital Building before renewable energy renovation. Both pre-renewable energy renovation simulation models, default and modified, were created for the mediana international hospital and are compared against each other and against the actual metered renewable energy use. The comparison between actual renewable use and simulated renewable use of the building with default values and modified values. The comparison between the simulated heating and cooling energy use, respectively.

Actual data of heating and cooling energy consumption are not available. Table 4-11 provides a summary of the total energy use.

Table 4.11: Summary of Medicana international hospital Building Actual and Simulated Energy Use Before Renewable energy renovation.

Energy Type	Actual Metered	Simulation-Default	Simulation-Modified
Renewable Energy in kWh (kBtu) [kWh/m ² (kBtu/ft ²)]	5,535,400 (18,900,000) [207 (66)]	5,127,000 (17,500,000) [190 (61)]	5,775,000 (19,705,000) [215 (68)]
Heating in kWh (kBtu) [kWh/m ² (kBtu/ft ²)]	N/A	2,760,000 (9,405,000) [103 (33)]	2,215,000 (7,557,000) [83 (26)]
Cooling in kWh (kBtu) [kWh/m ² (kBtu/ft ²)]	N/A	1,170,000 (4,004,000) [44 (14)]	1,257,000 (4,289,000) [47 (15)]

The comparisons show that simulations with default inputs have a significant influence on the heating energy as well as renewable use and little influence on the cooling energy use. Simulated renewable energy consumption with modified inputs has predicted 7.2% above actual metered renewable data while the default model predicted 4.9% below actual renewable use. Using Micro-Grid indices to represent how well a simulated model describes the variability in the measured data; both modified and default models have achieved accurate results; with the modified model having a Solar of 13.2 % and Wind of 11.1 %, and the default model having a Solar of 11.7% and a Wind of 10.5%.

4.5.4 After Renewable Energy Renovation

Here is an analysis of the energy models of the Medicana International Hospital Building after renewable energy renovation is performed and a comparison to actual metered data is performed.

Similar to the before-renewable energy renovation results, the after-renewable energy renovation simulation results from the default model are compared with the modified model and with the actual energy use. The post-renewable energy renovation data was obtained in October, limiting the analysis to a 9-month range instead of a full year. The comparison between actual renewable

use and the simulation with default and modified values. The comparison between the simulated heating and cooling energy use, respectively, again without actual metered data for reference.

Table 4.12: Summary of Medicana international hospital Building Actual and Simulated Energy Use After Phase 2 of the renewable energy renovations.

Energy Type	Actual Metered	Simulation-Default	Simulation-Modified
Renewable Energy in kWh (kBtu) [kWh/m ² (kBtu/ft ²)] 9 months	3,800,000 (13,000,000) [190 (60)]	3,341,000 (11,400,000) [124 (39)]	3,647,000 (12,444,000) [136 (43)]
Renewable Energy in kWh(kBtu) [kWh/m ² (kBtu/ft ²)] 12 months	5,067,000 (17,300,000) [190 (60)]	4,455,000 (15,200,000) [166 (53)]	4,834,000 (16,500,000) [180 (57)]
Heating in kWh (kBtu) [kWh/m ² (kBtu/ft ²)] 12 months	N/A	1,600,000 (5,396,000) [59 (19)]	1,624,000 (5,540,000) [60 (19)]
Cooling in kWh (kBtu) [kWh/m ² (kBtu/ft ²)] 12 months	N/A	950,000 (3,230,000) [35 (11)]	1,067,000 (3,642,000) [40 (13)]

After modeling the renewable energy renovation, the modified model's heating and cooling energy use results are less sensitive to the model inputs. The accuracy of the modified model and the default model is 8.6% and 11.5%, respectively, below the actual metered data. Research illustrates that the actual renewable use for February has an unusual increase with a value at 31% higher than the average of all other recorded data. This increase may be due a metering error; therefore, when calculating the micro-grid indices, February is excluded from the calculations.

Calculating the indices, the modified model has a Solar of 12.22% and a Wind of 11%, while the default model has a Solar of 14.4% and 13.4%. The indices show that the modified model has a better description of the variability in the measured data than the default model.

4.5.5 Simulated Analysis

This sub-subsection discusses the energy savings from applying the renewable energy renovation process in both energy models, default and modified, then compares the results against actual metered savings. The discussion also includes an explanation of the thermal behavior of the models.

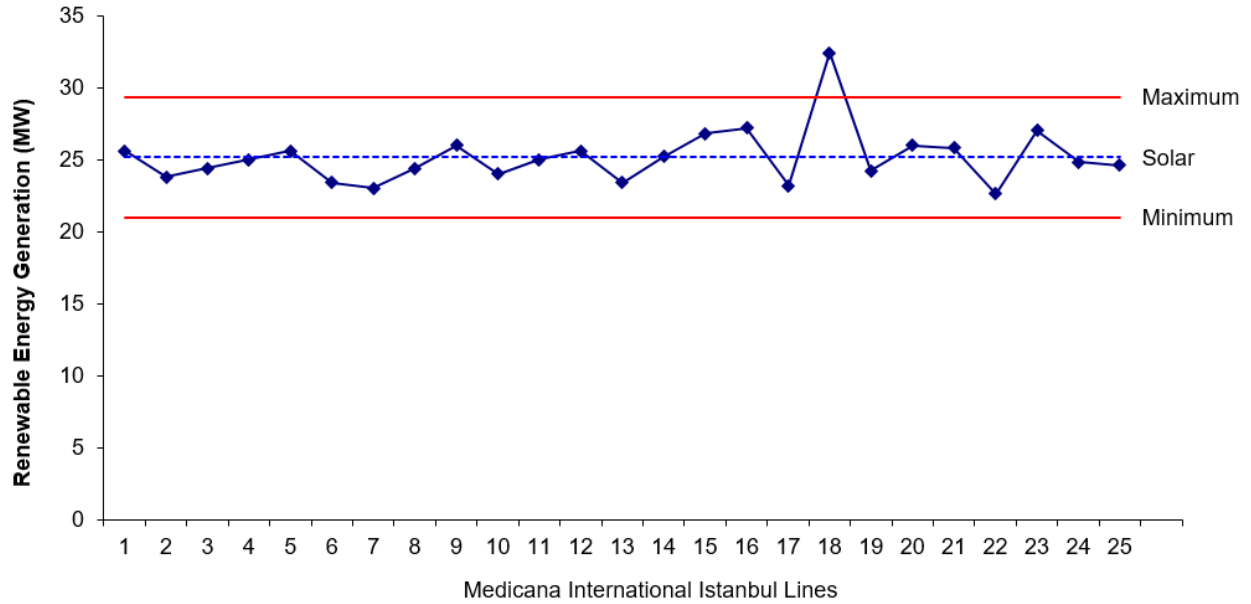


Figure 4.23: The prediction of renewable solar energy generation at Medicana International Istanbul during winter, while minimum can be observed at 21.5 MW however maximum can be observed at 29.5 MW.

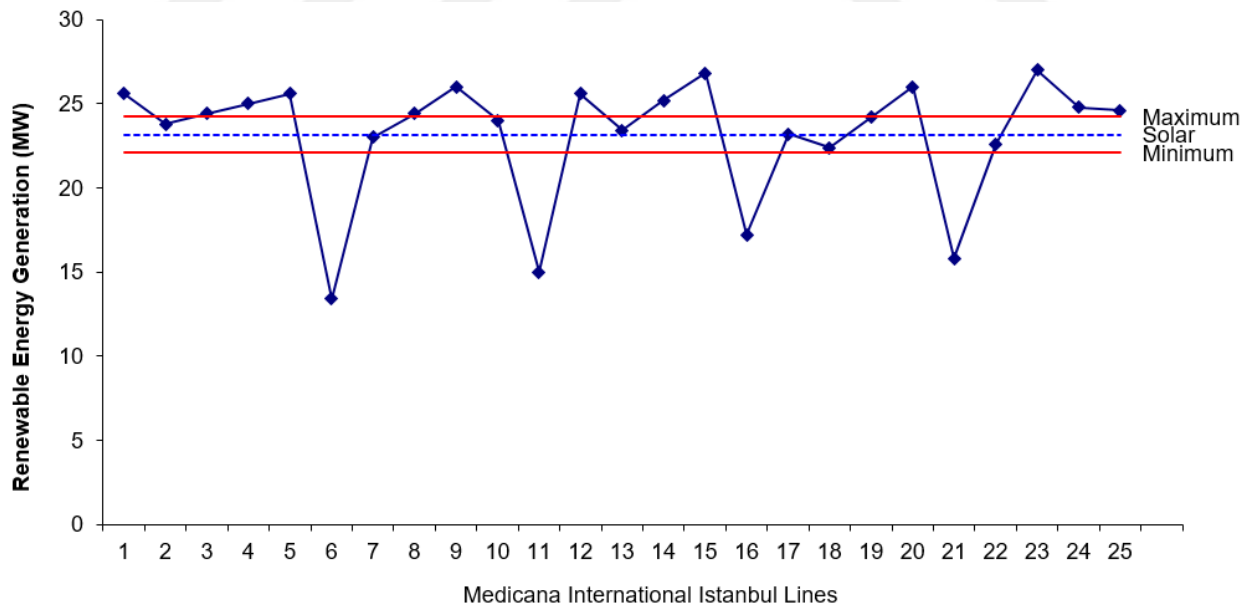


Figure 4.24: The prediction of renewable solar energy generation at Medicana International Istanbul during autumn, while minimum can be observed at 23.8 MW however maximum can be observed at 24.2 MW.

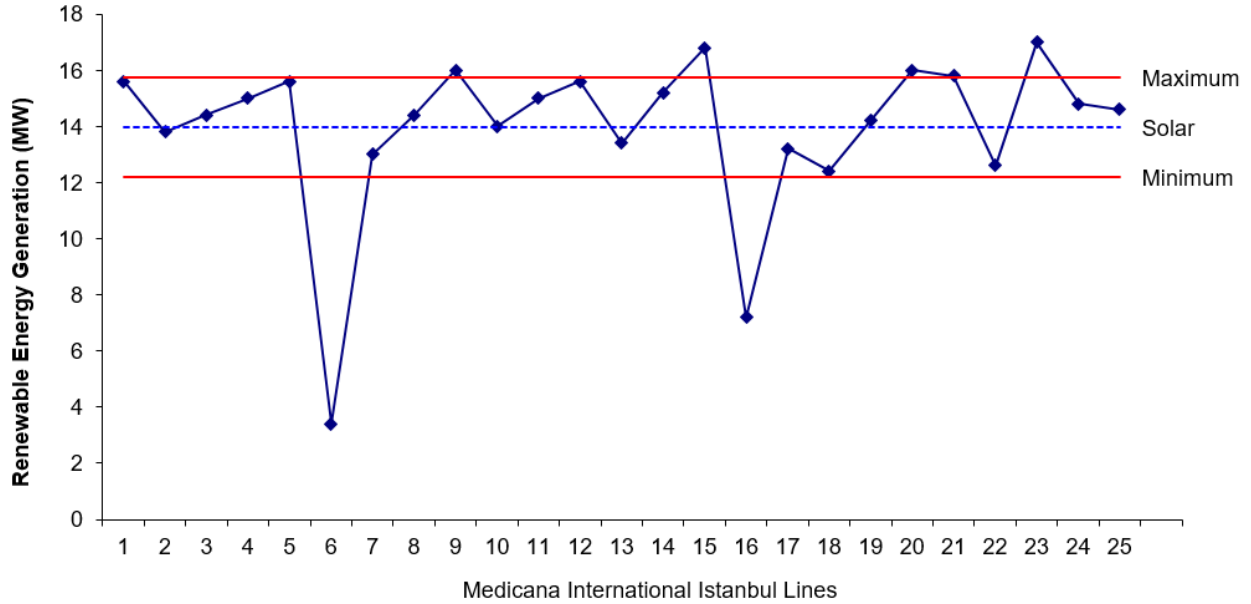


Figure 4.25: The prediction of renewable solar energy generation at Medicana International Istanbul during summer, while minimum can be observed at 12.1 MW however maximum can be observed at 15.7 MW.

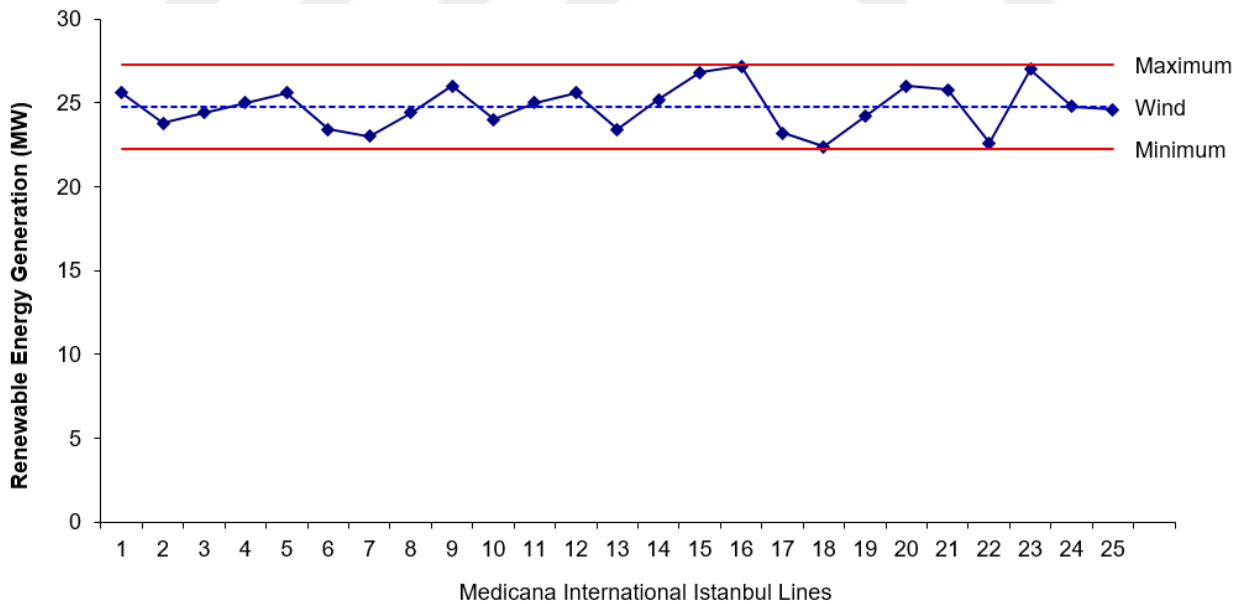


Figure 4.26: The prediction of renewable wind energy generation at Medicana International Istanbul during winter, while minimum can be observed at 22.5 MW however maximum can be observed at 27.7 MW.

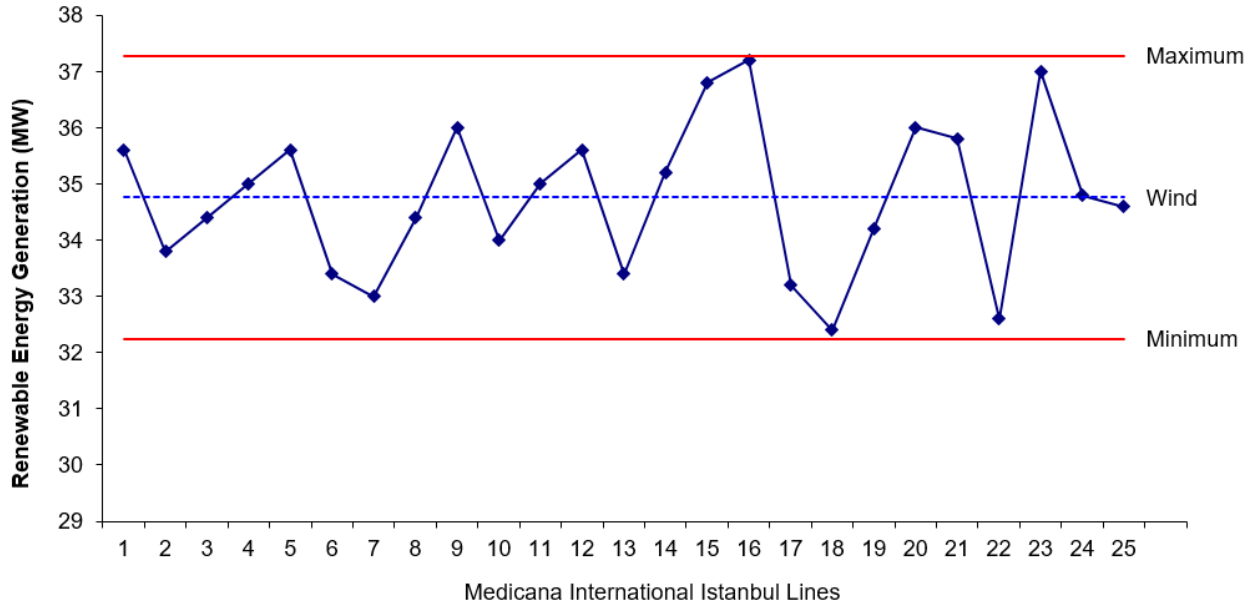


Figure 4.27: The prediction of renewable solar energy generation at Medicana International Istanbul during autumn, while minimum can be observed at 32.3 MW however maximum can be observed at 37.25 MW.

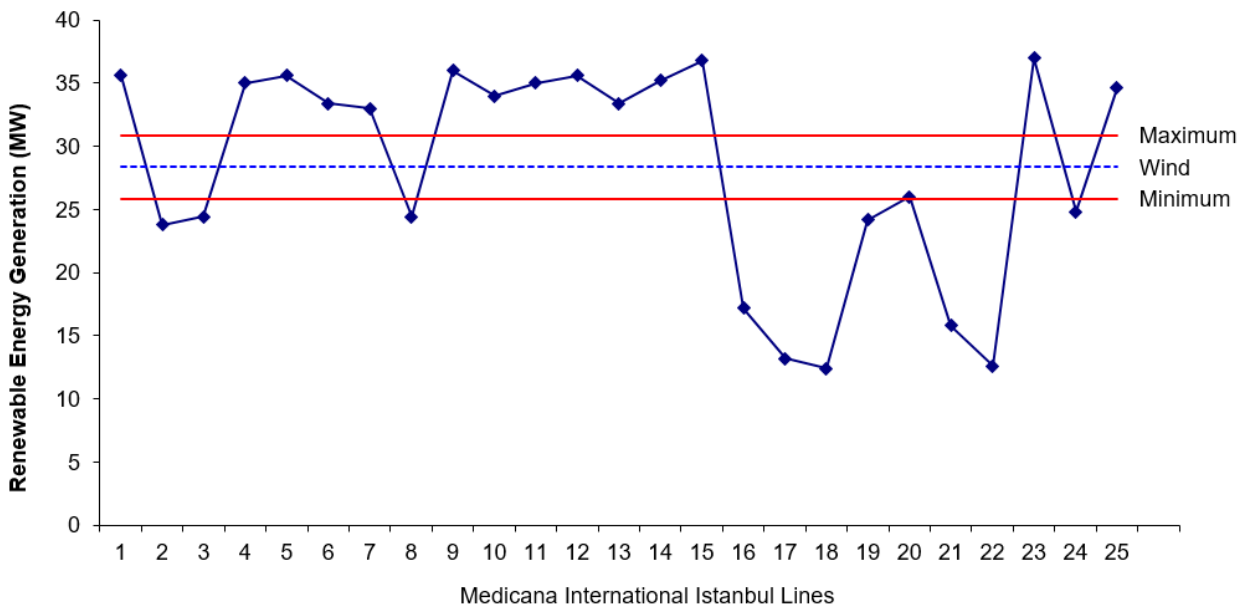


Figure 4.28: The prediction of renewable solar energy generation at Medicana International Istanbul during summer, while minimum can be observed at 26.10 MW however maximum can be observed at 31.3 MW.

The metered renewable energy use shows 468,400 kWh/year (1,600,000 kBtu/year) of energy savings, while the modified and the default energy simulation models show 941,000 kWh/year (3,205,000 kBtu/year) and 672,000 kWh/year (2,300,000 kBtu/year) of renewable energy savings, respectively, as presented in Tables 4-11 and 4-12. Therefore, both models overestimated the expected renewable energy savings. Furthermore, both simulation models showed a pattern that is less affected by the weather and is more consistent throughout the year. This result is consistent with the internally load dominated buildings, such as healthcare facilities. In fact, the renewable energy use for both case studies remains at a constant level regardless of the outside weather conditions.

Although no metered thermal data were provided, comparing thermal energy simulation results of both default and modified models was performed to measure the impact that modified inputs would have on the thermal energy use predictions. Comparing the heating energy use and pattern in Tables 4-11 and 4-12, the modified model is calculating a more conservative thermal energy savings after renewable energy renovation compared to the default simulation model predictions. The modified model predicted a 591,000 kWh/year (2,017,000 kBtu/year) savings compared to the default model that predicted savings of 1,160,000 kWh/year (4,009,000 kBtu/year). The cooling energy however had a consistent savings between both models. The modified model had a cooling energy savings of 190,000 kWh/year (647,000 kBtu/year) compared to 220,000 kWh/year (774,000 kBtu/year) from the default model.

The reason behind such a big shrink in heating energy savings between the modified and the default model is due to the strict temperature set-points and temperature setbacks shown in Table 3-1 that laboratory spaces require. A moderately cold climate, the medicana international hospital building requires more heating energy to maintain the temperature set-points than it needs cooling. Therefore, the modified model predicted more heating consumption, which means less heating savings, to meet NIH's temperature and humidity requirements for laboratory spaces. Detailed monthly metered renewable energy data of the Medicana international hospital building and monthly modeled renewable and thermal energy data of both pre-renewable energy renovation and post-renewable energy renovation, default and modified.

In conclusion, performed research on a majorly-renewable energy renovation case- study which is the Medicana International Hospital building The section first introduces detailed description of

the building's properties the nature of the renewable energy renovation project. Then it reviewed building the default and modified energy models of the building in both before- and after-renewable energy renovation phases. After that an analysis of the energy models performance against the actual metered data in both phases was performed. Finally, there was a review for the energy savings in the models against the metered saving and a discussion on the thermal behavior of both default and modified energy models. Due to the small percentage of laboratory floor-area, the influence of the modification was small in terms of renewable energy. Although no metered thermal data were provided, however, the modification of the inputs had a significant influence on the heating behavior of the building.

5. DISCUSSIONS

Reading the results of the three case-studies, the modification of the identified influential parameters has a major impact on the energy predictions and produce results that have good agreements with the actual metered data. Additionally, the research found that the impact of these modifications depends on the percentage the laboratory spaces occupied from the total area of the building. Micro-Grid is used to measure the accuracy of the energy models before and after the parameter modification using solar and wind renewable energy generation. Table 5-1 summarizes the percentage of laboratory spaces and the renewable energy generation of the models for each case-study.

Table 5.1: Accuracy measures of the default and modified energy models for the case-studies using micro-grid guideline renewable energy generation for all three major Turkish Hospitals .

Case-study	Total Generation (%)	Phase	Simulation-Default		Simulation-Modified	
			Renewable	Thermal	Renewable	Thermal
Central Hospital Istanbul	31%	New Construction	Renewable	Solar= 27.1%	Renewable	Solar= 11.2%
				Wind= 27.8%		Wind= 10.0%
Koc Life Sciences	55%	Before Renewable energy renovation	Renewable	Solar= 57.2%	Renewable	Solar= 10.9%
				Wind= 57.2%		Wind=9.9%
			Thermal	Heat=83.2%	Thermal	Heat= 33.9%
		After Renewable energy renovation	Renewable	Solar=45.6%	Renewable	Solar=8.1%
				Wind=45.0%		Wind=7.9%
			Thermal	Heat=86.2%	Thermal	Heat=31.2%
Medicana International Hospital	22%	Before Renewable energy renovation	Renewable	Solar= 11.7%	Renewable	Solar= 13.2%
				Wind= 10.5%		Wind= 11.1%
		After Renewable energy renovation	Renewable	Solar= 14.4%	Renewable	Solar= 12.2%
				Wind= 13.4%		Wind=11.0%

The table shows that the improvements in the renewable energy generation are directly related to the percentage of laboratory spaces. Although most zones in the building have gone through the parameter modification, the biggest impact on the energy results are related to the laboratory

spaces since they are the most energy intensive zones in the case-studies, especially with the very strict thermal controls requirements.



6. CONCLUSION

This chapter provides a conclusion from the work performed in this thesis. In addition, it discusses potential future work to affirm the results of this research and to further expand the research to cover different types of commercial buildings.

6.1 CONCLUSION

The purpose of this thesis is to improve the energy accuracy of building energy simulation for healthcare buildings by adding renewable energy usage for identifying primary input parameters recommended by previous research and modify these parameters based on applicable building codes, technical reports, and research on healthcare and laboratory spaces. Healthcare buildings are high energy consumers in the building industry. The nature of the critical functions performed in hospitals and the continuous hours make this type of commercial buildings a high energy-intensity type building compared to other types of commercial buildings.

Reviewing sensitivity analyses performed by previous studies, the most influential parameters that most of the reviewed papers and publications are: (1) Load densities of equipment and lighting in hospitals. (2) Schedules of equipment, lighting, and occupants in hospitals. (3) Ventilation rates, especially for laboratories in hospitals. (4) Temperature and humidity control points and patterns in hospitals. The parameters were modified to values to micro-grid Standard 90.1 on MATLAB. To test the impact of these parameters, three buildings along with their metered energy consumption created the case-studies for this thesis and they are: The Central Hospital Istanbul which was an example of a new building case-study, the Koc Life Sciences Building which as an example of a minor-renewable energy renovation case-study, and finally the Medica international hospital as a major renewable energy renovation case-study. Two energy models for each building were created, one with the program default values of the parameters and the other model with the modified values from the codes and research reports. The goal was to study the impact and the influence of the modification of these parameters on the accuracy of the energy models.

The results from the accuracy measures obtained from each case-study after the parameter modification provide a great example of the effectiveness and influence the changes of parameters

have on energy modeling. On average, the energy models of all case-studies produced results that were within 9.3% from the actual metered data.

6.2 FUTURE WORK AND RECOMMENDATIONS

This thesis sets one of the initial steps in narrowing down and defining correct values for influential parameters in the building energy simulation field for a specific building type. To affirm the major findings of this research, additional healthcare case-studies from different weather zones will be needed in order to confirm the accuracy improvements for general healthcare energy modeling purposes. Furthermore, similar steps can be done to create a database of recommended input parameters for accurate simulation of different commercial buildings.

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