DESIGN OF A SOLAR THERMAL POWER PLANT

YAŞAR UNIVERSITY
DEPARTMENT OF ENERGY SYSTEMS ENGINEERING

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ABSTRACT

The main purpose of this project is to analyze and design a solar thermal power plant with a capacity of 1 MW and to develop a design algorithm for this purpose. In this regard, different parameters of the system such as external diameter of receiver tube, receiver tube material and heat transfer fluid have been selected for the operation and performance evaluation of the system. The efficiency of the collector on the solar field, number of feedwater heater, efficiency of turbine, boiler pressure, boiler temperature and condenser pressure are main parameters. The importance of effect created by each parameters are investigated by parametric study.

INTRODUCTION

Solar thermal power plants have high efficiency, high economic return [1]. In addition, these power plants enable more power generation due to thermal storage and hybrid system application. Thus, electricity production continues even on cloudy days where sunlight are inadequate [2]

METHODOLOGY AND FLOW DIAGRAM

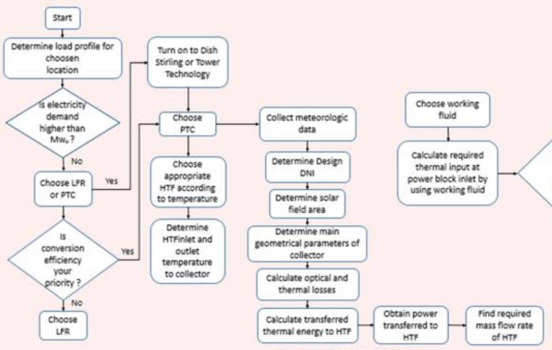

Figure 1. System Methodology

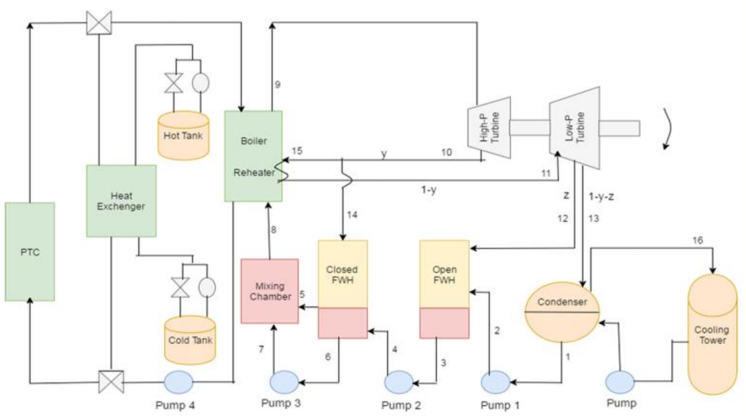

Figure 2. System Flow Diagram

RESULTS

In the power block, thermal efficiency of Rankine Cycle is directly proportional with boiler pressure, boiler temperature, turbine efficiencies

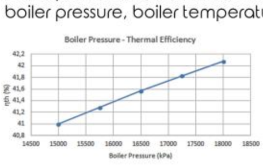

Figure 3 . Effect of Boiler Presssure on ηth

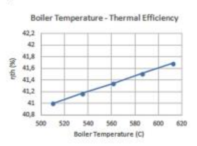

Figure 4. Effect of Boiler Temperature on ηth

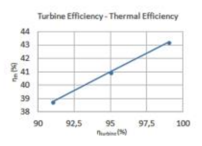

Figure 5. Effect of Turbine Efficiency on ηth

However, thermal efficiency is inversely proportional with condenser pressure. And also pump efficiency causes slightly increment on thermal efficiency.

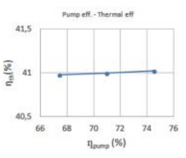

Figure 6. Effect of Pump Efficiency on ηth

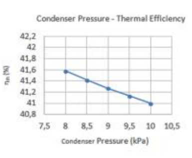

Figure 7 . Effect of Condenser Presss. on ηth

Increase in turbine efficiency from 91% to 99% results in increment of thermal efficiency of cycle, which provides reduction in total collector area or increase in storage capacity and net power output

Turbine Efficiency Design Conditions (95%)				
Turbine eff. (%)	ηth (%)	Area (m2)	Storage (h)	Net Output (kWe)
95	41	13.103	2	924,5

Figure 8. Turbine efficiency design conditions

Turbine eff. (%)	η_{th} (%)	Storage capacity (h)
91	38,77	1,6
95	41	2
99	43,23	2,4

Figure 9. Effect on collector area

Turbine eff. (%)	η_{th} (%)	Net output (kW)
91	38,77	874,3
95	41	924,5
99	43,23	974,9

Figure 10. Effect on storage capacity

Turbine eff. (%)	η_{th} (%)	Area (m2)
91	38,77	13.854
95	41	13.103
99	43,23	12.425

Figure 11. Effect on net power output

-Collector efficiency is directly proportional with mass flow rate and tube diameter. At the same tube diameter and same mass flow rate, copper is a better choice than stainless steel as a receiver tube material.

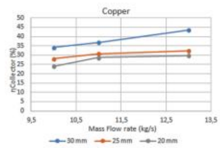

Figure 12 . Copper tube diameter effect

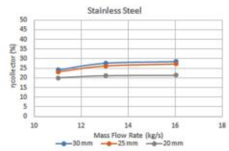

Figure 13 . Stainless steel tube diameter effect

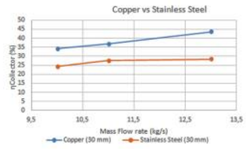

Figure 14 . Copper vs Stainless Steel tube diameter effect

Copper Design Conditions (Diameter, 30 mm)				
mass flow rate (kg/s)	ηsolartoheat (%)	Area (m2)	Storage (h)	Net Output (kWe)
10	34,15	13103	2	924,5

Figure 13 . Copper tube design conditions

mass flow rate (kg/s)	ηsolartoheat (%)	Area (m2)
10	34,15	13.103
11	36,86	12.138
13	43,56	10.271

Figure 15 . Effect on collector area

mass flow rate (kg/s)	ηsolartoheat (%)	Storage Capacity (h)
10	34,15	2
11	36,86	2,6
13	43,56	4

Figure 16 . Effect on storage capacity

mass flow rate (kg/s)	ηsolartoheat (%)	Net output (kW)
10	34,15	924,5
11	36,86	998,1
13	43,56	1180

Figure 17 . Effect on net power output

The highest collector efficiency rate of 43.56% is achieved by copper receiver tube with 30 mm diameter and mass flow rate of 13 kg/s. Tthree option are present to develop efficient solar thermal power plant. First one is to decrease total collector area, rising storage capacity and net power output.

After parametric study, system is improved and storage capacity and overall plant efficiency have increased with less solar collecting area.

Design Conditions for a Solar Thermal Power Plant with a 1 Mwe capacity										
	Material	Diameter (mm)	Mass Flow rate (kg/s)	ηsolartoheat (%)	ηpump (%)	ηth (%)	Area (m2)	Storage (h)	Net Output (kWe)	ηplant(%)
Case 1	Copper	30	10	34,15	94	41	13.103	2	924,5	0,14
Case2	Copper	30	13	43,56	99	43,23	9.741	3	924,5	0,19

Figure 18 . Comparison of plant before and after parametric study

Figure 19 . Monthly Available DNI for Nazilli

For specific location Nazilli, extracting monthly available DNI graph help the specify maximum and design DNI values for location

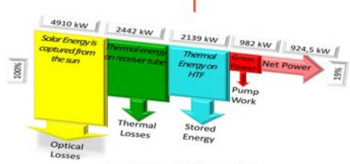

Figure 20 . Sankey Diagram of Plant

Sankey diagram shows required solar and thermal energy values for system from entrance to exit.

Monthly heat transfer fluid energy graph helps to find storage capacity monthly. System requires constant thermal energy value that is 2139 kW at the power block inlet. If system gains thermal energy more than 2139 kW, storage occurs in the system.

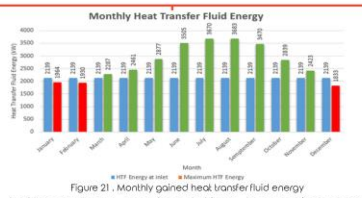

Figure 21 . Monthly gained heat transfer fluid energy

Figure 22 . Monthly storage capacity

In the system, payback time have decreased to 7 years with the installation cost is 5.653.818 $. Also most expensive part of system have found solar field. And other overall system results are given below.

Figure 23 . Payback time

Parameters	Results
Design DNI	504 W/m2
Maximum DNI	646 W/m2
Solar field collector area	9741 m2
Solar multiple	1,28
Solar field solar energy gain	4910 kW
Solar field collector optical losses	2468 kW
Solar field receiver thermal losses	303,3 kW
Solar filed collector efficiency	43,56%
Solar field end-loss efficiency	92%
Solar field shadow efficiency	100%
Solar field optical efficiency	71%
Solar field cleanliness efficiency	98%
HTF thermal energy	2139 kW
HTF (Terminol VP-1) mass flow	13 kg/s
Storage medium (molten salt) mass flow	3,96 kg/s
Storage medium amount	33.660 kg
Storage capacity	3 hour
Rankine cycle thermal energy input	2139 kW
Rankine cycle gross power output	981,9 kW
Rankine cycle gross efficiency	45,91%
Rankine cycle thermal efficiency	43,23%
Pump I work	0,69 kW
Pump II work	5,89 kW
Pump III work	19,4 kW
CSP net output	924,5 kW
CSP net efficiency	18%
CSP total installation cost	5.998.430 $
Payback time	7 years

Figure 25 . Overall system results

CONCLUSION

-Increase in collector efficiency and thermal efficiency enhance storage capacity of the system and net power output.
-Copper tube is more appropriate preference than stainless steel at the same conditions.
-Turbine efficiency is a most important parameter impacting on the thermal efficiency.
-This power plant is capable of storing energy during 2 hours.

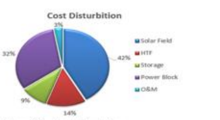

Figure 24 . Cost disturbtion

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Yasar University | Faculty of Engineering | Energy System Engineering

ENERGY PERFORMANCE AND MANAGEMENT ANALYSIS OF A MEAT PROCESSING PLANT SYSTEM

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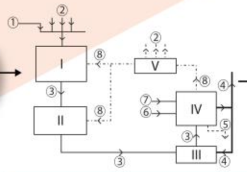
Asst. Hüseyin Günhan OZCAN

ABSTRACT & INTRODUCTION

In this project, energy performance and management analysis of a meat processing plant in was conducted. The method used has progressed through the boiler system, which has the highest energy consumption. The mass, energy and exergy balance of the components used for the boiler system were created by Engineering Equation Solver. There are different opportunities for energy saving and calculations are made. As a renewable solution for the plant, solar energy system has been studied.

METHODOLOGY

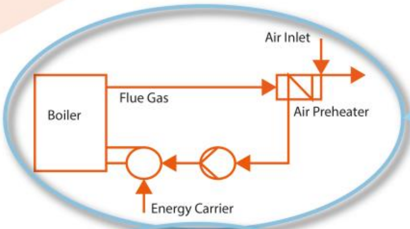
Literature Survey → Energy Flow Diagram → Determination of Energy Consumption from Propotion of Production for Selected Line → Baseline Analysis / Significant Energy Users / Calculate SEC & TOE According to This Consumption → Specify the System and Components (Boiler)

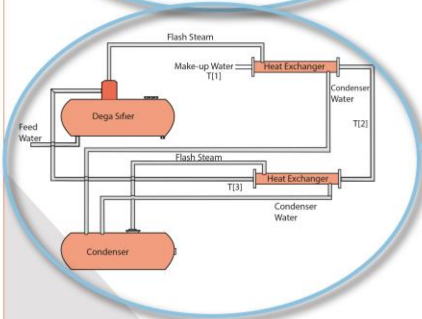


Components	Inlet-Outlet
I.Condenser	1.Make-up Water
II.Degasifier	2.Process
III.Economiser	3.Feed Water
IV.Boiler	4.Flue Gas
V.Steam Collector	5.Blowdown
	6.Natural Gas
	7.Combustion Air
	8.Steam

Calculate Energy & Exergy Analysis for Boiler → Make the Assumptions → Write Equation in EES → Does the EES Codes Run? (No → Complete Missings, Fix the Errors) (Yes → Recommended Solutions) → Energy Saving Opportunities / State of Art Technology / Renewable Energy Solution → Is All Calculation Completed? (No → Control & Complete) (Yes → Perform the Economic & Enviromental Analysis) → Write the Thesis → Preperation Video for Project → Finish

RESULTS





Energy Saving Opportunities

Heating of Boiler Combustion Air from Waste Flue Gas Heat
Saving Energy = 30,956.38 kg/year
Saving Amounts = 63,693.436 TL/year

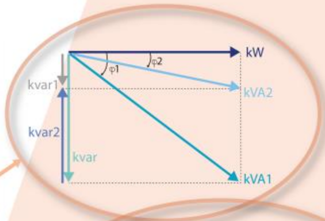
Space Heating by Using Compressor Waste Heat
Saving Energy = 7,440 kWh/year
Saving Amounts = 992 TL/year

Heat Recovery from Flash Steam Energy by Using the Heat Exchanger
Saving Energy = 73,475.08 kg/year
Saving Amounts = 149,154.41 TL/year

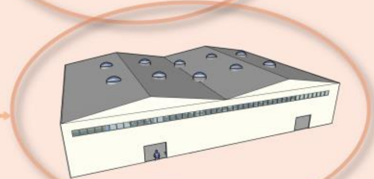
Insullation of Valves and Flanges
Saving Energy = 29,790.25 kg/year
Saving Amounts = 60,474.21 TL/year

Reduction of with Appropriate Selection and Operation of Transformers
Saving Energy = 17,205.12 kWh/year
Saving Amounts = 6,882.048 TL/year

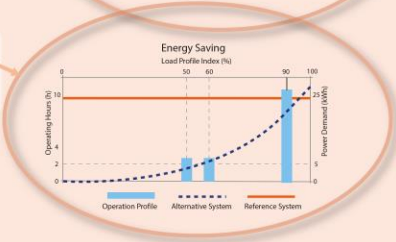
Improving the Power Factor
Saving Energy = 8,113,105.00 kWh/year
Saving Amounts = 5,464,486.23 TL/year

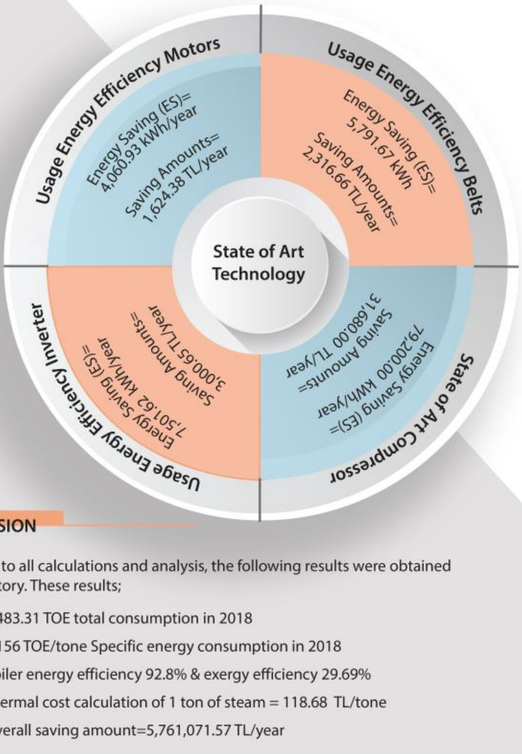


Free Lighting by Using Daylight Tube Lighting System
Saving Energy = 22,572 kWh/year
Saving Amounts = 9,028 TL/year



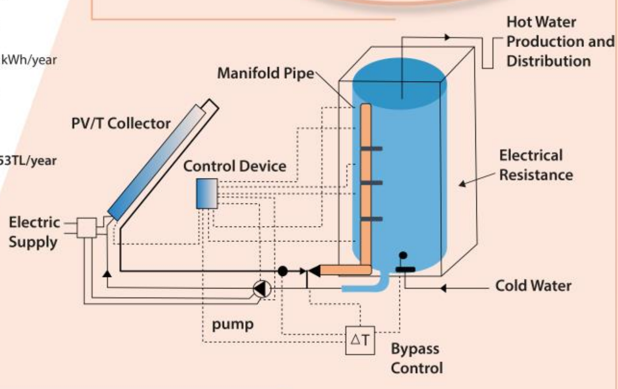
Using of Inverters
Saving Energy = 38,473.12 kWh/year
Saving Amounts = 15,389.25 TL/year





PV-T SYSTEM

Number of Panel	242 Panel
Total power	77.4 kW
Annual Production	119,000 kWh/year
Electrical Efficiency	19.05%
Thermal Efficiency	56.5%
Total Saving Amounts	**23,068.53TL/year**



CONCLUSION

According to all calculations and analysis, the following results were obtained for the factory. These results;

- 4,483.31 TOE total consumption in 2018
- 0.156 TOE/tone Specific energy consumption in 2018
- Boiler energy efficiency 92.8% & exergy efficiency 29.69%
- Thermal cost calculation of 1 ton of steam = 118.68 TL/tone
- Overall saving amount=5,761,071.57 TL/year

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DESIGN OF A HYBRID PV AND RADIANT CEILING SYSTEM FOR AN INDUSTRIAL BUILDING

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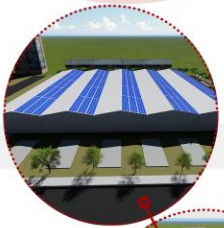
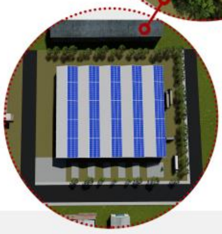




INTRODUCTION

In this research, the building has examined in two different ways; one of them is its electricity need and the other one is improving radiant ceiling system for office areas by using calculation of the heating & cooling requirement of the building. **PV modules** are installed on the roof to meet the electricity needs of the building and is investigated whether the generated electricity is sufficient or not for the building, the cost of the radiant system applied and the feasibility of these systems are examined. In this regard, the calculations required for **Radiant ,Ceiling Technology** for office areas are made and its suitability is examined. Our main goal is to integrate renewable energy technology via using solar energy with industrial building to capture low levels of **CO_2 emissions**. Moreover, the ways of improving our energy efficiency by making improvements in the current situation and combining these improvements by developing technology such as radiant ceiling technology have been made.

DESIGN METHODOLOGY

In order to meet the electricity need of the industrial building, PV application is made on the roof of the factory. The power generated by the **PV System** is calculated by using **PVSOL** and **MATLAB** programs. The flow charts of the designing a PV system and the calculation of the radiant ceiling technology are given in Fig. 1 and Fig. 2 respectively.

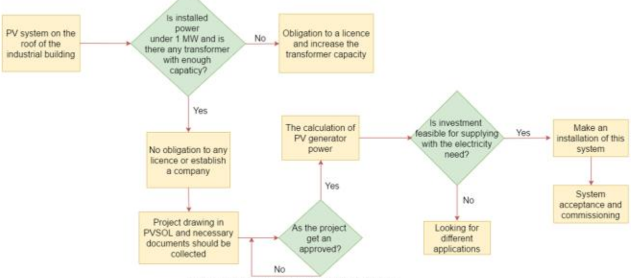


Figure 1. Flow Chart of PV System Design

Heating and Cooling Capacities of the building are calculated according to **TSE2164** and **ASHRAE** standards to examine the existing heating & cooling system performance of the building and to provide improvement recommendations. The values required for the **Radiant Ceiling Application** to be applied in the office areas are taken from the simulation results. By these calculations, the number of modules and other required information for the office areas has been specified according to **Heating Peak Loads**.

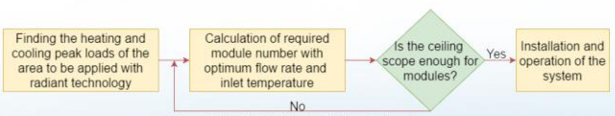


Figure 2. Flow Chart of Radiant Ceiling Technology

RESULTS

Completed results are as shown below according to calculation process.

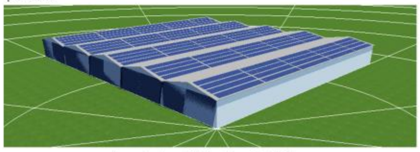


Figure 3. The Building View in PVSOL

Table 1. The Results of PV System According to PVSOL in Denizli Region

Climate Data	Denizli (1986-2005)
Grid type	On grid
Number of PV modules	1920
Number of inverter	15 SMA25000 and 5 SMA20000

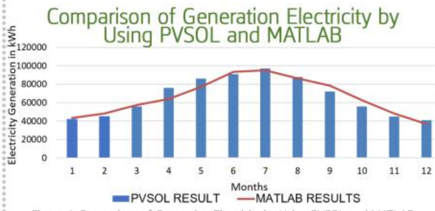


Figure 4. Comparison of Generation Electricity by Using PVSOL and MATLAB

The annual electricity generation of the **PV system** is theoretically calculated by writing the **MATLAB** algorithm and estimated at **792.5 MWh**. It is checked by **PVSOL** software and annual electricity generation is found as **796.8 MWh**. Thus, only **0.5 %** difference is obtained according to the determined theoretical value.

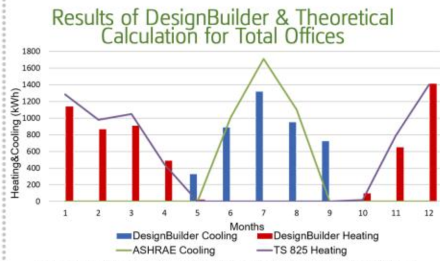


Figure 5. Results of DesignBuilder & Theoretical Calculation for Total Offices

Results are checked and examined according to **TSE2164** and **ASHRAE** standards by 24 hours running calculation. The difference between methods are obtained as **6.5%** and **2.5%** for heating and cooling load, respectively.

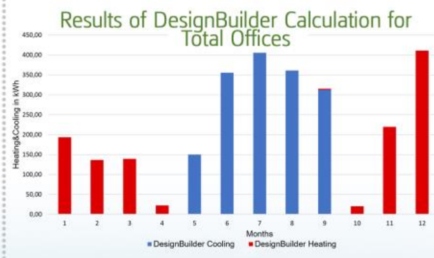


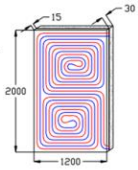
Figure 6. Results of DesignBuilder Calculation for Total Offices

Office areas are rearranged with the real schedules . (8:00-18:00)

Table 2. Selection Criteria of a Radiant System

Parameters	Unit	Heating	Cooling
Dimensions	mm	2000x1200x45	2000x1200x45
Area	m²	2.4	2.4
Outside Dry-Bulb Temp.	°C	39	-3.50
Qpeak	kW	2.82	0.99
AmbientTemperature	°C	20	24

Number of modules to be used in radiant ceiling application is found as **11**. The surface temperatures of radiant modules and the inlet & outlet temperatures of the water passing through the module are calculated according to the **3 different flow rate**.



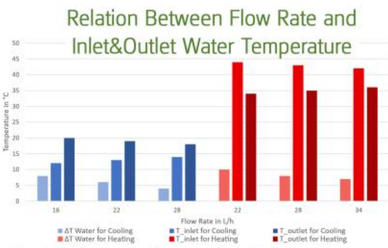


Figure 7. Relation Between Flow Rate and Inlet&Outlet Water Temperature

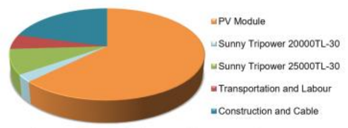


Figure 8. Cost Distribution Pay Chart For PV System

Cost of the **PV system** is calculated as **1,961,000 TRY** and payback period of the system is determined as approximately **9 years**. When lifecycle of the PV system is considered as 25 years and all expenses are deducted; the total profit is found as **4.912.000 TRY**.

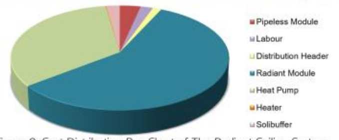


Figure 9. Cost Distribution Pay Chart of The Radiant Ceiling System

The total cost of the **radiant ceiling application** assisted with heat pump is found as **45.269 TRY**. When the existing systems are examined, it is seen that this system is applicable.

CONCLUSION

Installed PV system, will provide approximately **33%** of annual needs of the industrial building. The establishment of **PV systems** and the use of renewable energy will reduce the energy dependency of the country in a certain extent.

Despite the relatively high investment cost of **radiant ceiling technology**, it is feasible when thermal comfort, insulation, easy installation and aesthetic appearance are considered.

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DESIGN OF A RESIDENTIAL COOLING SYSTEM ASSISTED BY GEOTHERMAL ENERGY

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ABSTRACT

The main objective of this study is to design a geothermal assisted cooling system with a Vapor Absorption Chiller (VAC) to meet cooling demand of a 140 m^2 single-family house in Izmir, Turkey. The monthly and annual cooling demands of the house were calculated first. Next, some thermodynamic properties of the VAC system such as pressures, temperatures, ammonia concentrations and flow rates of each stream were determined. The performance of the whole system was evaluated through Coefficient of Performance (COP). In performing the theoretical and design studies, Engineering Equation Solver (EES) software package was utilized. Finally, economic and environmental analyses were performed. As a result of the analysis, the cooling demand of the house was calculated as 4.48 kW. The COP of the VAC system was found to be 0.7 based on the operating conditions, with a simple payback period of 5 years. CO_2 emission of the system is 2.04 kg CO_2/kWh.

Keywords: vapor absorption chiller, geothermal energy, residential cooling, energy and exergy analyses

INTRODUCTION

Nowadays, there are many reasons for looking to renewable energy sources. One of these reasons is that the sources of fossil fuels begin to decrease and there are harmful effects of the CO_2 gas emitted by these fuels on the environment. When the issues like these are considered, Vapor Absorption Chiller (VAC) systems are one of the appropriate systems that enable the use of renewable energy sources for cooling. These systems can use solar energy, geothermal energy and biomass energy sources. They are at the same time being quiet, vibration-free and ecological, they need low maintenance, so interest in these systems has increased from day to day [1].

When we think about systems that are operated using heat of water, geothermal energy has an important place in terms of usability. Also, in residential cooling technologies with absorption chillers, geothermal energy has a quite substantial place in energy sources [2].

METHODOLOGY AND FLOW CHART

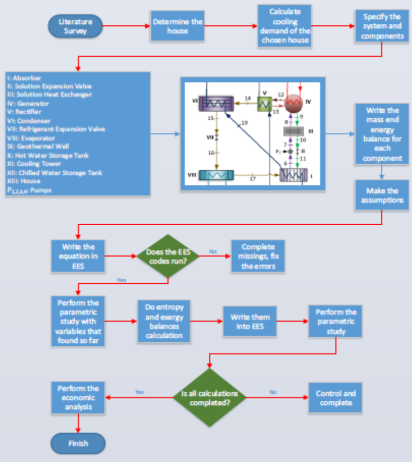

Figure 1. System Methodology.

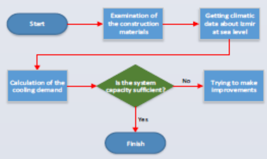

Figure 2. Design methodology of cooling load.

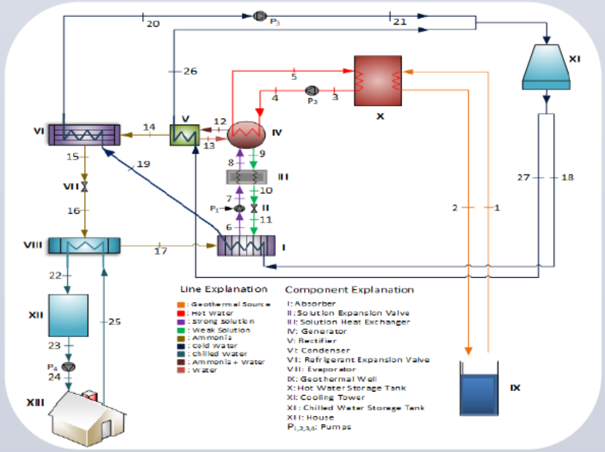

Figure 3. System flow chart.

THERMODYNAMIC BALANCES

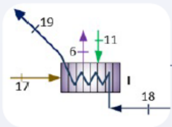

Figure 4. System component (Absorber).

Mass balance;

$$\dot{m}_6 = \dot{m}_{11} + \dot{m}_{17}$$

$$\dot{m}_6 X_6 = \dot{m}_{11} X_{11} + \dot{m}_{17} X_{17}$$

$$\dot{m}_{18} = \dot{m}_{19}$$

Energy balance;

$$\dot{Q}_{11} + \dot{Q}_{17} = \dot{Q}_{abs} + \dot{Q}_6$$

$$\dot{Q}_{abs} = \dot{m}_{18}(h_{19} - h_{18})$$

Entropy balance;

$$\dot{S}_{gen,abs} = \dot{m}_6 s_6 - \dot{m}_{17} s_{17} - \dot{m}_{11} s_{11} + \frac{\dot{Q}_{abs}}{T_0}$$

Exergy balance;

$$\dot{E}x_{dest,abs} = \dot{m}_{17}\varphi_{17} + \dot{m}_{11}\varphi_{11} - \dot{m}_6\varphi_6 - \left(1 - \frac{T_0}{T_{abs}}\right)\dot{Q}_{abs}$$

RESULTS

Table 1. Main results of the system at operating conditions T_6 = 30 ℃, T_9 = 95 ℃ and T_{17} = 2 ℃

Parameter	Value	Unit
Generator heat capacity	6.34	kW
Condenser heat capacity	4.452	kW
Evaporator heat capacity	4.48	kW
Absorber heat capacity	6.275	kW
Heat exchanger heat capacity	7.088	kW
Pump power	0.02945	kW
COP of the VAC	0.7033	-
Reversible COP of the VAC	2.274	-
Exergetic efficiency of the VAC	30.92	%
Thermal efficiency of the whole system	80.22	%
Exergetic efficiency of the whole system	63.37	%

Table 1 shows the capacities (kW) of components, power of pumps, COP of the VAC, thermal and exergetic efficiency of whole system at operating conditions. They were calculated by EES software.

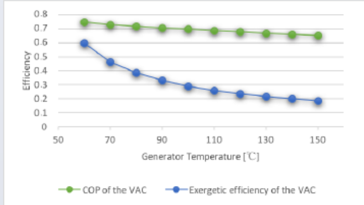

Figure 5. The variation of COP and exergy efficiency of the system with generator temperature

The behavior of COP and exergy efficiency of the absorption system for cooling application with generator temperatures is shown in Figure 5. Rising generator temperature increases more refrigerant vapor, but at the same time more irritability due to more input sources of ignition, which increases the exergetic efficiency of the system.

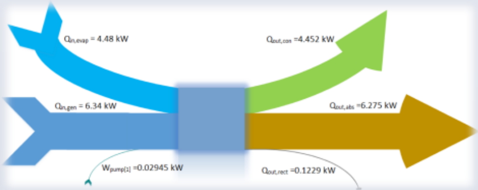

Figure 6. Sankey diagram.

Input and output balances were established for the Sankey diagram of this system in terms of heat and energy.

Percentages of exergy destruction values in the whole system is shown by creating Grassmann diagram.

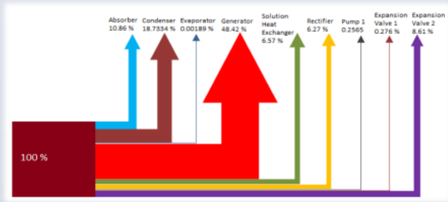

Figure 7. Grassmann diagram

CONCLUSIONS

- The evaporator load was found to be 4.48 kW in the calculated cooling calculations.
- The thermodynamic calculations of the system based on the evaporator load have been made in the EES program.
- As a result of thermodynamic analysis, the coefficient of performance the system is calculated as 0.7.
- As a result of the economic analysis carried out for the VAC, the cost of the system was calculated as 3523.005 $ and it was determined that the system would be profitable within 5 years.
- As a result of environmental analysis 2.04 kg CO_2 / kWh was found.

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[2] Yilmaz C. (2017). Thermodynamic and economic investigation of geothermal powered absorption cooling system for buildings. Geothermics, 70, 239-248.

ENERGY PERFORMANCE EVALUATION AND IMPROVEMENT OPPORTUNITIES

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ABSTRACT & INTRODUCTION

In industrial plants, one of the most important cost is the energy cost. Energy efficiency is an increasingly important concept in terms of reducing costs and improving environmental performance. Energy efficiency studies that can be applied in industrial facilities and renewable energy applications are aimed to improve the operation costs of this facility. [1]
In this thesis, it is aimed to study energy and exergy analysis of evaporative condenser in cooling system of a factory in İzmir. In addition to these, energy saving opportunities and performance and economic analysis of the equipment selected at the factory were studied. These opportunities were analyzed in two categories which are thermally and electrically. Furthermore, it is aimed to use photovoltaic panel to meet the energy consumed in the factory with a renewable energy-oriented method. As a result, the environmental impact and economic analysis of the renewable project were calculated.

METHODOLOGY AND FLOW DIAGRAM

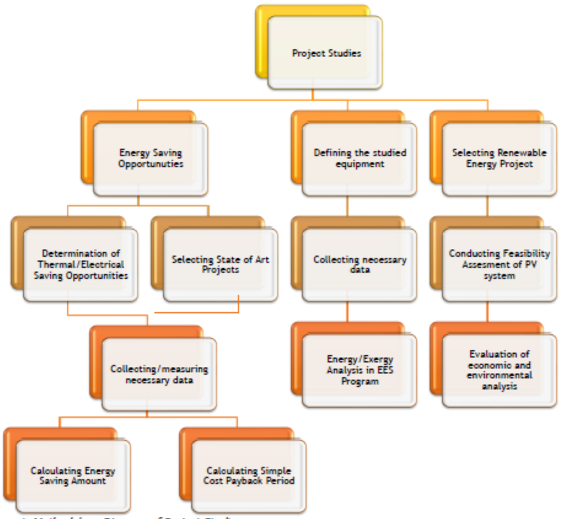

Figure 1. Methodology Diagram of Project Studies

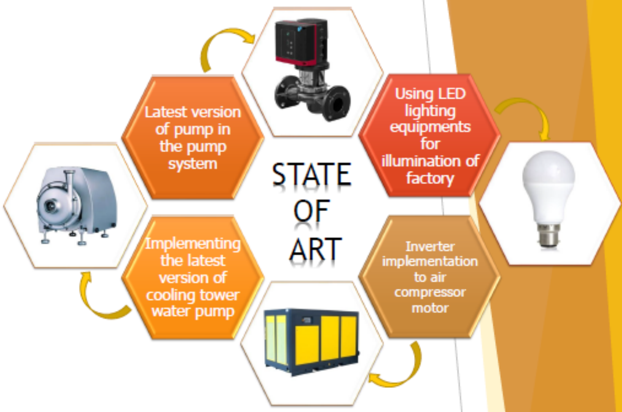

Figure 4. State of Art Projects for selected equipments

STUDIED EQUIPMENT IN THE PLANT

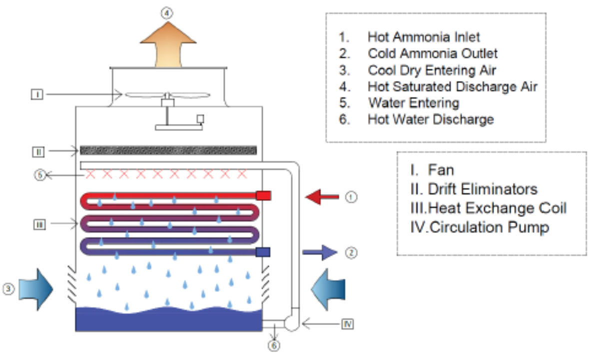

Figure 2. Evaporative Condenser in the Cooling System

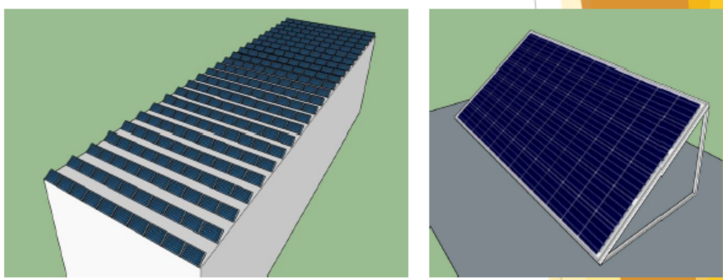

Figure 5. Visual Model of Rooftop PV System

- Monocrystalline Si (STC efficiency: 19%, 25°C, 1000W/m^2)
- Roofmounted with slope of 30°
- Annual average efficiency: 17.20%

- 240 PV panels
- 32.875 Wh per panel

ENERGY SAVING OPPORTUNITY PROJECTS

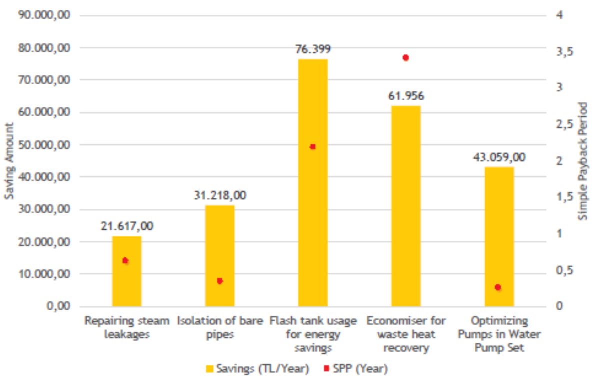

Figure 3. Thermal & Electrical Energy Saving Opportunities Saving Amount and SPP Calculation [2]

RESULTS

- ❖ Effectiveness and exergy efficiency of the evaporative condenser are 58.07% and 83.38%, respectively.
- ❖ Saving amount and simple payback period for state of projects are:
  - Latest version of pump in the pump system
    - ✓ Energy Saving: 61,416 kWh/year
    - ✓ Saving Amount: 24,566.4 TL/year
    - ✓ SPP: 5 months
  - Inverter implementation to air compressor motor
    - ✓ Energy Saving: 238,544.42 kWh/year
    - ✓ Saving Amount: 95,417.77 TL/year
    - ✓ SPP: 3 months
  - Using LED lighting equipments for illumination of factory
    - ✓ Energy Saving: 115,468 kWh/year
    - ✓ Saving Amount: 46,187 TL/year
    - ✓ SPP: : 1.36 year
  - Implementing the latest version of cooling tower water pump
    - ✓ Energy Saving: 31,825 kWh/year
    - ✓ Saving Amount: 12,730 TL/year
- ❖ By Roofmounted PV Panels
  - ✓ Electricity Production: 68,171 kWh/year
  - ✓ Saving Amount: 27,268 TL/year
  - ✓ SPP: 17.5 years
  - ✓ Environmental Analysis: 2181.52 kg CO_2 emissions reduced

CONCLUSION

- ❖ During the thesis project, Engineering Equation Solver (EES), PVSol and Meteonorm were used.
- ❖ In boiler, in order to use rejected heat, economiser application was made.
- ❖ For electricity savings, optimization of the pumps which are working in pump set was made.
- ❖ Energy recovery was achieved with flash tank application.
- ❖ Electricity savings were made by repairing compressed air leaks.
- ❖ Insulation in the pipes is potimized to increase energy savings.
- ❖ Performance evaluation of the lightning system was carried out.
- ❖ Steam leakages are detected and repaired to save energy.
- ❖ Cooling tower performace evaluation was carried out.
- ❖ Photovoltaic solar panel study was carried out on the roof area to provide a certain part of the electricity consumption of th facility from renewable energy source.

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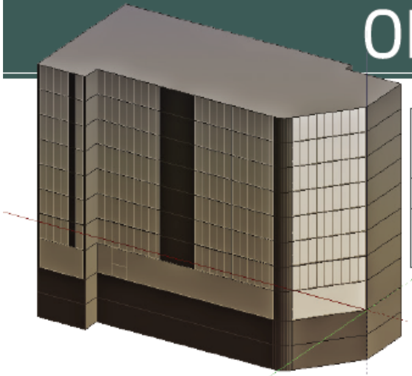
BİNALARDA TERMAL KONFORU SAĞLAMAK İÇİN OPTİMUM KONTROL VE İZLEME SİSTEMİ



PROJE EKİBİ

Ayşegül KAHRAMAN - 17400007006
Ş. Birce ONGUN - 17400007003

Akademik Danışman
Dr. Emrah BIYIK

YAŞAR ÜNİVERSİTESİ
Elektrik ve Elektronik Mühendisliği Bölümü

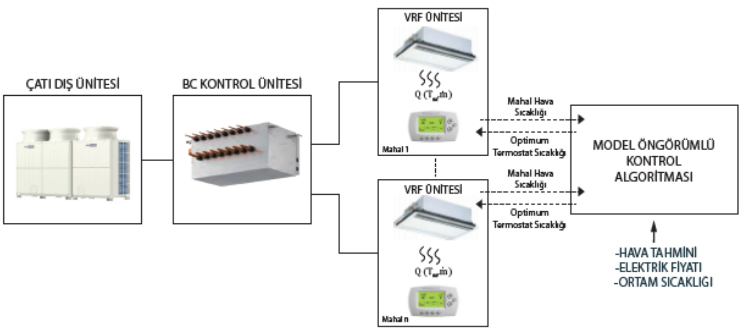
2018

GİRİŞ

Binalar, **küresel enerji tüketiminin** yaklaşık %40'ından sorumludur, bu tüketimin büyük bir kısmı ısıtma, soğutma ve havalandırma (HVAC) sistemlerinden kaynaklanmaktadır. Bu çalışmada, hem enerji tüketimini hem de pik yük talebini azaltmak için HVAC sisteminin verimli bir şekilde kullanılmasını sağlayan, **optimal mahal sıcaklığını** bulan ve gerçek zamanlı ölçümler ile desteklenen **Model Öngörümlü Kontrol (MPC)** algoritması geliştirilmiştir. Bu algoritma, ısıtma/soğutma yükünü minimize ederken, içerideki konforu belirlenen seviyenin üzerinde tutarak, optimal mahal sıcaklık değerlerini bulmaktadır. MPC, değişken dinamiklere sahip büyük ölçekli sistemleri (örneğin ortam hava sıcaklığı, iç ısı kazançları vb.) idare edebilmesi nedeni ile bu projede tercih edilmiştir. Oluşturulan kontrol algoritmasının uygulanması termostatlar aracılığıyla gerçek bir binada uygulanamadığı için oluşturulan **Arduino** tabanlı demo aracılığıyla optimum bölge sıcaklıklarının temsili olarak saptanması gösterilmiştir.

YÖNTEM

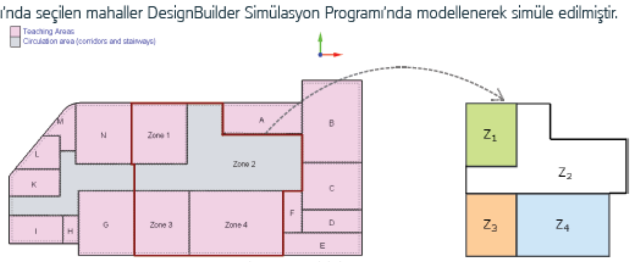
Projenin temel mantığı, doğrudan HVAC ünitelerini kontrol etmek yerine, **en uygun sıcaklık** değerlerini mahal termostatlarına göndererek sistemin **dolaylı** olarak kontrol edilmesini sağlamaktır.



Şekil 1. Proje Çalışma Şeması

DESIGNBUILDER MODELİ:

T Binası'nda seçilen mahaller DesignBuilder Simülasyon Programı'nda modellenerek simüle edilmiştir.

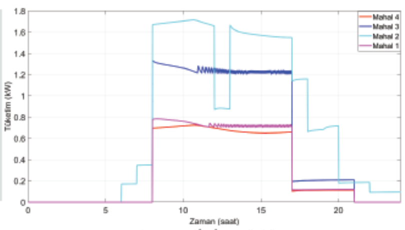


Şekil 2. T Binası Mahal Planları

Bina dinamik modeli, Yaşar Üniversitesi kampüsünün (T binası) 2. katında belirlenen 4 mahal için DesignBuilder-TM simülasyon programı kullanılarak oluşturulmuştur [1]. Seçilen mahallere yerleştirilen sıcaklık sensörleri aracılığıyla, mahallerin hava, duvar ve üfleme sıcaklıkları ölçülmektedir.

Şekil 3. Sensör Data Akış Şeması

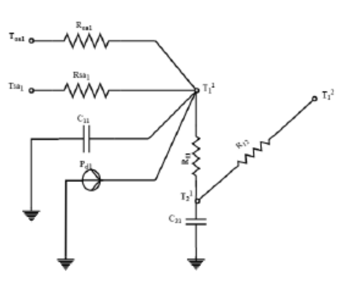
Sistem tanımlamada kullanılmak üzere T binasının dış etken (kontrolümüzde olmayan) değerlerini elde etmek için DB simülasyon sonuçları kullanılmıştır. Dış etkenler; mahal pencerelerinden aydınlatma, insan yoğunluğu ve güneş enerjisi kazanımı gibi her bir mahal için ayrı ayrı bulunmuş, ve bir örneği insan yoğunluğu için Şekil-4 de verilmiştir.



Şekil 4. Her Mahal İçin İnsan Yoğunluğu Etkisi

KONTROL ALGORİTMASI:

Mahallerin birbiri ile olan ilişkisinin ve birbirlerine olan etkilerinin matematiksel olarak modellenmesi Şekil-5'de gösterilmiştir.



Şekil 5. Mahal İlişkilerini Gösteren Matematiksel Model

Her bir direnç bitişik mahaller arasındaki termal dinamiği, her bir kapasitans mahallerin termal kapasitesini temsil etmektedir. Bu ilişkilerin formüle edilmiş hali Eşitlik (1)-(2) ile verilmiştir [2].

$$C_1^j\dot{T}_1^j = \dot{m}^j C_p^j\left(T_{sa}^j - T_1^j\right) + \frac{T_2^j - T_1^j}{R_1^j} + \frac{T_{oa} - T_1^j}{R_{oa}^j} + P_d^j \quad (1)$$

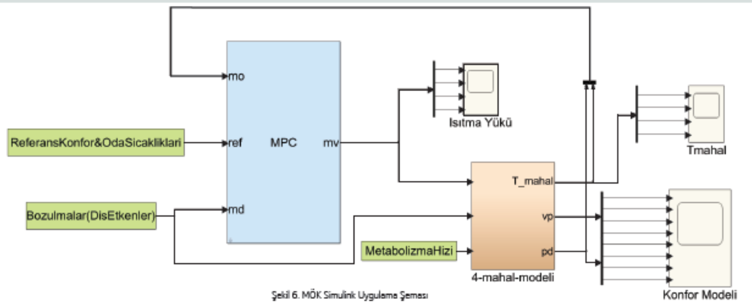
$$C_2^j\dot{T}_2^j = \frac{T_1^j - T_2^j}{R_1^j} + \sum_{i \in N_j} \frac{T_1^i - T_2^j}{R_{ij}} \quad (2)$$

Modeldeki R ve C değerlerini bulmak için, kısıtsız çok değişkenli doğrusal olmayan optimizasyon problemi çözülmüştür. Bu amaçla, aşağıdaki optimizasyon problemi formüle edilmiştir.

$$P = \min_{\{R,C\}} \frac{1}{N}\sum_{k=1}^{N}\sum_{j=1}^{n_z}\left(T_1^{j,m} - T_1^{j,e}(P,U)\right) \quad (3)$$

MODEL ÖNGÖRÜMLÜ KONTROL:

MÖK algoritması ile 24 saat içerisinde belirlenen aralıklarla ileriye bakarak her bir mahal için optimum sıcaklık değerlerini bulmaktadır. Oluşturulan algoritmanın çalışma prensibi Şekil-6' da gösterilmiştir.

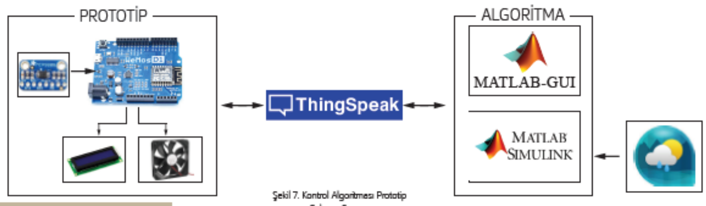


Şekil 6. MÖK Simulink Uygulama Şeması

MPC modelimizde Fanger'in [3]% 80 memnun kişiye ulaşmasını sağlayan termal konfor modeli uygulanmaktadır.

PROTOTİP:

Oluşturulan kontrol algoritmasının gerçek sistemler üzerinde nasıl çalışacağının temsili Şekil-7'de gösterildiği şekilde sağlanmıştır.



Şekil 7. Kontrol Algoritması Prototip Çalışma Şeması

BULGULAR

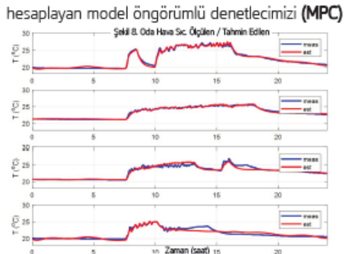
Bir günlük veri topladıktan sonra, elde edilen R ve C değerleri Tablo 1'de verilmiş, model tarafından tahmin edilen mahal hava sıcaklıklarının sensör ölçümleri ile karşılaştırılması Şekil-8 da verilmiştir.

Tablo 1. T Binası 1-4 Mahalleri İçin Parametre Tanımlama Sonuçları

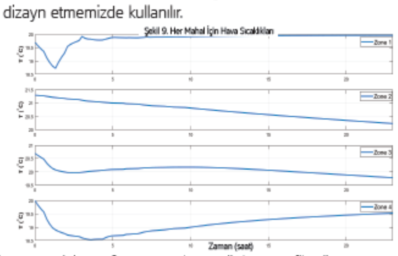
Parametre	Değer	Parametre	Değer
C_{11}	1760.26	R_{oa1}	3.4272
C_{21}	18794.17	R_{22}	0.3294
C_{12}	7473.97	R_{23}	0.1714
C_{22}	467457.60	R_{24}	13.5480
C_{13}	3315.02	R_{oa2}	10.7485
C_{23}	84627.16	R_{33}	0.4404
C_{14}	2217.39	R_{34}	20.6000
C_{24}	7126.61	R_{oa3}	3.9676
R_{11}	0.9756	R_{44}	0.5387
R_{12}	1.0065	R_{oa4}	5.6419

Devamında, bu model ısıtma/soğutma yükünü minimize etmek adına her bir mahal için optimal hava sıcaklıklarını hesaplayan model öngörümlü denetlecimizi **(MPC)** dizayn etmemizde kullanılır.

Şekil 8. Oda Hava Sıc. Ölçülen / Tahmin Edilen



Şekil 9. Her Mahal İçin Hava Sıcaklıkları



Bu model için, referans sıcaklık, sabit bir değer olarak 24 saat için 20 ° C'ye ayarlanır, böylece grafik gün boyunca bu sıcaklığa gitme eğilimindedir.

SONUÇLAR

Bu projenin ana hedefi, bina HVAC ünitelerinin pik yükleri ve enerji tüketimini azaltmak için yeni ve ölçeklenebilir bir optimal kontrol algoritması geliştirmek, ardından geliştirilmiş algoritmanın oluşturulan prototip üzerinde çalıştığını göstermektir. Algoritma geliştirilirken ortamdaki termal konfor seviyesi %80'in üzerinde tutulmuştur. Sonraki çalışmalarımız arasında mahallere yerleştirilecek olan termostatların kullanılarak Yaşar Üniversitesi T Binasının hava sıcaklıklarının kontrolünün sağlanması bulunmaktadır. Buna ek olarak, ısıtma yükünü en aza indirmeye dayalı sistemin tüm tasarımı ve uygulaması, aynı şekilde soğutma yükünü minimize etmek için soğutma dönemi için de uygulanacaktır.

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