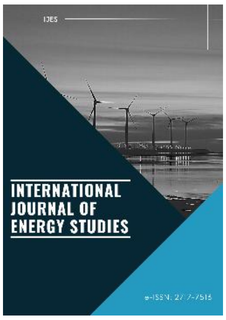
INTERNATIONAL JOURNAL OF ENERGY STUDIES

e-ISSN: 2717-7513 (ONLINE); homepage: https://dergipark.org.tr/en/pub/ijes



Research Article

Int J Energy Studies 2025; 10(3): 787-806

DOI: 10.58559/ijes.1750386

Received : 25 July 2025
Revised : 25 July 2025
Accepted : 14 Aug 2025

A holistic design of an energy-efficient data center with solar PV integration

Muhammed Burak Oyacı[a]*, Önder Kızılkan[b]

[a] *Isparta University of Applied Sciences, Institute of Graduate Education, 32200, Isparta, Türkiye, 0009-0003-3313-5948*

[b] *Isparta University of Applied Sciences, Faculty of Technology, Department of Mechanical Engineering, 32200, Isparta, Türkiye, 0000-0002-4865-6135*

*(*Corresponding Author: burakoyaci@hotmail.com)*

Highlights

- A Tier III-compliant, 500 m² data center was designed using Ankara's peak summer conditions for accurate cooling load estimation.
- Detailed CLTD-based thermal calculations determined a total internal heat gain of 470.63 kW, guiding CRAH and chiller capacity selection.
- Integration of an 85.05 kWp rooftop PV system reduced annual grid consumption by 192 MWh, yielding ~727,102 TRY savings.
- A ground-mounted PV configuration (29.33 MWp) was dimensioned to fully meet the facility's 10.76 GWh annual energy demand.

You can cite this article as: Oyacı MB, Kızılkan Ö. A holistic design of an energy-efficient data center with solar PV integration. Int J Energy Studies 2025; 10(3): 787-806.

ABSTRACT

The rapid growth of digital services has increased the demand for energy-intensive data centers, making sustainability and efficiency essential design priorities. This study presents the design and performance evaluation of a Tier III-compliant, 500 m² data center tailored to Ankara's climatic conditions. Cooling loads were calculated using the CLTD method, resulting in a total internal heat gain of 470.63 kW, which guided the sizing of CRAH units and free-cooling-capable chillers. Detailed thermal analysis was combined with architectural planning, including cold aisle containment and raised flooring, to optimize airflow and energy use. The UPS system was sized at 462 kW to ensure continuous operation of critical loads, supported by redundant power generation. A rooftop PV system of 85.05 kWp was integrated, producing 192 MWh annually and covering 2.07% of the 9.28 GWh yearly demand, yielding cost savings of ~727,102 TRY. A ground-mounted PV system of 29.33 MWp was also proposed to meet the full annual energy demand, with an estimated saving potential of ~35.066 M TRY. The results demonstrate how integrating precise load estimation, energy-efficient cooling, and renewable generation can reduce both operational costs and environmental impact in mission-critical facilities, providing a replicable model for similar climates.

Keywords: Data center, Sustainability, Solar energy, Energy efficiency

1. INTRODUCTION

The rapid advancement of technology, the widespread adoption of cloud computing, the growing demand for digital services, and the increasing importance of data storage have led to a global expansion in data center usage. However, the substantial energy consumption of these facilities has raised concerns regarding environmental impact and energy sustainability [1]. This is especially critical given that electricity production still relies significantly on fossil fuels such as coal, oil, and natural gas [2],[3],[4]. As a result, energy efficiency has become a central issue in modern data center design, where minimizing energy use while maintaining operational reliability is essential. For instance, a typical 465 m² data center can consume over 1,100 kW of power across critical equipment and supporting infrastructure [5]. In parallel, integrating renewable energy sources, particularly photovoltaic (PV) systems, offers a promising approach to reducing carbon emissions and operational costs. With an average annual solar radiation of 1,527.46 kWh/m² and 2,741 hours of sunlight, Türkiye holds significant potential for PV applications [6-7].

Efforts to enhance energy performance in data centers have generally focused on thermal management and cooling strategies, infrastructure optimisation, and energy recovery or renewable integration. In the field of thermal management, Greenberg et al. [8] compiled best practices to improve energy efficiency, including optimised air management, correctly sized ventilation systems, economisers for free cooling, controlled humidification, and high-efficiency uninterruptible power supplies. Pan et al. [9] applied multiple ASHRAE-based efficiency strategies—such as high-performance insulation, lighting upgrades, and HVAC improvements—in two existing Chinese data centers, achieving an estimated 21% reduction in annual energy costs. Nada et al. [10] conducted computational fluid dynamics (CFD) analyses to study airflow and temperature distributions under different operating and geometric conditions, showing the effectiveness of cold aisle containment and appropriate computer room air conditioner - computer room air handler (CRAC – CRAH) spacing. Türkmen [11] implemented cold aisle containment, equipment relocation, CRAC fan speed control, and leakage isolation, reducing the power usage effectiveness (PUE) from 1.95 to 1.40. Erden and Türkmen [12] modelled CRAH bypass configurations, finding that the approach could be economically viable with a payback period of 3–4 years under certain conditions.

In terms of infrastructure and operational optimization, Dörterler et al. [13] redesigned a university server room by calculating cabinet, power, and cooling requirements and aligning them with safety and fire protection policies. Sharma et al. [14] emphasized that data center efficiency starts with the architectural design phase and is strongly linked to proper equipment selection. Yüzgeç and Günel [15] examined planning criteria and certification requirements, concluding that well-designed infrastructure minimises downtime during faults or maintenance. Sürücü [16] analysed container-type data centers designed to meet Tier III certification, showing they could be deployed 40% faster than conventional facilities. Demir [17] discussed the role of advanced automation systems for real-time monitoring and control of mechanical and electrical loads, improving operational reliability and efficiency. Zhang et al. [18] compared four free cooling technologies, finding that water-based systems operating in multiple modes offered the highest energy savings.

With respect to energy recovery and renewable integration, Woodruff et al. [19] investigated seasonal waste heat recovery from data centers, achieving over 10% efficiency gains when integrated into building heating systems. Ali et al. [20] developed a high-gain, transformer-isolated GaN-based DC–DC converter for integrating low-voltage PV panels into high-voltage DC data center systems, achieving 95.56% efficiency in laboratory tests.

A review of the literature indicates that while numerous studies have addressed cooling efficiency, infrastructure optimisation, and partial renewable energy integration, no previous work has combined precise CLTD-based cooling load estimation, Tier III-compliant architectural and infrastructure design, and dual-scale PV integration (rooftop and ground-mounted) within a single framework for a medium-scale data center. Furthermore, the direct supply of critical IT infrastructure from PV systems—supported by quantitative energy and cost analyses—has not been comprehensively investigated.

In this study, a sustainable data center is designed for the climatic conditions of Ankara. Heat gain calculations are performed for conditioned rooms to guide the selection of appropriate cooling systems and equipment. A photovoltaic system is then integrated into the design to meet part or all of the facility's energy demand using solar power. While previous research has primarily applied renewable energy to support non-critical loads, this work focuses on directly powering critical IT infrastructure. An energy analysis tailored to local conditions is conducted, followed by an assessment of potential carbon emission reductions. Finally, the annual energy savings and environmental benefits achieved by the proposed design are presented.

2. MATERIALS AND METHODS

A mid-scale data center was developed with a total floor area of 500 m², designed to accommodate 60 cabinets, each with a height of 45U and an average energy consumption of 7 kW. The infrastructure complies with at least Tier III certification standards to ensure high availability and fault tolerance. Tier classification refers to a certification system defined by the Uptime Institute to evaluate the availability, redundancy, and operational sustainability of data centers. It consists of three certification stages: Design Documents, Constructed Facility, and Operational Sustainability. Tier levels range from Tier I to Tier IV, each ensuring increasing levels of fault tolerance and uptime (see Figure 1). Although certification is not mandatory, these standards guide critical infrastructure design decisions, particularly for power, cooling, and monitoring systems.

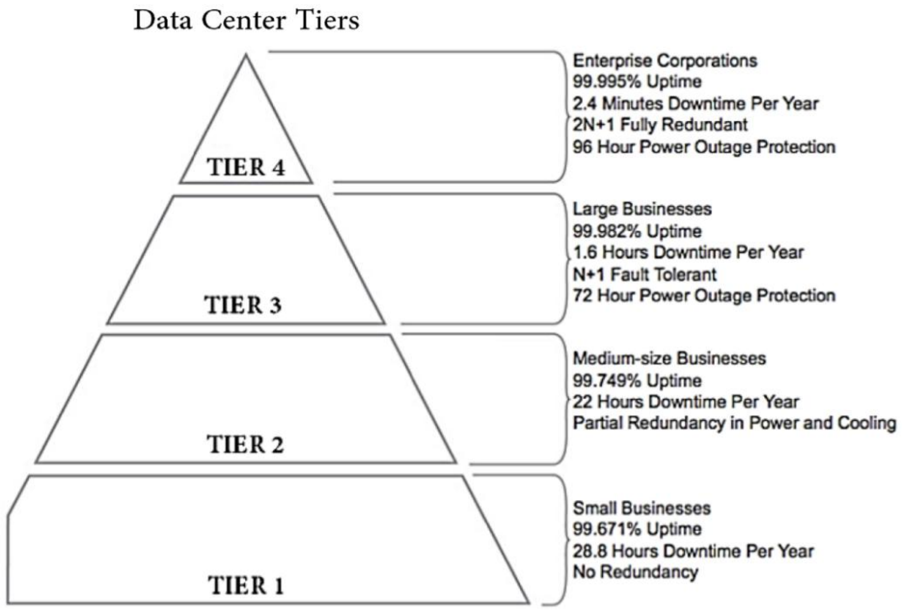


Figure 1. Different tiers of data centers [21]

All cooling load and thermal calculations were based on the highest summer climatic conditions recorded for Ankara. The design dry-bulb temperature is 34°C, the relative humidity is 40%, and the ground temperature is 15°C [22]. To enhance energy efficiency and airflow management, the infrastructure includes a raised floor system and cold aisle containment throughout the white space.

For sustainable data center operation, IT equipment must be maintained within appropriate environmental conditions. According to the American Society of Heating, Refrigerating and Air-Conditioning Engineers (ASHRAE) [23], the recommended operating temperature range is 18°C to 27°C for Class A1 devices, such as standard servers and networking equipment. For Class A2 devices, including some storage units, this range is extended to 10°C to 35°C. In practice, ASHRAE permits an extended range of 15°C to 32°C for Class A1 environments under specific operating conditions. These temperature thresholds are essential to prevent hardware degradation and to optimize thermal performance.

In terms of humidity control, ASHRAE recommends maintaining relative humidity between 40% and 60% to minimize risks of static discharge or condensation [23]. The dew point should not exceed 8°C at 60% humidity to avoid moisture-related failures. Additionally, manufacturers may impose stricter climate control guidelines for specific components; for example, while a server might comply with Class A4 standards, its CPU may require Class A3 conditions. The classification of environmental requirements for IT equipment is illustrated in Figure 2.

In the proposed data center configuration, the white space was designed within a 12 m × 18 m footprint, where standard-sized cabinets (60 cm × 120 cm) were placed on a raised floor. Cold aisle containment was implemented to improve airflow management. The spacing between cabinets and adjacent walls was set as multiples of the standard 60 cm tile unit to ensure uniform static load distribution. A distance of 3 m was maintained between cabinets and surrounding walls to allow proper air circulation. Cooling in both the white space and the UPS room is provided by CRAH units connected to the chilled water system, which are specifically designed for precise temperature and humidity control in data centers.

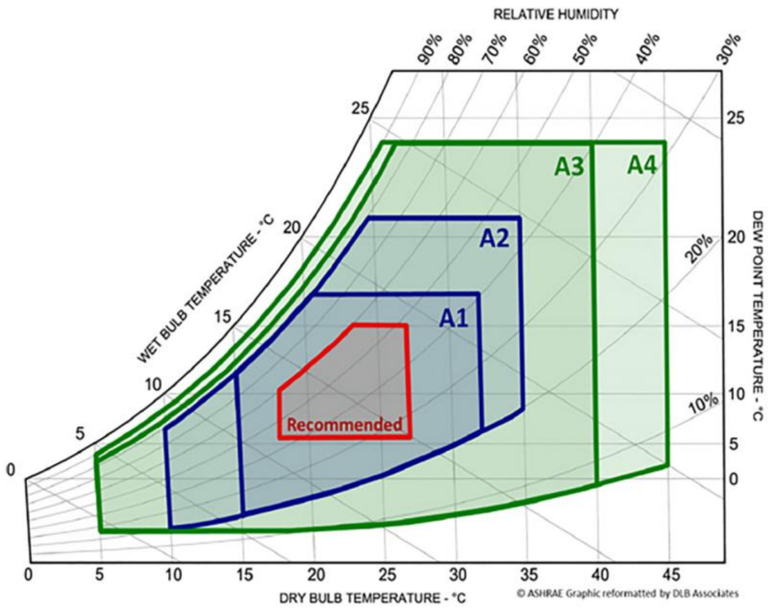


Figure 2. Recommended environmental classes for IT equipment based on ASHRAE [24]

Cabinets were arranged so that hot aisles faced each other, maintaining a distance of 1.8 m between rows, while cold aisles were set at 1.2 m to ensure effective cooling delivery. Standardized architectural elements were applied, with all doors sized at 180 cm × 250 cm and windows at 80 cm × 120 cm. This configuration balances structural simplicity with operational efficiency. Figure 3 illustrates the cabinet layout and cold aisle containment strategy applied in white space.

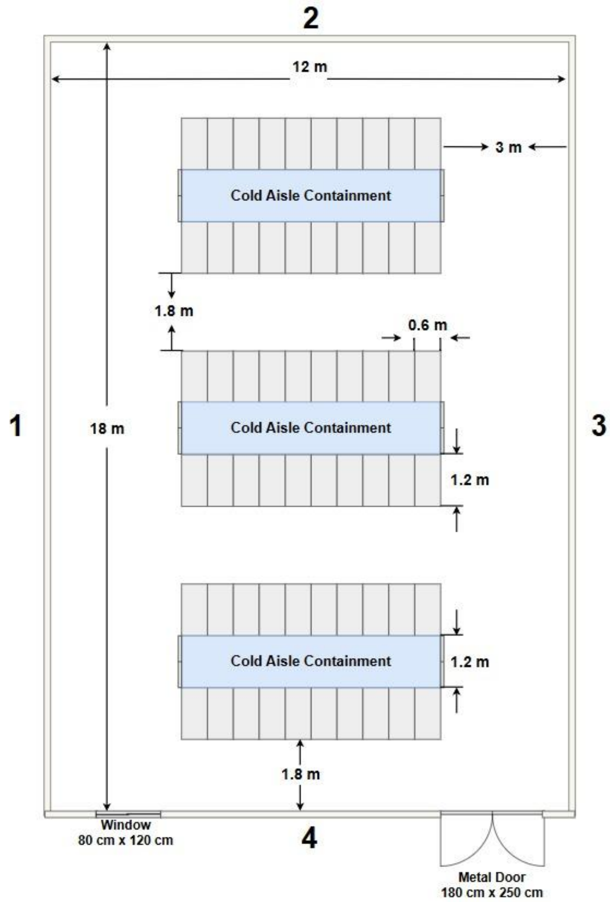


Figure 3. Cabinet positioning and layout

The approach begins with the calculation of PUE, a widely accepted metric for assessing data center efficiency [25]:

$$\text{PUE} = \frac{\sum P_{\text{Facility}}}{P_{\text{IT,eq}}} \quad (1)$$

In above equation, $\sum P_{\text{Facility}}$ is the total facility load and $P_{\text{IT,eq}}$ is the IT equipment energy consumption. The facility is structured across two levels and includes separate compartments for server racks, uninterruptible power supply (UPS) systems, batteries, administrative offices, and control infrastructure. Layout planning was performed based on accessibility and airflow zoning standards. The data center designed in this study occupies a total usable floor area of 500 m² and includes a white space (server room), UPS room, battery room, Network Operations Center (NOC) and control room, as well as technical corridors and administrative offices. Spatial organization was developed to ensure safe operation, efficient maintenance access, and effective air zoning.

To determine the cooling requirement of the white space, the CLTD method was used. The total cooling load is expressed as:

$$\sum\dot{Q} = \left(\sum\dot{Q}_{eq} + \dot{Q}_{people} + \dot{Q}_{light} + \cdots + \dot{Q}_{n}\right) \times SF \quad (2)$$

where, SF denotes the safety factor. These components represent internal heat gains from IT equipment, lighting fixtures, human occupancy, conductive heat transfer through structural elements, and air leakage into the space. Equipment loads were based on actual power demand, while lighting gains were calculated based on installed luminaire power and operating schedules. Infiltration loads were minimized by sealing cable trays and access panels. The basic power formula is given in Equation (3):

$$P = V \times I \times \cos(\phi) \quad (3)$$

In this equation, P represents power (W), V is voltage (V), I is current (A), and cos(φ) denotes the power factor. The UPS capacity calculation is provided below:

$$P_{UPS} = \left(P_{IT,eq} + P_{Other\ critical\ loads}\right) \times SF \quad (4)$$

Devices requiring UPS backup should be clearly identified, and the UPS capacity must be selected accordingly. Since not all input energy is delivered as usable output, internal losses within the UPS must be considered. These losses are primarily dissipated as heat, contributing to internal thermal gain. The heat load due to UPS inefficiency is given by:

$$\dot{Q}_{UPS\ losses} = \frac{P_{UPS} \times \sum_{UPS\_inefficiency}}{100} \quad (5)$$

In this equation, $\dot{Q}_{UPS\ losses}$ represents the heat released into the environment due to inefficiencies in the UPS system, including conversion and battery charge/discharge losses.

To size the generator and transformer, the inrush current during startup of mechanical and electrical systems must be considered. The estimated power for mechanical loads and UPS-backed loads is calculated using Equations (6) and (7), respectively [26]:

$$\sum P_{Facility,mech} = (P_{mech}) \times 1.55 \tag{6}$$

$$\sum P_{Facility,UPS} = (P_{UPS}) \times 1.3 \tag{7}$$

Total facility load is the sum of both components and is expressed as:

$$\sum P_{Facility} = \sum P_{Facility,mech} + \sum P_{Facility,UPS} \tag{8}$$

The pump power requirement is calculated by [11]:

$$P_{Pump} = \frac{\rho \times Q \times H}{367 \times \eta} \times SF \tag{9}$$

Here, Q is the volumetric flow rate (L/s), H is the pump head (m), ρ is the density (kg/dm^3), and η is the hydraulic efficiency. The required capacity for the generator and transformer is calculated using the equation below:

$$P_{Gen,transformer} = \frac{\sum P_{Facility}}{\text{Power Factor}} \times SF \tag{10}$$

The output power of PV systems determined by:

$$W_{PV} = n \times P_{max} \tag{11}$$

where W_{PV} is the total PV power output and P_{max} is the rated capacity of one panel. Efficiency loss due to temperature is found by:

$$\eta_{temp.\,loss} = \mu_p \times (T_{max} - T_{nom}) \tag{12}$$

Here μ_p is the temperature coefficient, T_{max} is the maximum panel temperature, and T_{nom} is the nominal test temperature. Overall AC-side efficiency of the PV system is computed as:

$$\eta_{AC} = \eta_{temp} \times \eta_{reflected} \times \eta_{mismatch} \times \eta_{inv} \tag{13}$$

The AC power required from the PV system to meet load demand is then given below:

$$W_{PV,AC} = \frac{\Sigma P_{Facility}}{\eta_{AC}} \tag{14}$$

The inverter's maximum short-circuit current for the MPPT input is calculated as:

$$I_{SC,MPPT(max)} = b \times I_{SC,PV} \tag{15}$$

where b is the number of MPPT inputs and $I_{SC,PV}$ is the panel's short-circuit current.

3. RESULTS AND DISCUSSION

In this study, a medium-scale data center was designed for Ankara, Türkiye, with attention to architectural layout, internal thermal loads, equipment selection, and integration of sustainable energy solutions. The white space was dimensioned as 12 m × 18 m, and a total internal heat gain of 470.63 kW was calculated. To handle this load, three CRAH units were deployed in a 2N redundant configuration, positioned face-to-face with cold aisle containment to enhance cooling performance and airflow efficiency. The physical layout ensured sufficient clearance for airflow and maintenance access.

Based on critical loads, the UPS system was sized at 462 kW, and scalable modular units were selected to accommodate future expansion while operating near optimal efficiency levels. The UPS and computer room air handler (CRAH) units in the UPS room were also dimensioned with redundancy, targeting a cooling demand of 170.33 kW. All thermal loads from the white space and UPS rooms were addressed through a chilled water system consisting of two 750 kW chillers, each capable of free cooling operation. Pumping requirements were computed based on a 30% glycol–

70% water mixture, with final selections considering system redundancy and frequency control for dynamic demand adaptation.

The chilled water system includes standard thermal management infrastructure such as buffer tanks, balance tanks, and headers, all located beneath a raised floor for easy access and mechanical flexibility. These ensure thermal stability, pressure management, and energy-efficient operation during part-load conditions. The layout supports maintenance continuity by incorporating isolation valves and redundant piping routes. Mechanical connectivity and spatial integration of the chilled water network are illustrated in Figure 4.

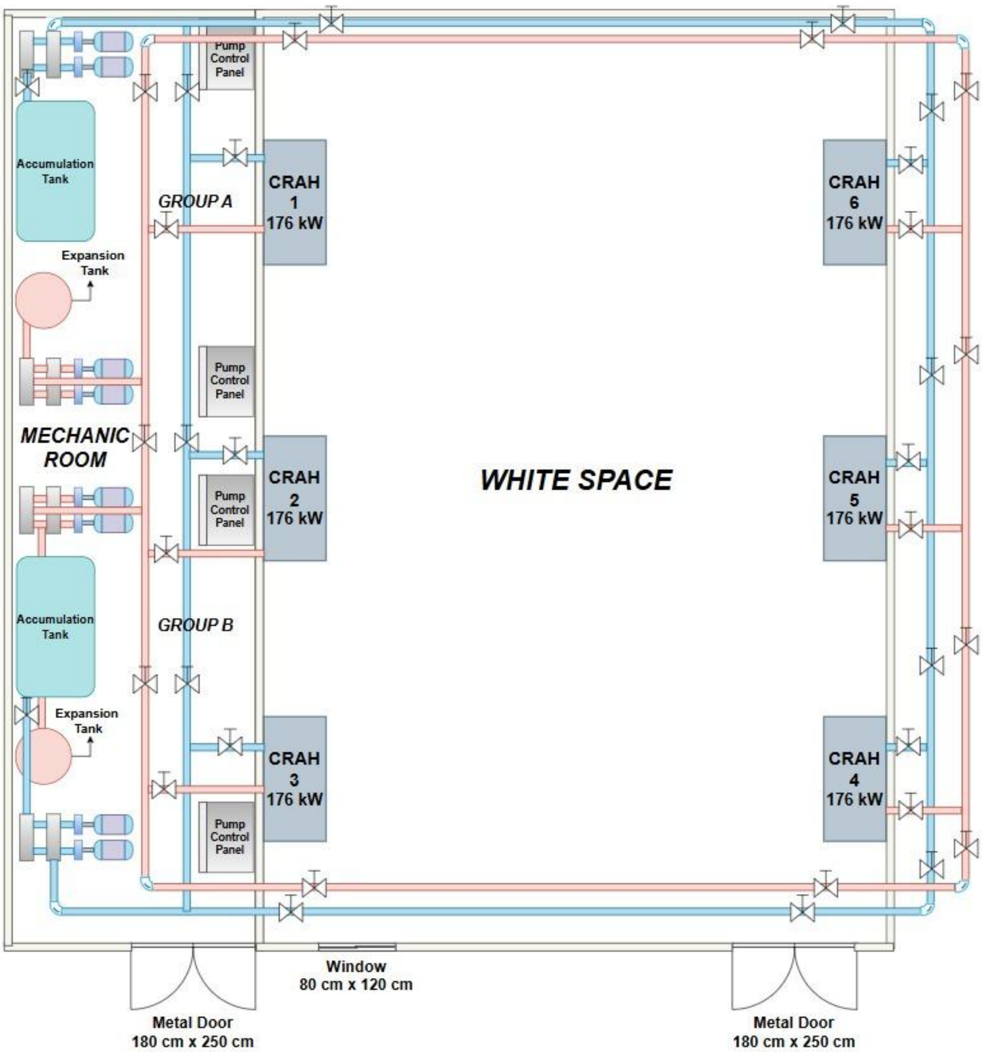


Figure 4. Mechanical room layout and white space connection diagram

To ensure backup during power outages, the cooling systems were configured to operate directly from diesel generators rather than the UPS system. A brief cooling gap of approximately 30 seconds during generator startup was deemed acceptable based on the residual thermal mass and pre-cooled air volume in the white space. Generator loads were estimated as 1,645.3 kVA (including cooling and IT equipment), and two 1,700 kVA units were selected with N+1 redundancy. Fuel autonomy for 72 hours requires 28,800 L of underground storage tanks per generator. The choice of underground installation offers safety, thermal stability, and land-use efficiency, and is preferred for long-term storage with integrated fuel polishing systems to maintain fuel quality.

The data center design complies with Tier III standards by implementing N+1 redundancy in critical systems. This includes dual CRAH units arranged in a 2N redundant configuration, modular and scalable UPS units, and twin 750 kW chillers supporting free cooling operation. Redundancy is further ensured by parallel piping with isolation valves in the chilled water network and by dual diesel generators sized with N+1 redundancy and underground fuel storage for extended autonomy. While explicit dual power and cooling paths are architecturally provided, these elements ensure uninterrupted operation under maintenance or component failure, fulfilling Tier III fault tolerance requirements.

Fire detection and suppression systems were designed with cold aisle containment, raised floors, and high equipment density in mind. Heat and smoke detectors, air sampling units, and sensor networks were integrated to ensure early detection and full redundancy. An integrated DCIM platform enables real-time monitoring of environmental and operational parameters, with visualized system status and metrics provided through flow and single-line diagrams.

In support of sustainability goals, photovoltaic (PV) panel integration was evaluated in both rooftop and ground-mounted configurations. One of the most effective methods to reduce energy costs in facilities with high electricity demand is the use of photovoltaic systems that generate free electricity from solar energy. As a renewable and green energy source, maximizing the utilization of solar energy is crucial. Türkiye has a favorable solar potential for power generation, and in particular, the average daily solar insolation for Ankara is 7.15 hours, as illustrated in Figure 5. Correspondingly, the global solar radiation profile for the region is shown in Figure 6.

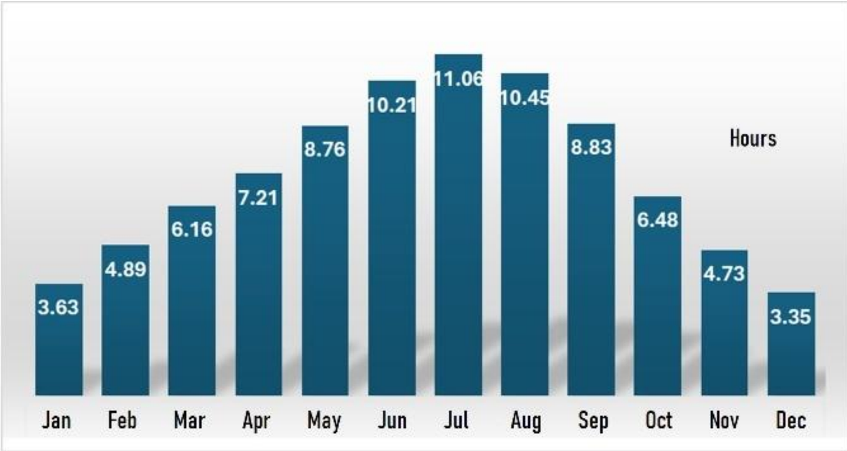


Figure 5. Monthly average sunshine duration in Ankara [6]

Figure 6. Monthly average global solar radiation in Ankara [6]

Following the design of the data center, a solar PV application was selected to supplement energy consumption using renewable resources. Based on solar potential assessments and technical analysis, PV panel integration was studied to determine its contribution to overall energy demand. After surveying commercially available high-efficiency technologies, monocrystalline PV modules were selected for implementation. The key characteristics of the selected module are presented in Table 1.

Table 1. Technical specifications of the selected photovoltaic panel [27]

Specification	***Value***
Maximum Power (Pmax)	675 Wp
Module Efficiency	21.73 %
Maximum Power Voltage (Vmp)	38.5 V
Maximum Power Current (Imp)	17.54 A
Open Circuit Voltage (Voc)	46.20 V
Short Circuit Current (Isc)	18.56 A
Panel Dimensions (mm)	2384×1303×35
Temperature Coefficient (Isc)	+0.040 %/°C
Temperature Coefficient (Voc)	–0.260 %/°C
Temperature Coefficient (Pmax)	–0.340 %/°C
Nominal Operating Cell Temperature	+25 °C
Minimum Operating Temperature (Tmin)	–40 °C
Maximum Operating Temperature (Tmax)	+85 °C

Based on the evaluated solar potential and panel specifications, rooftop PV modules were installed over 500 m² of usable space, accounting for maintenance corridors. High-efficiency monocrystalline panels (675 Wp, 21.73% module efficiency) were used, yielding a total of 85.05 kWp installed capacity. Daily AC energy output was computed as 527 kWh, covering approximately 2.07% of the data center's daily consumption of 25,416 kWh. The rooftop layout and orientation of the photovoltaic panels are illustrated in Figure 7.

Given the limited rooftop area, a ground-mounted PV system was proposed to meet the full energy demand. Technical calculations based on panel and inverter compatibility determined that 6,192 panels (0.675 kWp each) and 43 inverters (100 kW) would be required. Total installed DC capacity was estimated at 29,325 kWp, producing sufficient energy when accounting for inverter efficiency (98.4%) and system losses. Layout optimization ensures that each inverter operates with optimal MPPT configuration, and inverter–panel interconnection is shown in Figure 8.

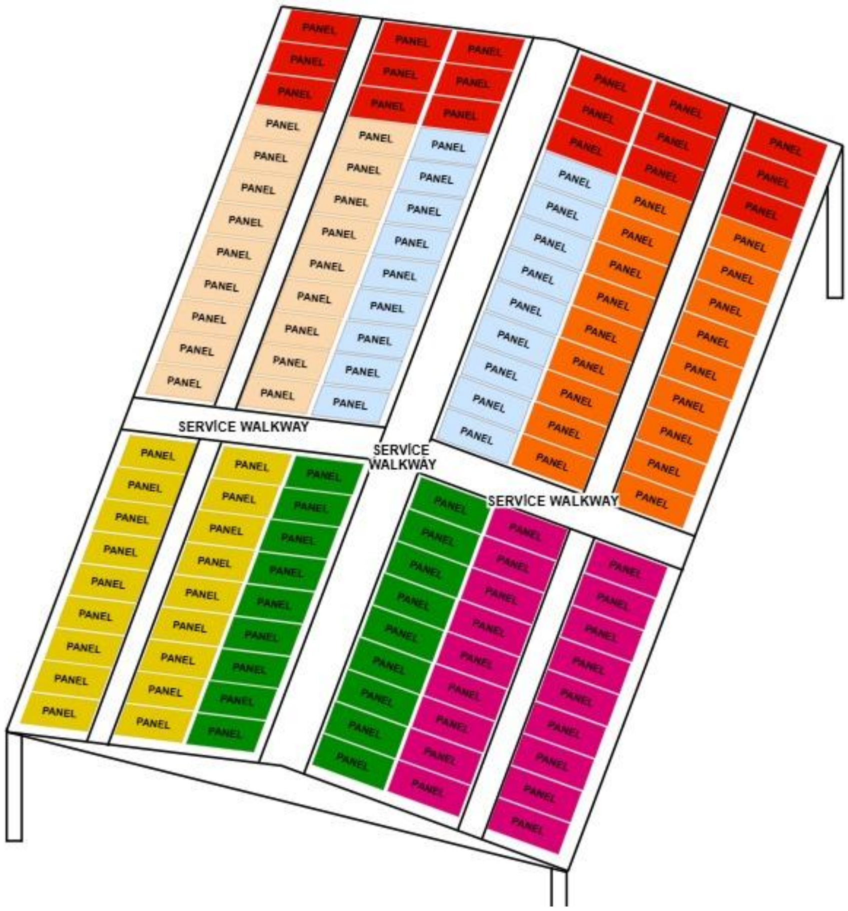


Figure 7. Rooftop photovoltaic (PV) panel installation layout

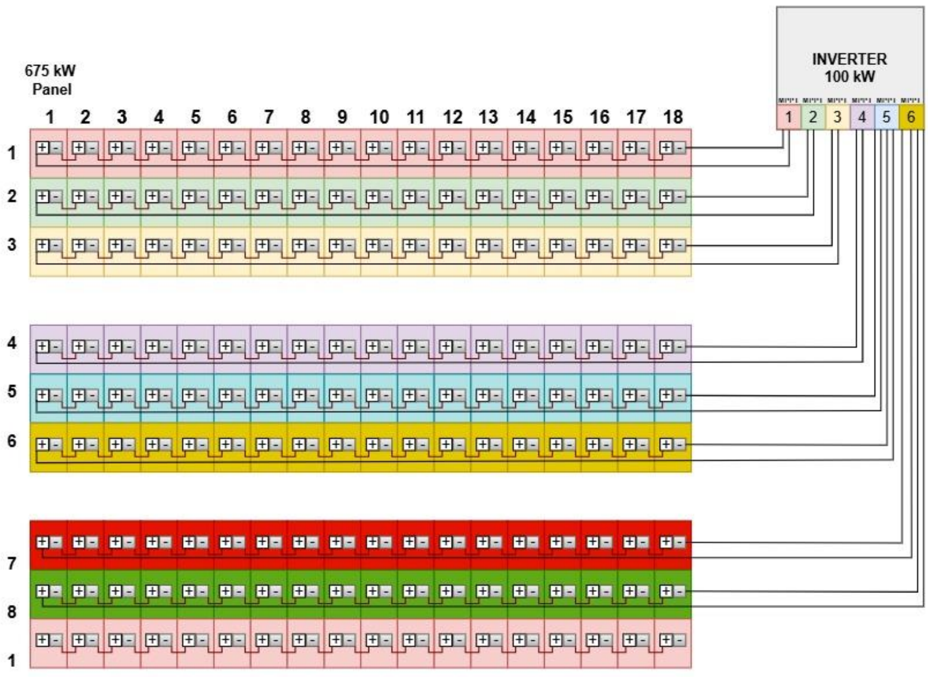


Figure 8. Panel–inverter interconnection diagram

The rooftop PV system is estimated to generate approximately 192,355 kWh annually, while the ground-mounted PV system would produce about 9.28 GWh annually, meeting 2.07% and 100% of the data center's annual energy demand, respectively. Considering Türkiye's 2023 average grid emission factor of 0.42 kg CO_2/kWh [28], the rooftop PV system would reduce annual CO_2 emissions by approximately 80.8 tonnes, and the full-scale ground-mounted system would achieve an estimated 3,897.6 tonnes of annual CO_2 reduction.

Based on the commercial electricity tariff of 3.78 TRY/kWh valid as of April 17, 2023 [29], the rooftop PV system could yield annual savings of approximately 727,102 TRY, covering only 2.07% of the data center's average daily electricity demand of 25,416 kWh. Due to the limited number of panels that could be installed on the roof and the inherently high energy needs of the facility, the rooftop contribution remained modest. Therefore, a ground-mounted PV system was dimensioned to fully meet the facility's load, resulting in an estimated annual savings potential of 35,066,455 TRY. However, due to weather-related intermittency, such systems are not recommended as the sole energy source for mission-critical facilities. Instead, solar integration should complement the grid supply. Battery storage was excluded due to high capital costs; instead, leveraging the existing UPS infrastructure was proposed. By incorporating ATS (Automatic Transfer Switch) -controlled dual-mode charging—PV during sunny days and grid supply during low-sun periods—solar contribution can be optimized without compromising UPS reliability.

The results indicate that tailoring the data center design to Ankara's climatic conditions allows for optimized cooling performance and reliable operation, supported by Tier III redundancy measures. The combined use of rooftop and ground-mounted PV systems effectively offsets a substantial portion of the facility's energy consumption, demonstrating the practical benefits of renewable integration in medium-scale data centers. These findings highlight the importance of site-specific design and energy efficiency considerations in reducing operational costs and environmental impacts.

4. CONCLUSION

This study presents a comprehensive design and performance evaluation of a medium-scale data center tailored to Ankara's climatic and operational conditions. The novelty lies in combining detailed CLTD-based cooling load estimation, Tier III redundancy, and dual-scale photovoltaic

(PV) integration specific to the region—a combination not previously explored in similar studies. The facility's cooling system manages a total heat gain of 470.63 kW using redundant CRAH units and free-cooling chillers. The rooftop PV system, with an installed capacity of 85.05 kWp, contributes to about 2.07% of daily energy demand, while the ground-mounted system, sized at 29,325 kWp, fully covers the energy needs. Together, these PV systems provide an estimated annual reduction of approximately 279 tonnes of CO_2 emissions.

Challenges such as solar intermittency and the absence of dedicated battery storage are addressed through an ATS-controlled dual-mode charging strategy utilizing existing UPS infrastructure to maintain system reliability. Future research should focus on integrating energy storage and real-time energy management systems to maximize renewable utilization and expanding the design methodology to other climates and larger facilities. The results demonstrate that integrating renewable energy and energy-efficient infrastructure can significantly reduce operational costs and environmental impacts, supporting sustainable and low-emission data center development.

NOMENCLATURE

AC	Alternative current
ASHRAE	American Society of Heating, Refrigerating and Air-Conditioning Engineers
CRAC	Computer room air conditioner
CRAH	Computer room air handler
PUE	Power usage effectiveness
UPS	Uninterruptible power supply
NOC	Network operations center
CLTD	Cooling load temperature difference
H	Pump head (m)
inv	Inverter
I	Current (A)
IT	Information technology
mech	Mechanical
MPPT	Maximum power point tracking
n	Number of PV panels
P	Power (W)
PV	Photovoltaic

Q	Volumetric flow rate (L/s)
$\dot{Q}$	Cooling load (W)
SF	Safety factor
T	Temperature (°C)
V	Voltage (V)
ρ	Density (kg/m^3)
η	Hydraulic efficiency
μ_p	Temperature coefficient

DECLARATION OF ETHICAL STANDARDS

The authors of the paper submitted declare that nothing which is necessary for achieving the paper requires ethical committee and/or legal-special permissions.

CONTRIBUTION OF THE AUTHORS

Muhammed Burak Oyacı: Conceptualization, Methodology, Investigation, Modeling, Visualization, Data Analysis, Resources, Writing - Original Draft

Önder Kızılkan: Supervision, Conceptualization, Methodology, Validation, Interpretation of Data, Writing – Review & Editing.

CONFLICT OF INTEREST

There is no conflict of interest in this study.

REFERENCES

[1] Kocakuşak R. Solar energy of the renewable energy sources, the importance of Turkey and installation of GES research. MSc Thesis, Maltepe University, Institute of Social Sciences, Department of Business Administration, Istanbul, Turkey, 2018, 99 pp. (In Turkish)

[2] Szlazak J, Szlazak RA. Access to primary energy sources - the basis of national energy security. Mater Sci Eng 2017; 268: 012002. https://doi.org/10.1088/1757-899x/268/1/012002

[3] BP. Statistical Review of World Energy, 71st ed. London, UK, 2022. [Online] Available at: https://www.bp.com/content/dam/bp/business-sites/en/global/corporate/pdfs/energy-economics/statistical-review/bp-stats-review-2022-full-report.pdf (Accessed: January 2023).

[4] Energy Institute. Statistical Review. [Online] Available at: https://www.energyinst.org/statistical-review (Accessed: 13 July 2023).

[5] Vasques TL, Moura P, de Almeida A. A review on energy efficiency and demand response with focus on small and medium data centers. Energy Efficiency 2019; 12: 1399–1428. https://doi.org/10.1007/s12053-018-9753-2

[6] GEPA. Güneş Enerji Potansiyel Atlası. [Online] Available at: https://gepa.enerji.gov.tr/MyCalculator/pages/6.aspx (Accessed: 15 February 2023).

[7] T.C. Enerji ve Tabii Kaynaklar Bakanlığı, Ankara. [Online] Available at: https://enerji.gov.tr/bilgi-merkezi-enerji-gunes (Accessed: 12 July 2023).

[8] Greenberg S, Mills E, Tschudi B, Rumsey P, Myatt B. Best practices for data centers: Lessons learned from benchmarking 22 data centers. Proc ACEEE Summer Study on Energy Efficiency in Buildings, Asilomar, CA, USA, August 2006, 3: 76-87.

[9] Pan Y, Yin R, Huang Z. Energy modeling of two office buildings with data center for green building design. Energy Build 2008; 40(7): 1145-1152. https://doi.org/10.1016/j.enbuild.2007.10.008

[10] Nada SA, Said MA, Rady MA. CFD investigations of data centers' thermal performance for different configurations of CRACs units and aisles separation. Alex Eng J 2016; 55(2): 959–971. https://doi.org/10.1016/j.aej.2016.02.025

[11] Türkmen İ. Experimental investigation of UHEM data center termal profile and CFD analysis. MSc Thesis, Istanbul Technical University, Graduate School of Science, Istanbul, Turkey, 2019, 124 pp. (In Turkish)

[12] Erden HS, Türkmen İ. Energy and economic analysis of the bypass method for the computer room air conditioning units of a small data center. J Fac Eng Archit Gazi Univ 2022; 37(4): 1883–1898. (In Turkish)

[13] Dörterler M, Ateş V, Açıkgöz M. Founding a University Data Center: A Case of Gazi University. XIV. Akademik Bilişim Konferansı, Uşak, Turkey, 1–3 Feb 2012, pp. 383-390. (In Turkish)

[14] Sharma M, Arunachalam K, Sharma D. Analyzing the data center efficiency by using PUE to make data centers more energy efficient by reducing the electrical consumption and exploring new strategies. Procedia Comput Sci 2015; 48: 142–148. https://doi.org/10.1016/j.procs.2015.04.163

[15] Yüzgeç U, Günel A. Energy planning of a data center for universities. Bilecik Seyh Edebali Univ J Sci 2016; 2(2): 17–24 (In Turkish)

[16] Sürücü M. Container data center detailed design, power calculations and device selections. MSc Thesis, Yildiz Technical University, Graduate School of Science, Istanbul, Turkey, 2016, 101 pp. (In Turkish)

[17] Demir MT. Integration of BMS, PMS, and DCIM in data centers. Proc 5th Building Electronic Systems Symposium (Yapı Elektronik Sistemleri Sempozyumu), Izmir, Turkey, 2017. (In Turkish)

[18] Zhang Y, Wei Z, Zhang M. Free cooling technologies for data centers: Energy saving mechanism and applications. Energy Procedia 2017; 143: 410–415.

[19] Woodruff JZ, Brenner P, Buccellato AP, Go DB. Environmentally opportunistic computing: A distributed waste heat reutilization approach to energy-efficient buildings and data centers. Energy Build 2014; 69: 41–50.

[20] Ali K, Raman G, Xiao W, Peng JCH. A GaN-based high step-up half-bridge resonant converter for interfacing PV modules to DC data centers. Proc IEEE 4th Int Future Energy Electron Conf (IFEEC), Singapore, 1–4 Apr 2019, pp. 1–8.

[21] Abiodun K. Digital infrastructure & sustainable data centers investment in Africa: Role of Tier III & Tier IV. Int J Multidiscip Res Growth Eval 2025; 6(1): 1878–1888.

[22] Küçükçalı R, Arısoy A. Klima Tesisatı, Isısan Çalışmaları No. 305. Isısan Akademi, Istanbul, Turkey, 2001

[23] ASHRAE Releases Revised Version of Data Center Standard. [Online] Available at: https://www.ashrae.org/about/news/2019/ashrae-releases-revised-version-of-data-center-standard (Accessed: 21 February 2023).

[24] Awe O, Shah JM, Agonafer D, Singh P, Kannan N, Kaler M. Experimental description of information technology equipment reliability exposed to a data center using airside economizer operating in recommended and allowable ASHRAE envelopes in an ANSI/ISA classified G2 environment. J Electron Packag 2020; 142(2): 024501. https://doi.org/10.1115/1.4046556

[25] Sunbird. What's the Best PUE Ratio for Data Centers? [Online] Available at: https://www.sunbirddcim.com/blog/whats-best-pue-ratio-data-centers (Accessed: 1 June 2023).

[26] Cole D. Fundamentals of Data Center Power: Power Calculations. [Online] Available at: https://www.youtube.com/watch?v=1mTLJzPOSI0 (Accessed: 1 May 2023).

[27] CW-Enerji. Solar Panel Catalogue. [Online] Available at: https://cw-enerji.com/en/product/cw-enerji-675wp-132pm-m12-hc-mb-solar-panel-772.html (Accessed: 13 May 2023).

[28] Nassar YF, Salem MA, Iessa KR, AlShareef IM, Ali KA, Fakher MA. Estimation of CO2 emission factor for the energy industry sector in Libya: a case study. Environment, Development and Sustainability 2021;23:13998–14026.
[29] EPDK. Energy Market Regulatory Authority. [Online] Available at: https://www.epdk.gov.tr/Home/En (Accessed: 17 April 2023).