Sustainable Energy Concept in Design of Library Building in Sau Paulo-Brazil

Waleed Ethbayah[1,a], Moaz Y. Olama[2], Mohamed N. Abdelhamid[2], Ahmed H. Abdelhamid[2], Nouran A. Saber[2], Ahmed Hamed[2,b]*

[1] *Mechanical Power Engineering, Higher Institute of Energy, Public Authority for Applied Education and Training, Kuwait*
[2] *Mechanical Power Engineering, Cairo University, Egypt*
[a]*ethbayah2013@gmail.com*
[b,]**ahamed@eng.cu.edu.eg*

Abstract

This paper involved designing a sustainable, energy-efficient public library in São Paulo, Brazil, targeting Net Zero Energy and complying with ASHRAE and LEED standards. The library is a three-story structure with a basement, housing open library spaces, retail areas, a café, conference rooms, and support facilities. Key design features include a DX VAV HVAC system with terminal reheat, achieving a 30% reduction in energy demand and a 9% decrease in thermal loads. Strategies include LED lighting, daylight sensors, enhanced building envelopes, demand-controlled ventilation, heat recovery, and high-efficiency fans. Renewable energy integration through rooftop PV panels reduces energy consumption by 47%. The library is designed as a community hub promoting education, diversity, and sustainability, balancing functionality, comfort, and environmental impact.

Keywords: *Energy Efficiency; DX VAV with Terminal Reheat; Daylight Sensors; Demand-Controlled Ventilation;*

1. Introduction

The advancement of sustainable building practices is imperative in addressing global environmental challenges. As part of the 2024 Setty Family Foundation Net Zero Energy Design Competition, this report represents the journey to design an energy-efficient and sustainable public library situated in São Paulo, Brazil.

The primary objective of this project is to develop a Net Zero Energy building, where energy consumption is minimized, and renewable energy sources are maximized to achieve equilibrium. Compliance with owner's project requirements (OPR) and adherence to the latest ASHRAE Standards 55, 62.1, 90.1, 189.1, ASHRAE Handbooks, and LEED standards serve as guiding principles throughout the design process.

Emphasizing energy efficiency, occupant health and safety, comfort, functionality, future adaptability, site sustainability, water efficiency, indoor environmental quality, and overall environmental impact are paramount considerations. Furthermore, the design aims to ensure maintainability and a service life spanning 50 years.

The envisioned library will be a three-story structure with a basement level, envisioned as a community hub promoting education, community involvement, and diversity. It encompasses various spaces including open library areas, retail spaces, a café, conference and office rooms, and an automated storage and retrieval system, alongside supporting facilities such as restrooms, utility rooms, and storage spaces.

The selection of a sustainable site in Bauru, strategically located in the heart of São Paulo, serves as the foundation for this endeavor. A comprehensive data collection process facilitates load estimation and the commencement of model development using DesignBuilder software and HVAC design. Two scenarios are formulated: a baseline reflecting minimum ASHRAE Standards requirements, and a proposed scenario integrating innovative strategies and enhancements. The HVAC system is designed as a DX, VAV system with terminal reheat, resulting in significant reductions in thermal loads and energy demand.

Furthermore, the integration of PV panels harnesses renewable energy sources to mitigate energy consumption, contributing to a substantial decrease in overall energy demand. Water efficiency measures, including rainwater harvesting for non-potable use, further augment sustainability efforts, resulting in significant reductions in indoor water consumption and associated energy usage.

In summary, this project epitomizes a holistic approach to sustainable design, integrating cutting-edge technologies and innovative strategies to create a blueprint for energy-efficient, environmentally conscious public infrastructure. Through meticulous planning and execution, the envisioned library is poised to exemplify the potential of sustainable architecture in fostering vibrant, resilient communities while minimizing environmental impact.

The design team made every effort to provide a safety and sustainable design, taking into account: energy efficiency, occupant health and safety, occupant comfort, functionality, future flexibility as well as maintainability and a 50-year service life.

Estimated hours of operation are:

- Offices: 12 hrs/day, 7 days/week
- Library: 12 hrs/day, 7 days/week
- Community Space: 24 hrs/day, 7 days/week

Space Temperature and Space humidity requirements are defined below, if a space is not listed a general assumption of the space conditions should be made by the design team:

Table 1. Space temperature and space humidity requirements

Space Type	Season	Temperature and Relative Humidity Requirements (if any)
Offices, Office Support Areas, Conference rooms, Retail Space, Café	Summer	75°F DB maximum, 50% RH
	Winter	72°F DB minimum
Library spaces	Summer	75°F DB, 50% RH
	Winter	72°F DB minimum
Special Collections/Automated Storage and Retrieval System	Summer	75°F DB, 35-45% RH
	Winter	60°F DB, 30% RH minimum
Storage Rooms	Summer	72°F DB, 50% RH
	Winter	68°F DB
Mechanical equipment rooms and penthouse	Summer	80°F DB
	Winter	65°F DB
Electrical closets, Communication closets	Summer	75°F DB average, 80°F DB maximum
	Winter	65°F DB minimum

2. Sustainable Site Selection

One of the important goals of sustainable location is to reduce the environmental impact of the location of a building by protecting sensitive land so the selection was made to locate the building on previously developed land in the heart of São Paulo, Bauru, which is distinguished by the following factors:

- Bauru is a culturally rich city, and it is known for its warm weather and stunning architecture.
- It is considered the economic and cultural hub of the region.
- It is well-connected with transportation networks, well-developed road, and rail infrastructure. The city's location at the junction of three railroads and three highways make Bauru a major urban center of the State of São Paulo. Good access to basic transport services is important, as it helps to reduce automobile dependency.
- Bauru has been increasingly investing in renewable energy sources such as solar and wind power.

The coordinates of the selected location are (22°19'35"S 49°07'02"W) and 590 m elevation, and this site is near to cultural, historical, and natural attractions such as Zoological Garden, Municipal botanical Garden, Vitória Régia Park, SESC Bauru, auru’s Historical Museum, and Alameda Quality Center.

Site strategies to achieve sustainability in Building:

- Pavement system: The Grass create permeable pavement type, and it was selected due to:
  - The reduction in heat island effect.
  - Management of storm water runoff.

  - Recycled content is used in the application process as well as the concrete and sub-base.
  - The long lifespan and the low maintenance required.
- All exterior lighting shall be smart lighting controls, keeping lights closed to the ground, as directed. The lowest required lighting intensity will be used to avoid discomfort, distraction, or loss of visibility and the undesirable consequences on the wildlife and people.
- The total land area is 10,250 m^2 , and building area is 3,350 m^2, so 25% of this outdoor space is dedicated solely to vegetation, comprising trees and plantings of native and adapted plants like Turfroot, Zanzibar gem, papaya, and cherry guava, which achieve LEED requirements.
- Part of the outdoor area will be used for PV panels to reduce electricity from outside resources.
- Outdoor sorting recycle bins will be distributed to facilitate recycling processes.

3. Material and Construction

The loads that come from the building envelope are related mainly to the materials used in construction. Thermal insulation is the practice of using materials with low thermal conductivity to reduce heat transfer between the interior and exterior environments and increase thermal capacitance of the building. The selection of appropriate insulation materials is vital in achieving effective thermal insulation, as they significantly impact a building's energy consumption, occupant comfort, and environmental sustainability.

3.1 Strategies to Achieve Sustainability in Materials

- Choose materials that have excellent insulation properties (i.e., low U-values).
- Materials made from recycled or renewable resources further contribute to reducing environmental impact, aligning with the goal of minimizing the carbon footprint.
- Choosing windows with low SHGC and multiple glazing layers to enhance thermal insulation.
- Using local suppliers as local sourcing not only supports the regional economy but also drastically reduces the environmental impact associated with long-distance transportation.

3.2 Materials of Construction

Tables 2 and 3 provide lists of the constructional and thermal specifications for each assembly for both the baseline scenario, which is based on ASHRAE 90.1, and the proposed scenario, which is based on the material defined on the CAD drawings. The concept of the baseline scenario and the proposed scenario will be illustrated in the next section.[3]

Table 2. Construction materials for each assembly

Assembly	**Construction Material**	**U-value Based on ASHRAE 90.1 (Btu/h- ft^2.f)**	**Design U-value (Btu/h- ft^2.f)**
Level 3 Plaster Exterior wall assembly	7-layer wall	0.084	0.029
Basement	7-layer wall	0.084	0.029
Level: 1, 1.5 ,2 and 3 Curtain wall	Hard Limestone and glazing.	0.084	0.062
External wall Limestone rainscreen 1, 1.5 and 2	8-layer wall	0.084	0.029
Window	Double glazing and air gap.	0.45	0.3
Floor Levels:1.5,2,3	Concrete and Steel Iron	0.038	0.038
Roof	Ethylene propylene diene monomer (EPDM), Concrete, steel and foam.	0.039	0.009
Basement Wall with the ground	Concrete and vapor retarder.	C-1.14 U=0.45	0.092
Basement Ground Floor	Concrete and Steel Iron.	F-0.73 U=0.064	0.046
Partitions	Gypsum board, air gap and gypsum board	-	0.27
External Ceiling of basement	Foam, EPDM, Concrete, Steel, Sand layer and Paver system.	0.038	0.015
Partition Automated storage	Gypsum board, air gap, gypsum board air gap and gypsum board	-	0.113
External Ceiling of Level 2	Ethylene propylene diene monomer (EPDM), Concrete, steel and foam	0.039	0.023

3.3 Suppliers

By prioritizing local sourcing, structures are built while simultaneously fortifying communities and fostering a more sustainable and resilient future. The selected materials can be supplied from local suppliers, who are listed in Table 3.

Table 3. Local supplier

Product	Brazilian Companies
Gypsum board	Knauf
Fiberglass batt insulation	Owens Corning
Gypsum sheathing	Knauf
Mineral wool blanket insulation	Owens Corning
Double glazing	GlassecViracon
Fiber-reinforced plaster	FassaBortolo
Product	Brazilian Companies

4. Energy

4.1. Methodology

The goal was to construct and evaluate a baseline scenario of the library based on ASHRAE Standards, followed by the implementation of strategies for a proposed scenario aligned with sustainability principles, aiming for net zero energy. The library under study comprises over 200 spaces with a total building footprint area of almost 36,000 ft^2 (3,350 m^2) and a total floor area of nearly 110,000 ft^2 (10,181 m^2).

The initial step involved conducting a building survey to gather data on internal loads including: occupant behavior, plug loads, and lighting fixtures. Subsequently, the modeling phase entailed replicating the library's architectural geometry within DesignBuilder software using the provided drawings and integrating data obtained from the preceding building survey. Then, HVAC design stage focused on selecting an appropriate air conditioning system based on internal and external conditions. In the simulation stage, the results were utilized to refine the HVAC system and zones, ensuring thermal comfort throughout the spaces over the year, while also providing insights into energy consumption and space conditions.

Finally, for the proposed scenario, the proposed strategies addressed both demand and supply sides to develop a feasible and energy-efficient scenario. Strategies to reduce consumption, with practical solutions to be implemented, were tested and evaluated. Additionally, the feasibility of integrating PV panels as a renewable energy source for the building was explored.

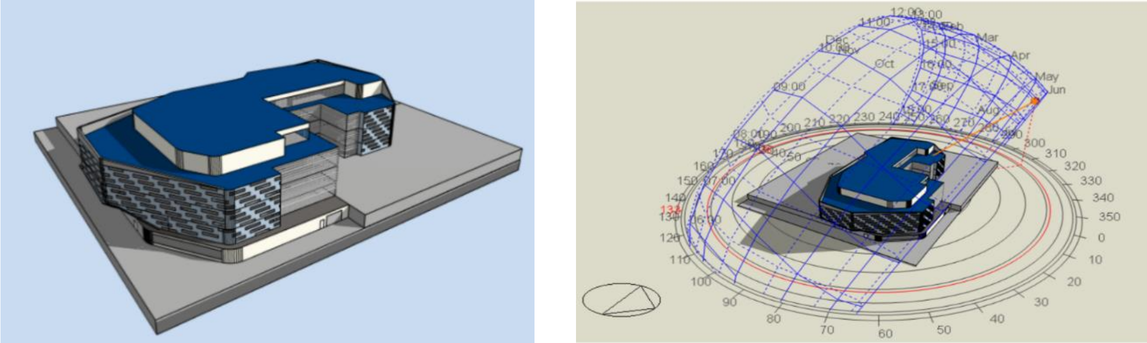


Figure 1: The created model on DesignBuilder.

4.2 Thermal loads

4.2.1. External Loads

External thermal loads originate from heat transfer through the building envelope, influenced by solar radiation, ground contact, and external weather conditions. This envelope comprises walls, roofs, floors, windows, and other surfaces that demarcate the interior from the exterior environment. Material specifications for the baseline adhere to ASHRAE 90.1 standards, while those for the proposed scenario are based on the provided CAD drawings. Detailed U-values of the external components of the building envelope for both the baseline and proposed scenarios are provided in Table 2, where further information regarding construction materials can be accessed.

4.2.2. Ventilation Loads

Ventilation is the process of exchanging or replacing air in any space with fresh air to provide the desired indoor air quality. The ventilation rates shown in table 4 are estimated according to ASHRAE 62.1, which gives values of the minimum requirement of fresh air based on the space purpose, number of people, and floor area.[4]

Table 4: Minimum Ventilation Rates in Breathing Zone

Space type	CFM/ft^2	CFM/person	Space type	CFM/ft^2	CFM/person
Automated storage	0.06	5	Community room	0.06	7.5
Meeting room	0.06	5	Seating area	0.06	5
Office room	0.06	5	Tech lab	0.12	10
Storage	0.06	5	Audio/media production	0.12	10
Zoom room	0.06	5	Eating/drinking area	0.18	7.5
Electrical room	2	0	Food preparing	0.12	7.5
Telecom room	0.06	5	Book area	0.06	5
Janitor	0.06	5	Children	0.12	7.5
Open office	0.06	5			

4.2.3. Internal Loads

Internal thermal loads come from heat generated by people, lighting, and equipment. Lighting and most equipment loads are sensible heat, while the metabolic heat generated by people’s bodies are a combination of sensible and latent loads. The occupancy, lighting power density, type of equipment and the heat gain from it are listed in the following tables.[3], [4], [5]

- The occupancy densities have been determined, as shown in table 5, in accordance with ASHRAE 62.1 guidelines, cross-referenced with architectural drawings to ensure compliance with the owner's specified.
- The baseline lighting power density and the required LUX are based on ASHRAE 90.1, and the proposed LPD is based on the recommended LED lighting and the input values are in table 6.

Table 5: occupancy density for each space type

Space Type	Occupancy Density (#/1000 ft2)	Space Type	Occupancy Density (#/1000 ft2)
Automated storage	2	**Seating area**	150
Meeting room	50	**Tech lab**	150
Office room	5	**Audio and media production**	25
Storage	2	**Eating/drinking area**	25
Zoom room	5	**Food preparing**	100
Janitor	60	**Book area**	20
Open office	2	**children**	25
Community room	5		

Table 6: the LPD of baseline and proposed scenario for required LUX

Space type	Baseline LPD (W/ m^2)	Proposed LPD (W/ m^2)	LUX (lm/m^2)	Space type	Baseline LPD (W/ m^2)	Proposed LPD (W/ m^2)	LUX (lm/m^2)
Automated storage	6.8	2.3	339.1	**Audio and media production**	13.2	4.4	920.3
Meeting room	13.2	4.4	662	**Eating/drinking area**	7	2.3	662
Office room	11.9	4	597.4	**Food preparing**	13	4.3	349.8
Storage	6.8	2.3	339.1	**Book area**	11.4	3.8	651.2
Zoom room	13.2	4.4	667.4	**children**	11.4	3.8	570.5
Electrical room	4.5	1.5	662	**Hall, corridor, Vestibule**	7.1	2.4	570.5
Telecom room	4.5	1.5	226	**Looby**	9.7	3.2	355.2
Janitor	6.5	2.2	226	**Bathrooms, Family**	9.7	3.2	484.4
Open office	10.6	3.5	322.9	**Break/Work**	7.9	2.6	349.8
Community room	15.6	5.2	527.4	**Cultural room**	13.4	4.5	392.9
Seating area	5.8	1.9	780.4	**Pre-Function**	7.9	2.6	667.4
Tech lab	18.4	6.1	290.6				

4.3. HVAC System

To meet the required thermal conditions, the selected HVAC system for both the baseline and proposed scenarios comprises a Direct Expansion (DX) Variable Air Volume (VAV) system with terminal reheat. The building's interior spaces have been categorized into nine distinct zones.

HVAC zones were designated to ensure that spaces within the same zone share similar characteristics, including space purpose, thermal load, desired temperature, humidity levels, and operational schedules as outlined in the OPR. A comprehensive listing of all zone groups and their corresponding served space types is provided in table 7.

Table 7: Zone groups

AHU #	**Space type served**	**AHU #**	**Space type served**
1	Telecom and electrical rooms.	**6**	Family, wellness
2 *Table 0*	Automated storage and retrieval system.	**7**	Exposed offices.
3	Storages.	**8**	Internal offices.
4	Community room.	**9**	(Floor2+floor3) exposed offices
5	Vestibules and entrances.		

The nine zones were served by using nine different VAV-AHUs with a cooling coil in each AHU. The VAV terminals are equipped with dampers, to manipulate the flow at part loads, and electric reheat coils to manipulate the supply temperature at the part loads reaching the minimum accepted flow rates.

5. Baseline Scenario Results

5.1. Thermal Loads Results

Despite the peak load of heating, the majority of spaces require cooling throughout the year due to internal thermal loads. Additionally, because there are relatively few heating hours during the year, heating energy consumption is low.

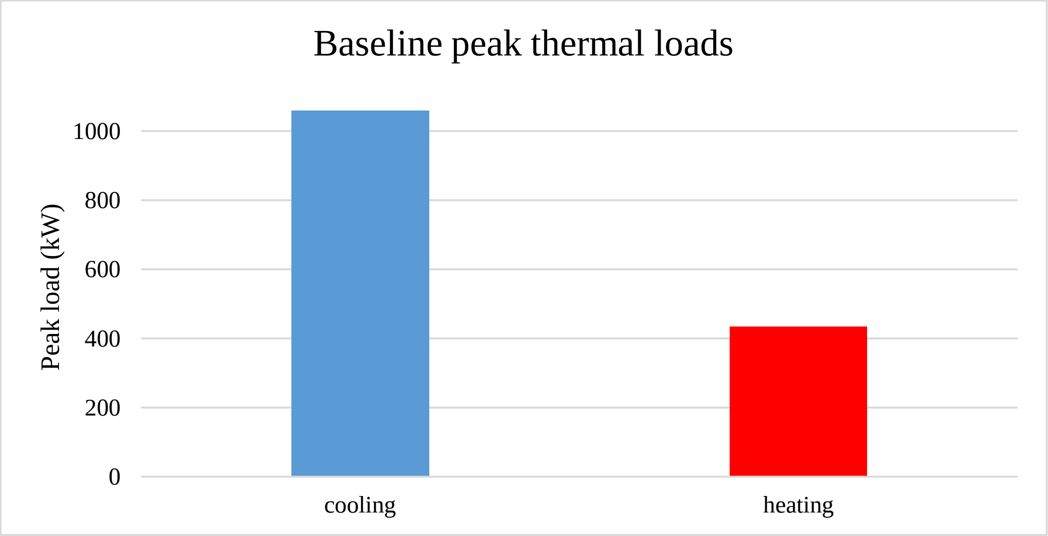


Figure 2: Baseline peak thermal loads.

	Peak Cooling Data		**Peak Heating Data**	
Max/Min Outdoor Temp.	32.1 °C		8.9 °C	
Peak Load	1,060 kW	104 W/m^2	435 kW	42.7 W/m^2

The distribution of contributors in the cooling thermal loads are illustrated in Figure 3. It is evident that occupancy load accounts for the highest impact on the thermal loads, where, according to the occupancy density given in table 5, the library's total occupancy is 970 people. On the other hand, the building envelope exerts the least influence, as the building has relatively low exposed area compared to its internal spaces. Additionally, the building construction based on ASHRAE 90.1 gives high insulating layers.

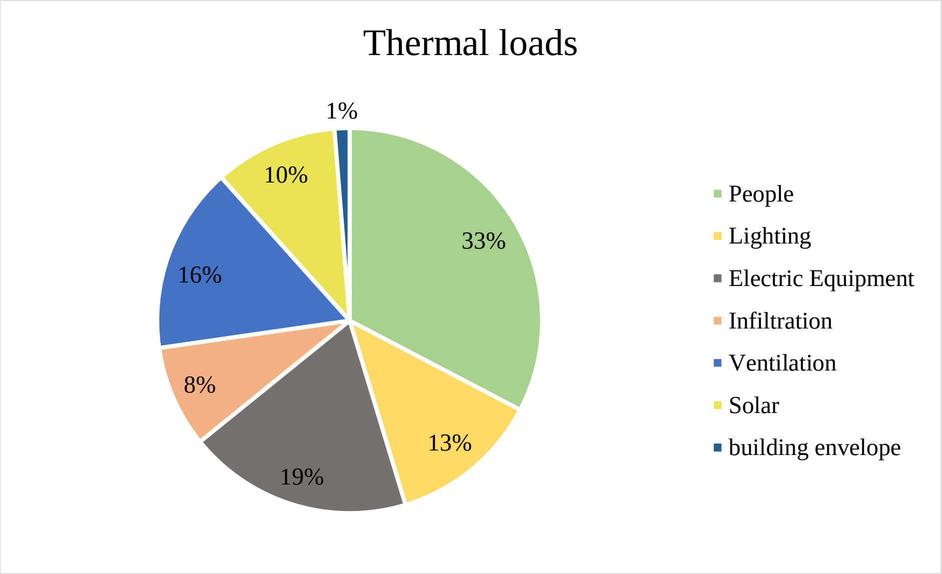


Figure 3: Thermal loads and the participation of each type.

5.2. Energy Consumption

The total energy consumption in the baseline scenario is 2,040.21 MWh/year, where the cooling loads represent the significant energy user in the building, and the contribution of each energy user is shown in figures 4 and 5.

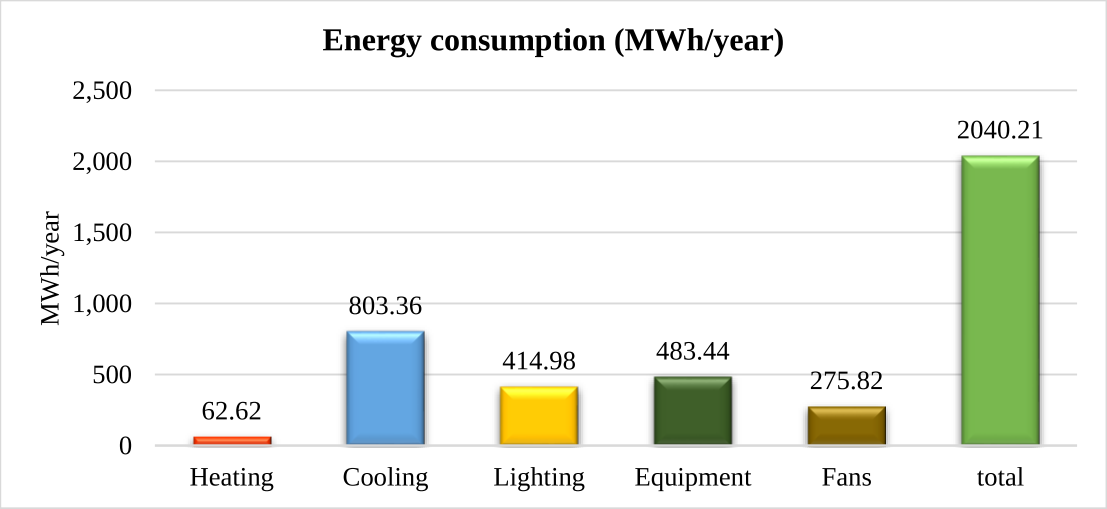


Figure 4: Energy consumption in baseline

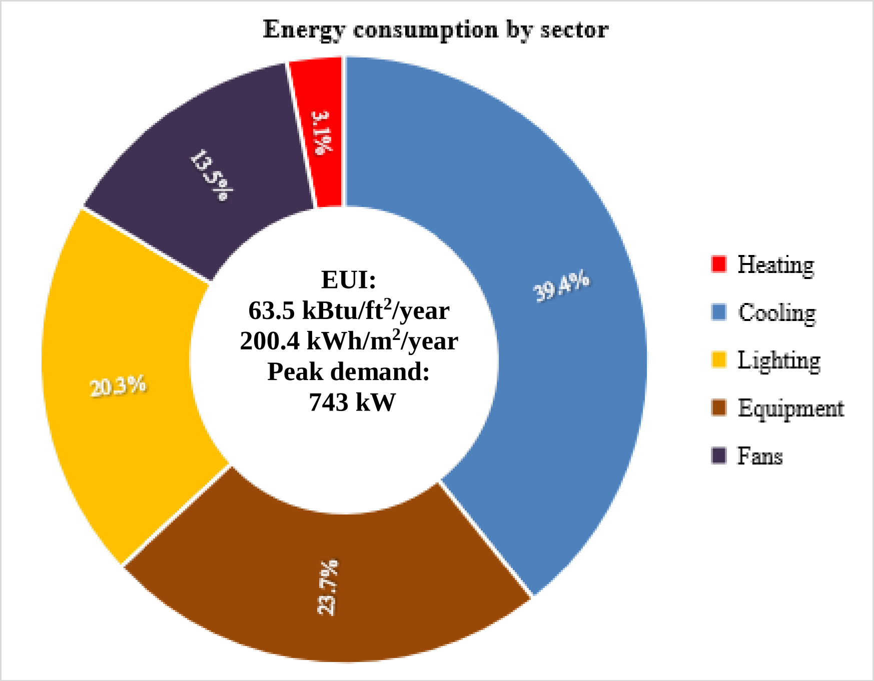


Figure 5: The percentage of each energy user in the consumption of baseline

6. Proposed Scenario Strategies and Results

As depicted in the preceding chart, the areas of Significant Energy Use (SEU) that warrant attention for reduction efforts are HVAC and lighting. Various strategies were explored and studied to mitigate their energy consumption. Subsequently, feasible strategies were implemented, ensuring that functionality and indoor environmental quality remained unaffected.

The studied strategies are the following:

- Choose LED lamps of better efficacy for lighting.
- Install daylight sensors for lighting control.
- Enhance the construction of the building envelope.
- Choose the optimum orientation for the building.
- Install enthalpy differential sensors.
- Apply demand-controlled ventilation.
- Apply heat recovery in the HVAC system.
- Choose fans with higher efficiency.

6.1. Lighting

Instead of the baseline efficacy of 50 lm/W according to ASHRAE standards, LED lighting with a higher efficacy of 150 lm/W was utilized to achieve the same required lux levels. This solution is projected to save two-thirds of the energy consumed in lighting. Additionally, since lighting contributes to the thermal loads, there will be a reduction in the cooling energy consumption, albeit with a slight increase in heating energy. Overall, this approach is expected to yield total energy savings of approximately 14%.

Furthermore, after conducting a simulation for daylight utilization within the building, a potential for further savings was identified by leveraging available daylight in many spaces. To capitalize on this, daylight sensors were installed in these areas to regulate lighting and reduce artificial illumination when natural daylight is present. This additional measure is projected to save an extra 6%, resulting in total energy savings of 20%. The effect on energy consumption of both solutions can be observed in the following chart.

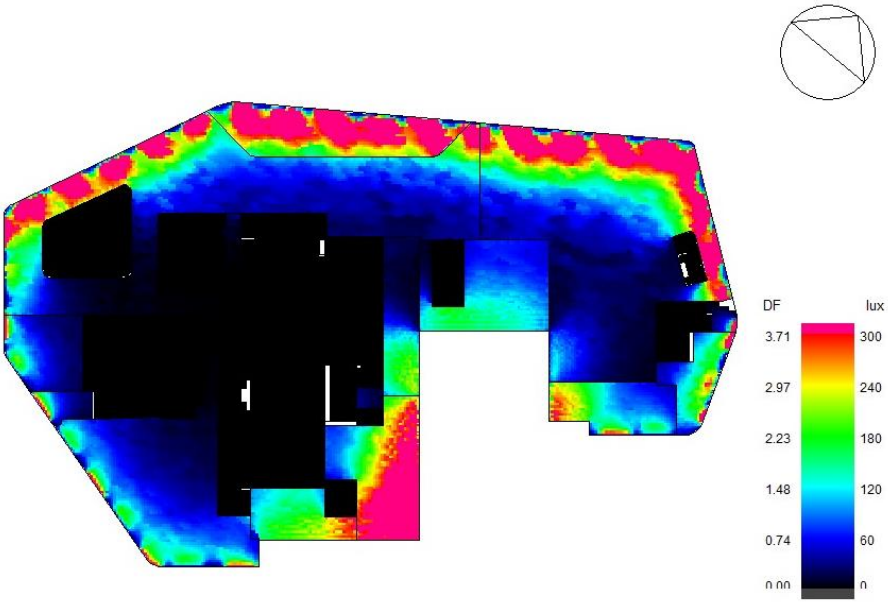


Figure 6: Daylight simulation for the building.

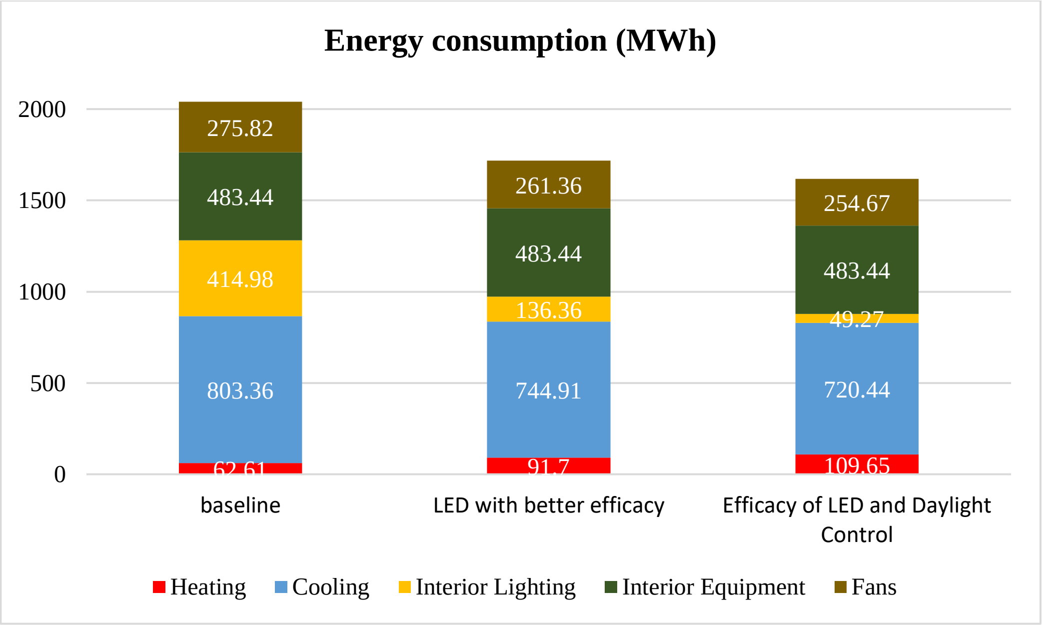


Figure 7: the effect of LED and daylight control on the energy consumption.

6.2. Construction

For the proposed scenario, the U-values of the materials selected by the owner in the design were considered, leading to 1% energy savings. This percentage is anticipated, given that the external load attributable to the building envelope is relatively small compared to the total thermal loads in the building, as depicted in Figure 6.4.

6.3. Orientation

Given the flexibility to orient the building in any direction, the chosen orientation for the proposed scenario is rotated 140 degrees CCW from the baseline orientation, resulting in savings of 0.22%. However, the influence of orientation is minor due to the building's uniform facades and the relatively low external load from walls and windows, as previously noted.

6.4. Enthalpy Differential Sensors

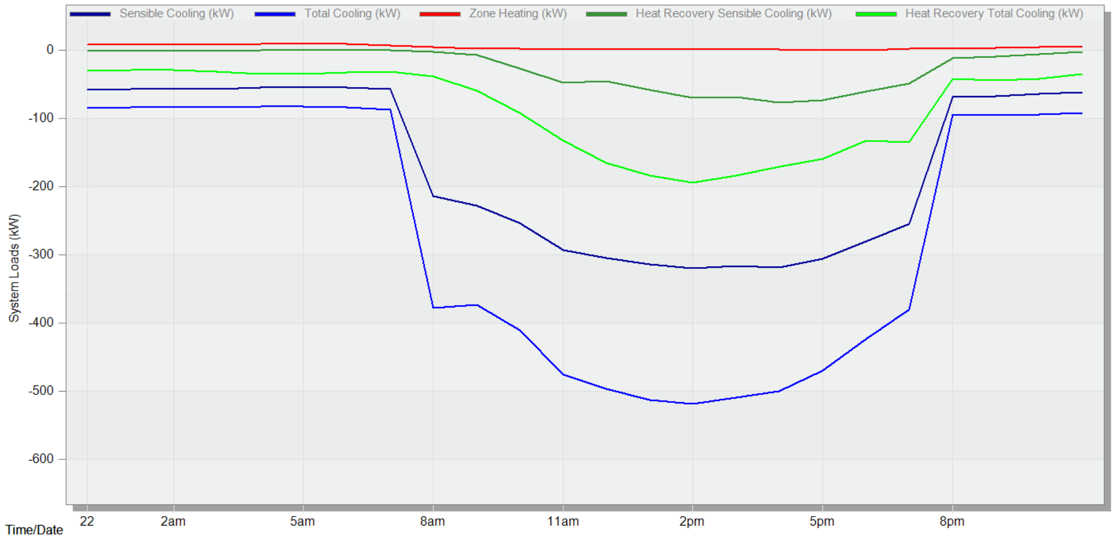
To take advantage of the relatively natural cool air outside when available, an enthalpy differential sensor was installed, resulting in savings of 5%.

6.5. Demand-Controlled Ventilation.

Due to the large number of people in the library, the thermal loads due to ventilation requirements are recognized as one of the primary loads in the building, as shown in figure 6.4. Implementing demand-controlled ventilation is considered advantageous. By using the simulation, utilizing a conservative occupancy schedule resulted in savings of 1.3%. However, in real-life scenarios, greater savings are anticipated.

6.6. Heat Recovery

Applying a rotary type of heat exchanger for sensible and latent heat recovery (e.g., desiccant silica-gel wheel) resulted in savings of 3% from the baseline. The contribution of the heat recovery in cooling demand reduction can be shown in figure 6.9.



Time/Date	22		2am			5am			8am			11am			2pm			5pm			8pm			
Sensible Cooling (kW)	-57.87	-57.19	-56.99	-57.02	-54.87	-53.42	-54.04	-56.66	-214.29	-228.22	-253.79	-293.07	-304.93	-313.72	-319.83	-316.56	-318.33	-305.43	-279.69	-255.07	-68.18	-66.67	-63.94	-61.26
Total Cooling (kW)	-84.65	-83.87	-83.50	-84.00	-82.94	-82.72	-83.92	-86.96	-377.43	-372.93	-410.96	-476.18	-496.72	-513.22	-518.74	-509.42	-499.93	-470.36	-423.95	-380.83	-94.48	-94.84	-94.10	-91.38
Zone Heating (kW)	7.91	8.24	8.44	8.57	9.02	9.35	9.52	6.82	4.95	2.59	2.13	1.09	1.02	1.80	1.77	1.76	1.74	0.07	0.22	2.06	2.67	4.02	5.30	6.32
Heat Recovery Sensible Cooling (kW)	-0.69	-0.46	-0.39	-0.39	-0.04	0.00	0.00	-0.33	-1.69	-6.86	-26.21	-47.73	-44.56	-58.11	-69.15	-67.91	-76.79	-73.16	-60.61	-49.06	-11.02	-9.12	-5.00	-1.88
Heat Recovery Total Cooling (kW)	-29.84	-29.05	-28.67	-31.32	-34.56	-34.13	-32.64	-30.93	-38.56	-58.54	-91.94	-132.19	-164.45	-183.37	-194.32	-183.22	-170.25	-159.01	-132.79	-134.24	-41.31	-44.10	-41.36	-34.30

Figure 8: the contribution of heat recovery in cooling.

6.7. Higher Efficiency Fans

In the baseline, fans' efficiency is based on ASHRAE 90.1 standard. Therefore, for optimizing demand, fans with efficiencies reaching up to 85% have been identified. By applying this efficiency to fans, which currently account for 13.5% of the total energy consumption, energy savings of 3.2% compared to the baseline are anticipated.

6.8. Combined Strategies Effect on Energy Consumption

Upon implementing all strategies within the same model and adjusting the HVAC system to meet the required space conditions, total savings of 32.5% are achieved. ***This results in an Energy Use Intensity (EUI) of 42.8 kBtu/ft^2/year (135 kWh/m²/year) (1,376.32 MWh/year), exceeding the owner's target of 50 kBtu/Ft^2/year.***

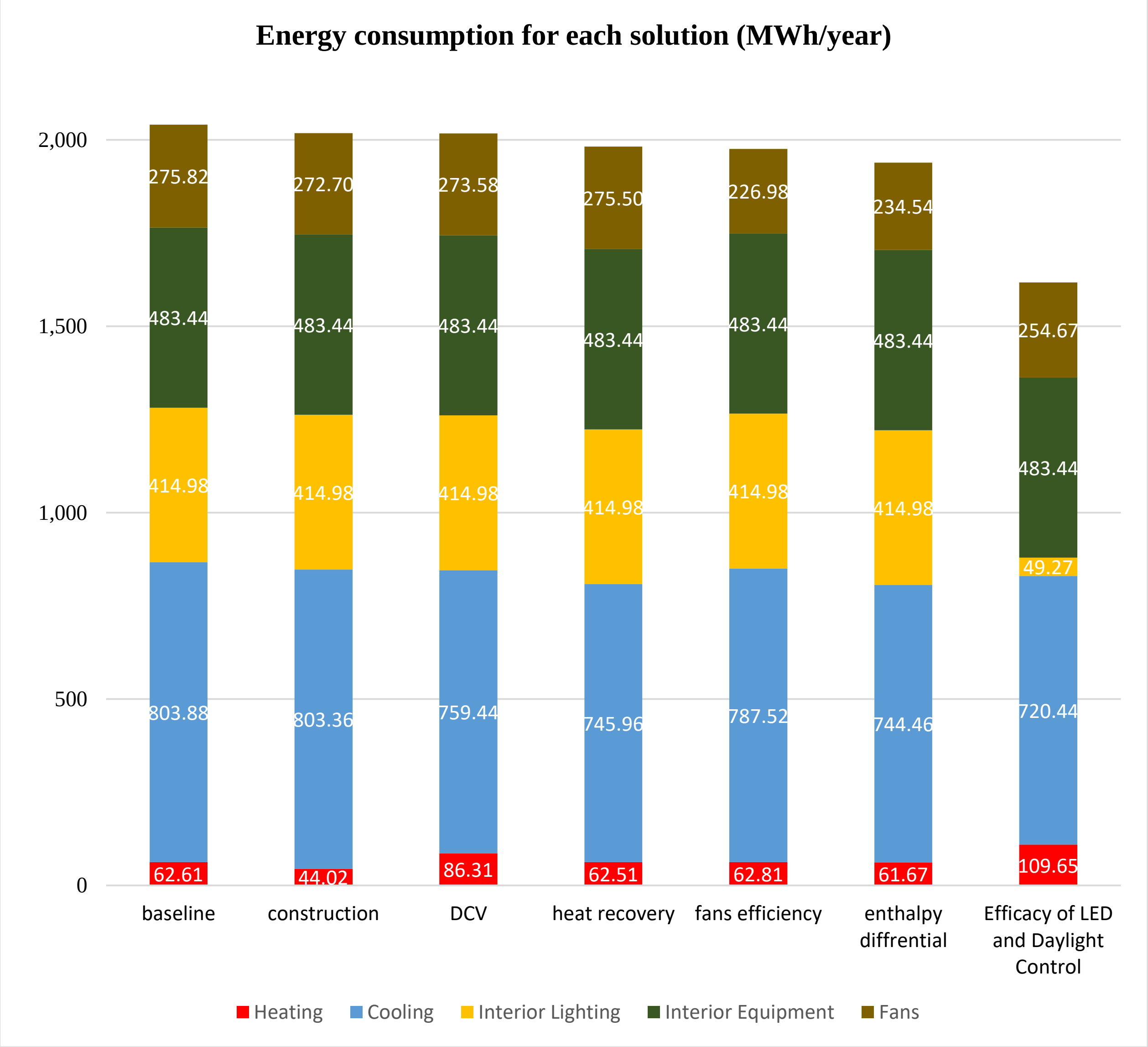


Figure 9: the effect of each strategy alone on the energy consumption.

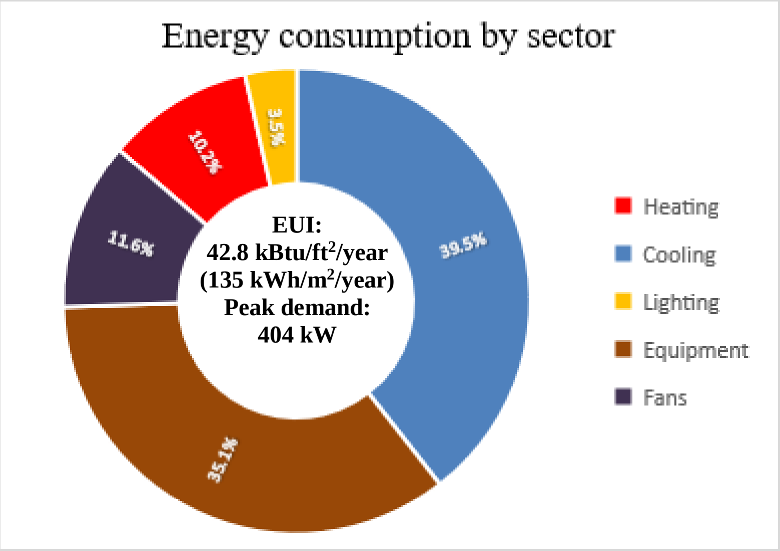


Figure 10: The percentage of each energy user in the consumption of proposed model.

	Peak Cooling Data		**Peak Heating Data**	
Max/Min Outdoor Temp.	32.1 C		8.9 C	
Peak Load	960 kW	95 W/m2	409 KW	41 W/m2

7. PV System

Renewable energy, often referred to as green energy, differs from conventional energy sources as it is generated without burning fossil fuels, thereby avoiding an increase in the greenhouse gas emissions. Moreover, renewable energy utilization helps in preserving conventional fuel resources and their corresponding energy cost. Among renewable energy sources, solar energy stands out, with photovoltaic panels converting sunlight into electrical energy.

The Map data of the selected location:[6]

Direct normal irradiation:	**1,806.9 kWh/m^2/year**
Global horizontal irradiation:	**1,920.2 kWh/m^2/year**
Diffuse horizontal irradiation:	**733.9 kWh/m^2/year**
Global tilted irradiation at optimum angle:	**2,071.6 kWh/m^2/year**
Optimum tilt of PV modules:	24 °

In the extensive design evaluation process, multiple design variations were explored, primarily by adjusting tilt angles. Two distinct designs were analyzed: one with a tilt angle of 24 degrees, which is the optimum tilt angle according to this location and latitude, and this leads to the optimum generation of energy per installed capacity. The other design was based on a tilt angle of 5 degrees, which is chosen to reduce the required spaces between PV rows. However, the second option is not zero degree to have inclination helping in sliding any droplets or dust particles off the panels. Both designs utilized the roof area, covering 2,056 m^2. The results of these evaluations are presented in Table 8.

Table 8: Comparison between 5° and 24° tilt angle		
Tilt angle	Number of panels	Annual Energy Generated (MWh/year)
5°	734 (326,630 kWp)	381.39
24°	646 (287,470 kWp)	331.65

Based on the findings, the design with a 5-degree tilt angle emerges as the optimal choice for maximizing energy production efficiency. Therefore, it is advisable to proceed with this design configuration.

Following the conclusion drawn from the design evaluation, additional measures were taken to integrate renewable energy solutions into the landscape. Specifically, a section of 1,430m² from the landscape, which can be a parking area roof, was allocated for more PV panels. This initiative entailed incorporating additional 570 panels into the system, thereby augmenting its capacity to generate renewable energy. These developments are poised to enhance sustainability efforts while promoting energy efficiency within the environment. Installed panels and power generated from both roof and landscape are as follows:

Roof	**Landscape**
2,056 m^2	1,430 m^2
734 panels (326,630 kWp)	570 panels (287,470 kWp)
381.39 MWh	293.11 MWh

To efficiently manage the energy generated by the 1,304 panels, five inverters with a capacity of 110 kW each were incorporated into the system. Through the deployment of these inverters, the project ensures optimal performance and reliability.
After integrating the PV system, the building's demand from outside resources will amount to 701.82 MWh/year, with an Energy Use Intensity (EUI) of 21.8 kBtu/ft^2/year (68.9 kWh/m²/year). This signifies a total reduction of 66% from the baseline.

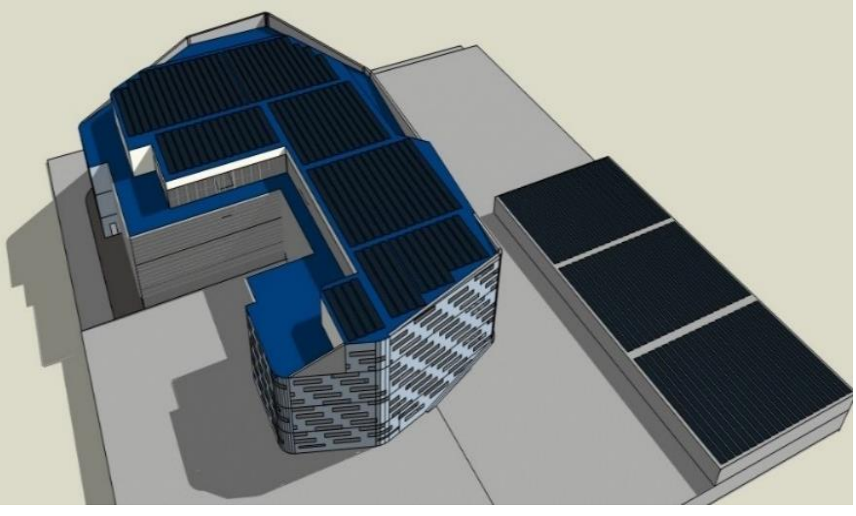


Figure 11: Modeling the PV modules over the building.

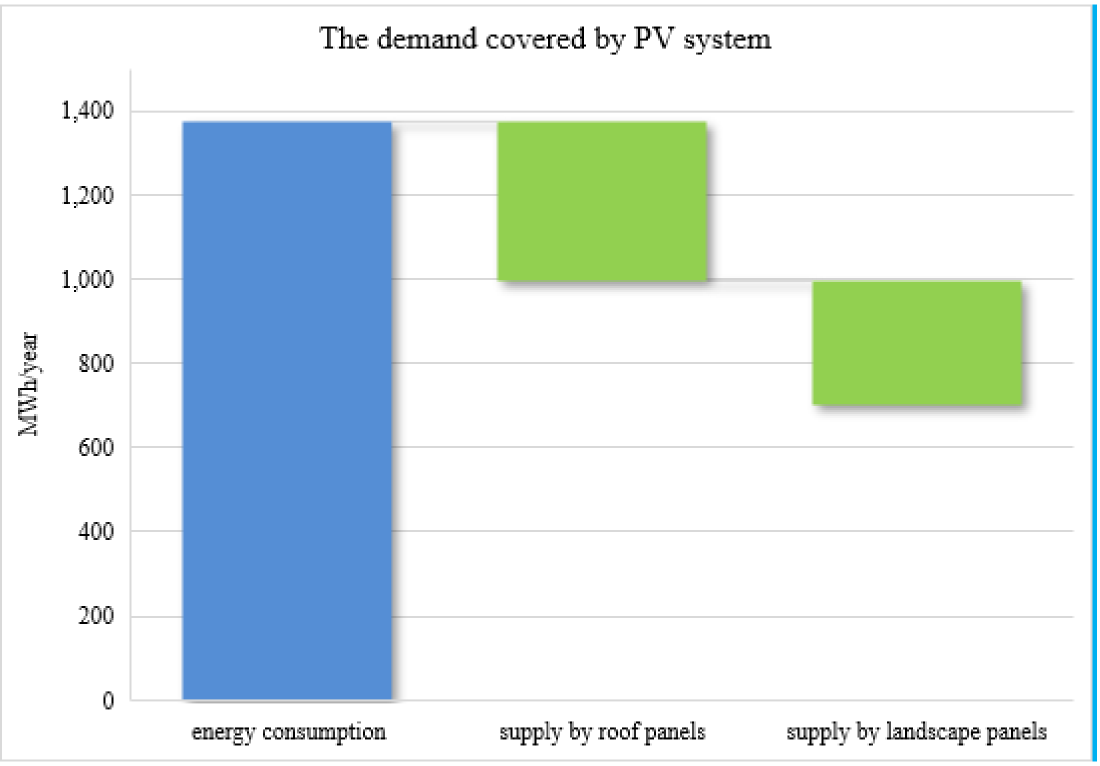


Figure 12: the contribution of the PV in the supply.

References

[1] R. and A.-C. E. American Society of Heating, ASHRAE® 189.1_2020

[2] “Home | Food and Agriculture Organization of the United Nations.” Available: https://www.fao.org/home/en/

[3] R. and A.-C. E. American Society of Heating, ASHRAE® 90.1_2022_IP

[4] R. and A.-C. E. American Society of Heating, ASHRAE® 62.1_2022

[5] R. and A.-C. E. American Society of Heating, *2021 ASHRAE® handbook. Fundamentals.*

[6] “Global Solar Atlas.”. [Online]. Available: https://globalsolaratlas.info/map?c=-22.267095,-49.104767,11&s=-22.323909,-49.117879&m=site

[7] “National Water and Sanitation Agency (ANA) — Agência Nacional de Águas e Saneamento Básico (ANA).”. Available: https://www.gov.br/ana/en

[8] “U.S. Environmental Protection Agency | US EPA.”. Available: https://www.epa.gov/

[9] “AHU With Heat Recovery - Air Handling Units | ACS Air Conditioning.” Available: https://acsklima.com/air-handling-unit/ahu-with-heat-recovery/

[10] “Air Handling Unit - Jinan Sendo Air Conditioning Co., Ltd. - page 1.” Available: https://sendoac.en.made-in-china.com/product-group/IqWmKyxrhYRZ/Air-Handling-Unit-catalog-1.html

[11] “New Carrier HH57ZC003 Differential Enthalpy Sensor Control Switch 33CSENTHSW | eBay.” Available: https://www.ebay.com/itm/325505805598

[12] “For Sensirion SCD30 CO2 Sensor For HVAC Systems Indoor Air Quality Monitoring | eBay.” Available: https://www.ebay.com/itm/384272751611

[13] S. Liescheidt, “Economizers in Air Handling Systems.” Available: www.cedengineering.com

[14] “How Does HVAC Economizer Work & Its Types | Green Leaf Air.” Available: https://greenleafair.com/how-does-hvac-economizer-work-its-types/

[15] A. Bhatia, “HVAC Design Overview of Variable Air Volume Systems,” 2007. www.PDHcenter.com

[16] “Demand-controlled ventilation - Increased comfort and lower costs.” Available: https://www.swegon.com/knowledge-hub/technical-guides/we-explain-demand-controlled-ventilation/

[17] “The Role of Air Filters in HVAC Systems.” Available: https://comfortcontrolsystemsnc.com/blog/f/the-role-of-air-filters-in-hvac-systems

[18] “Occupancy and Daylight Sensors – Automation for Energy Savings.” Available: https://www.verde.expert/solutions/daylight-occupancy-sensors.