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Research Article

Reduce Cooling Load using AI-based KNN Enhanced Roof System (KNN-ERS): CASE STUDY (TRIPOLI- LIBYA)

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ABSTRACT

Energy depletion is considered one of the greatest challenges facing the planet. One way towards solving this challenge involves architectural adaptations to the local climate to decrease energy use. This study looks at the city of Tripoli located in northern of Libya. People depend extensively on air conditioning systems that result in higher energy consumption. This study proposes implementing AI-based KNN Enhanced Roof System (KNN-ERS) in buildings to decrease cooling energy consumption. The focus is on the importance of insulating the external walls of the building, by adding 50.8 mm thick board insulation to the wall components and use of double glazing techniques. Our methodology consisted of an energy simulation using a hourly analysis program (HAP). Using this simulation, we assessed the effects of KNN-ERS on the reduction rate of cooling loads in library building at the Higher Institute for Science and Technology Qasr Bin Ghashir, Tripoli, Libya. Simulation results show that the proposed AI-based KNN Enhanced Roof System (KNN-ERS) reduce the cooling load significantly, from 32,242 kW to approximately 30,580 kW during peak cooling load in July. This represents a 5.15% reduction in the total cooling load. Insulating the external walls reduces the cooling load through the walls by 32%, and using double glazing technology reduces the thermal load through the windows by 33.7%. The significance of this impact suggests that architects should be more mindful about utilizing passive cooling methods in buildings, reducing the consumption of energy for residents and prompt accomplishing environmental friendly buildings.

Keywords: KNN-ERS Passive Cooling, cooling load, thermal insulation, double-glazing system.

INTRODUCTION

Energy depletion, climate change and global warming are some of the greatest challenges facing the planet. We can contribute to the sustainability of our planet by using local climate-based adaptive components in buildings. According to the International Energy Agency, the construction sector is responsible for nearly 40% of total CO_2 emissions and for 36% of the total energy consumption globally [1]. In Tripoli, Libya, energy consumption can be reduced by using passive cooling techniques in residential and government buildings. Most of the structures have been built with large single glass openings and thin, uninsulated walls that significantly increase the heat flow entering the building. Without a purposeful design to combat the heat, dwellers have no choice but to turn on air conditioning, thus increasing their cooling energy consumption. Without a solution, these issues will continue to plague future housing development in areas with high solar exposure. Therefore, architects for these regions need to use designs that increase comfort without the energy expense. For thousands of years, there were no air conditioning technologies to provide thermal comfort for building occupants. In hot climate regions, Arab, Roman and Greek architects used passive design methods as the only means for cooling buildings [2].

Today, HVAC systems are widely used in domestic buildings in order to control their internal conditions by providing adequate amounts of ventilation rates, heating, and cooling loads within the buildings. The motive behind this work is to find a potential solution for reducing the extremely high amounts of energy used for cooling buildings during the hot summer days [3].

Thermal loads in buildings

Thermal loads in buildings are considered one of the problems in energy consumption as a result of external influences that affect the internal environment of the spaces and the use of a mechanical cooling method to provide thermal comfort inside the spaces throughout the operating hours. Thermal loads are divided into two basic parts.

A. External thermal loads

External thermal loads are defined as the amount of thermal energy transferred from the hot external environment to the room, such as conduction through walls, ceilings and floors, solar radiation through window glass and doors, air leakage from the external environment to the room [4].

B. Internal thermal loads

Internal thermal loads are defined as the amount of thermal energy gained inside the room as a result of artificial lighting, electrical appliances, heat generated by people present in the place, any other heat sources inside the place, and also the heat resulting from the air conditioning system [5].

METHODOLOGY

The aim of this study is to test the implementation of several passive cooling strategies to prevent overheating of the building envelope and reduce the cooling load in library building at the Higher Institute of Sciences and Technologe, Qasr Bin Ghashir, Tripoli, Libya. To investigate the impact of these techniques on the reduction rate of the cooling loads, our methodology uses a hourly analysis program (HAP).

The hourly analysis program (HAP) from Carrier is considered one of the most important programs that helps engineers design heating and cooling systems in buildings. The program is based on the methods approved by the (ASHRAE) Association in calculating cooling loads and energy consumption [6].

The practical structure of this study is based on:

1- Based on calculating the thermal load of the library building with its existing components (walls windows roof and floor).

2- Calculating the thermal load of the building after adding thermal insulation to the external wall and using a double-glazing system for the windows consisting of two layers with a thickness of 3 mm, and 13 mm an air gap between them.

3- Compare the results between the two cases and discuss them.

Initially, before calculating the cooling loads, must be collected the information about the building, the location, the components of the wall, windows and roof, the dimensions of the building, the lighting system, devices and equipment used, and the number of people inside the building.

In this study, the library of the Higher Institute of Science and Technology, Qasr Bin Ghashir, Tripoli, Libya, was the case study. Figure 1 shows the horizontal layout of the library, indicating the building’s dimensions and orientation.

A powerful tool for handling difficult problems in a variety of fields is artificial intelligence, especially machine learning (ML) [10,12]. ML algorithms excel in cooling load estimate because they can integrate large datasets with a variety of characteristics, including external temperatures [11], humidity levels, occupancy patterns, and architectural elements.

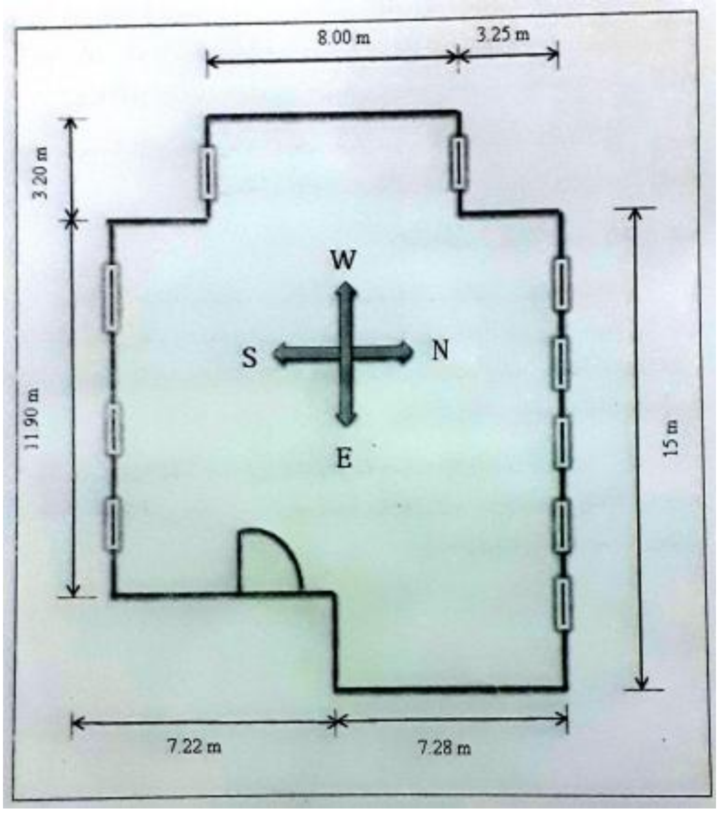


Figure 1: The horizontal layout of the library

Area data is entered to determine the geographic location and external design conditions such as temperature, humidity, and solar radiation falling on the roof of the building. In our study, we will focus on the loads resulting from the external walls, windows, and roof, and how AI-based KNN Enhanced Roof System (KNN-ERS) can be used to reduce the cooling load by insulating the external walls and using a double-glazing system [8,9].

Case 1:

Without thermal insulation Wall 1 thermal characteristics are depicted in the figure 2 along with information on its composition and functionality. Three layers make up the wall: an outer cement plaster layer (25 mm) a common brick layer (203 mm) and an inner cement plaster layer (25 mm). With a total R-value of 0.53 m^2K/W these layers have a comparatively low thermal resistance (R-value) which suggests poor resistance to heat transfer. Since the walls exterior is dark it can absorb 90% of the suns radiation increasing heat transfer into the building. This results in an absorptivity of 0.900. Thermal transmittance is measured by the overall U-value which is 1.893 $W/m^2 \cdot K$ indicating a significant gain or loss of heat. Because of its high U-value the wall is ineffective at lowering thermal loads which raises the energy requirements for cooling in hotter climates. By significantly lowering the U-value thermal insulation can enhance the walls energy efficiency and help reduce cooling loads.

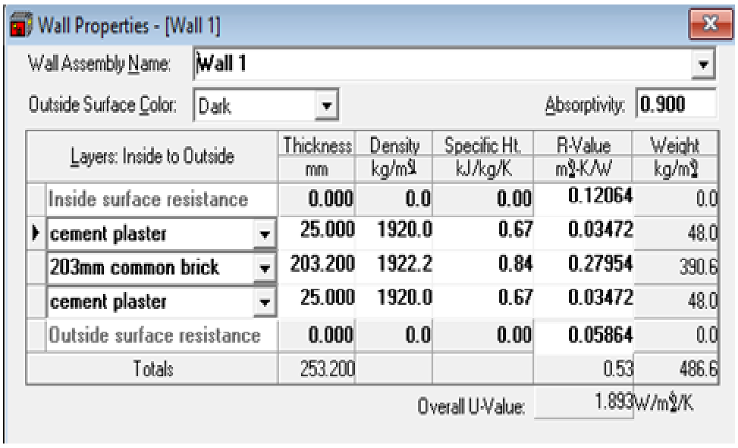


Figure 2: Wall components without a thermal insulator

We enter data for windows consisting of a single layer of regular glass with a thickness of 3 mm, as shown in the figure 3.

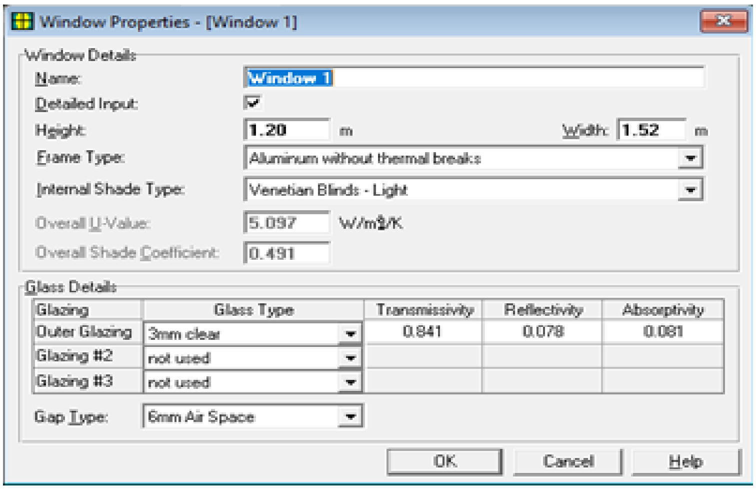


Figure 3: Windows consisting of a single layer of glass

The characteristics of Window 1 which has a single glazing layer and 3 mm clear glass are depicted in the figure. Light Venetian blinds are used for internal shading and the window has an aluminum frame without thermal breaks. The glass absorbs a lot of solar heat due to its high transmissivity (0.841) low reflectivity (0.078) and absorptivity (0.081). A total U-value of 5.097 W/m²·K suggests inadequate thermal insulation which raises cooling loads.

The structural composition of the roof is depicted in figure 4 which shows the following layers from inside to outside: sand (50 mm) cement plaster (25 mm) cement tiles (25 mm) heavy-weight concrete (203 mm) and cement plaster (25 mm). The roofs absorptivity is 0.900 because of its dark surface color and its overall U-value is 1.851 W/m²·K which indicates moderate thermal resistance. These characteristics point to substantial heat transfer which helps cool loads in hotter regions.

Roof Properties - [Roof 1]

Roof Assembly Name: Roof 1

Outside Surface Color: Dark   Absorptivity: 0.900

Layers: Inside to Outside	Thickness mm	Density kg/m³	Specific Ht. kJ/kg/K	R-Value m²-K/W	Weight kg/m²
Inside surface resistance	0.000	0.0	0.00	0.12064	0.0
cement plaster	25.000	1920.0	0.67	0.03472	48.0
203mm HW concrete	203.200	2242.6	0.84	0.11741	455.7
sand	50.000	1520.0	0.80	0.15151	76.0
cement plaster	25.000	1920.0	0.67	0.03472	48.0
cement tiles	25.000	2100.0	1.26	0.02272	52.5
Outside surface resistance	0.000	0.0	0.00	0.05864	0.0
Totals	328.200			0.54	680.2

Overall U-Value: 1.851 W/m²/K

Figure 4: Roof Components

After completing entering all the required data, we receive the final report showing us the program's calculations of the building's thermal loads, as shown in the table 1. The sensible and latent heat components are included in the cooling and heating design loads for Zone 1. The report summarizes the total zone loads for precise HVAC design taking into account contributions from a variety of sources including solar loads walls roofs and people.

Table 1: Calculations of the Building's Thermal Loads

Zone Design Load Summary for Default System

Project Name: khaire 4   08/17/2024

Prepared by: LIBYA   03:47

Zone 1	DESIGN COOLING			DESIGN HEATING		
	COOLING DATA AT Jul 1700 COOLING OA DB / WB 40.3 °C / 24.1 °C			HEATING DATA AT DES HTG HEATING OA DB / WB 3.9 °C / 0.4 °C		
	OCCUPIED T-ST[illegible]			OCCUPIED T-STAT 21.1 °C		
ZONE LOADS	Details	Sensible (W)	Latent (W)	Details	Sensible (W)	Latent (W)
Window & Skylight Solar Loads	20 m²	885	-	20 m²	-	-
Wall Transmission	123 m²	3138	-	123 m²	3540	-
Roof Transmission	221 m²	10244	-	221 m²	7034	-
Window Transmission	20 m²	1495	-	20 m²	1753	-
Skylight Transmission	0 m²	0	-	0 m²	0	-
Door Loads	0 m²	0	-	0 m²	0	-
Floor Transmission	221 m²	0	-	221 m²	0	-
Partitions	56 m²	1921	-	56 m²	0	-
Ceiling	0 m²	0	-	0 m²	0	-
Overhead Lighting	2441 W	2441	-	0	0	-
Task Lighting	0 W	0	-	0	0	-
Electric Equipment	180 W	180	-	0	0	-
People	25	1795	1502	0	0	0
Infiltration	-	7213	-1014	-	0	0
Miscellaneous	-	0	0	-	0	0
Safety Factor	10% / 10%	2931	49	0%	0	0
>> Total Zone Loads	-	32242	537	-	12326	0

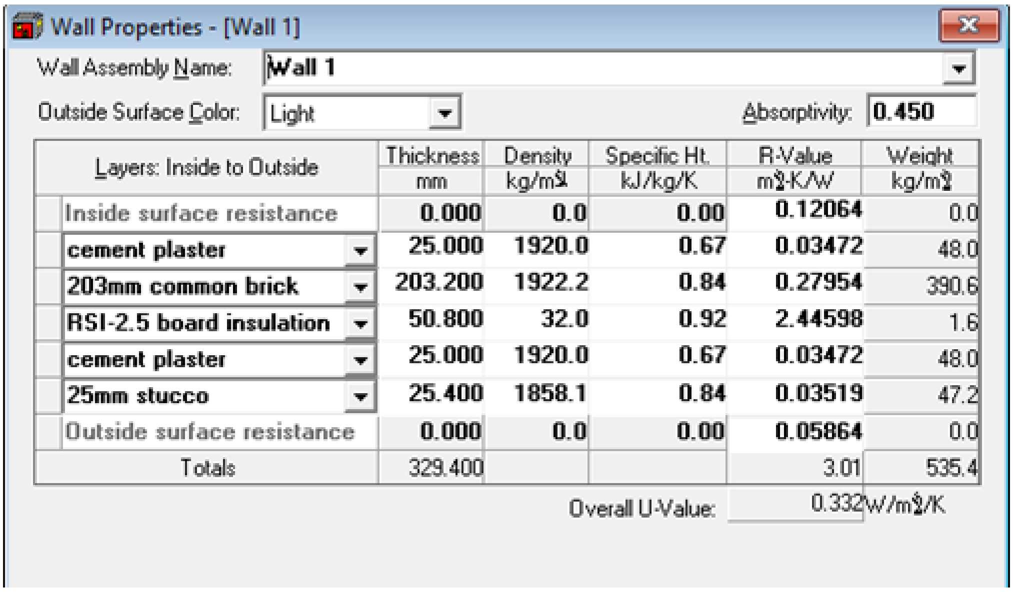
According to their directional exposure (N, S, W and H) the cooling loads for the roof windows and external walls are shown in Table 2. Each surfaces area U-values shading coefficients and computed solar loads and cooling transmission are all included. Details about heating transmission loads are also provided emphasizing each elements thermal performance.

Table 2: Cooling loads of the external walls, windows, and roof according to direction

TABLE 1.1.B. ENVELOPE LOADS FOR SPACE "library" IN ZONE "Zone 1"						
				COOLING	COOLING	HEATING
	Area	U-Value	Shade	TRANS	SOLAR	TRANS
	(m^2)	($W/(m^2 \cdot °K)$)	Coeff.	(W)	(W)	(W)
N EXPOSURE						
WALL	43	1.893	-	1185	-	1404
WINDOW 1	9	5.097	0.491	683	484	801
WINDOW 2	2	5.097	0.491	180	127	211
S EXPOSURE						
WALL	37	1.543	-	820	-	979
WINDOW 1	4	5.097	0.491	273	118	320
WINDOW 2	5	5.097	0.491	359	155	421
W EXPOSURE						
WALL	44	1.543	-	1133	-	1156
H EXPOSURE						
ROOF	221	1.851	-	10244	-	7034

Case 2:

In this case, the external walls are subjected to heat treatment by adding thermal insulation and entering the data of the wall components into the system as in the figure 5. The data entry for external wall components that have been heated by adding thermal insulation is shown in below figure. Layers of cement plaster regular brick board insulation and stucco are all part of the wall assembly and each has its own thickness density and thermal characteristics. The system determines the walls thermal resistance by computing the total R-value and overall U-value (0.332 W/m²K). These characteristics minimize heat transfer maximizing the walls energy efficiency.



Layers: Inside to Outside	Thickness mm	Density kg/m³	Specific Ht. kJ/kg/K	R-Value m²-K/W	Weight kg/m²
Inside surface resistance	0.000	0.0	0.00	0.12064	0.0
cement plaster	25.000	1920.0	0.67	0.03472	48.0
203mm common brick	203.200	1922.2	0.84	0.27954	390.6
RSI-2.5 board insulation	50.800	32.0	0.92	2.44598	1.6
cement plaster	25.000	1920.0	0.67	0.03472	48.0
25mm stucco	25.400	1858.1	0.84	0.03519	47.2
Outside surface resistance	0.000	0.0	0.00	0.05864	0.0
Totals	329.400			3.01	535.4

Figure 5: Wall components with a board insulator

Thermal treatment of windows is carried out using a double-glazing system, which is a system consisting of two panes of glass with an air gap between them. This system can consist of a single unit or double-glazed units with an air gap of 13 mm separating the two layers of glass with a thickness of 3 mm each, as in the figure 6 [7].

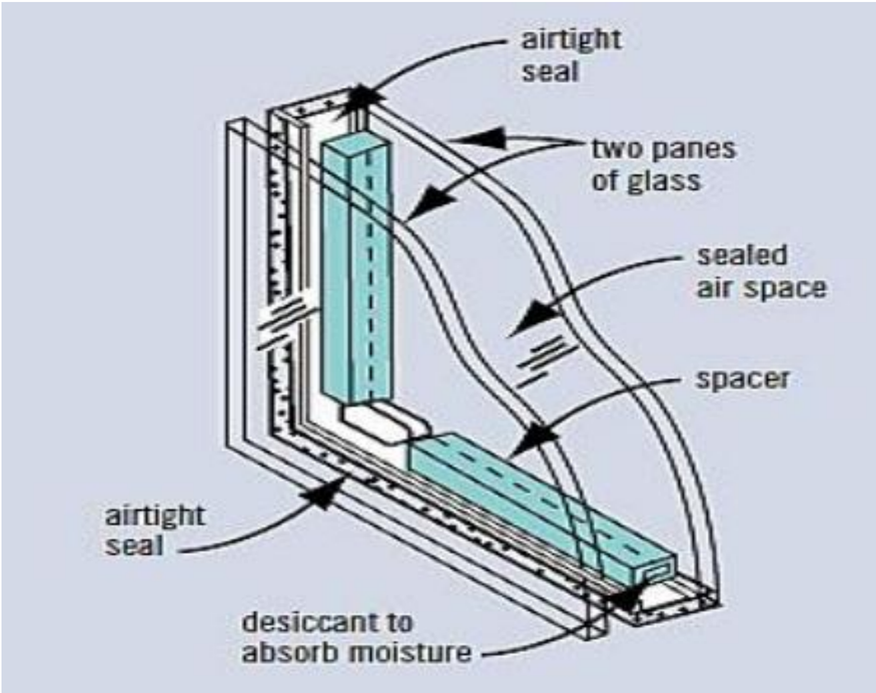


Figure 6: Perspective section of double glazing system

Windows made of double clear glass as shown in Figure 7, improve thermal performance by minimizing heat transfer. To determine the effect of the glass on heating and cooling loads the system usually enters the glass thickness U-value and shading coefficient. This setup preserves day lighting and visibility while increasing energy efficiency.

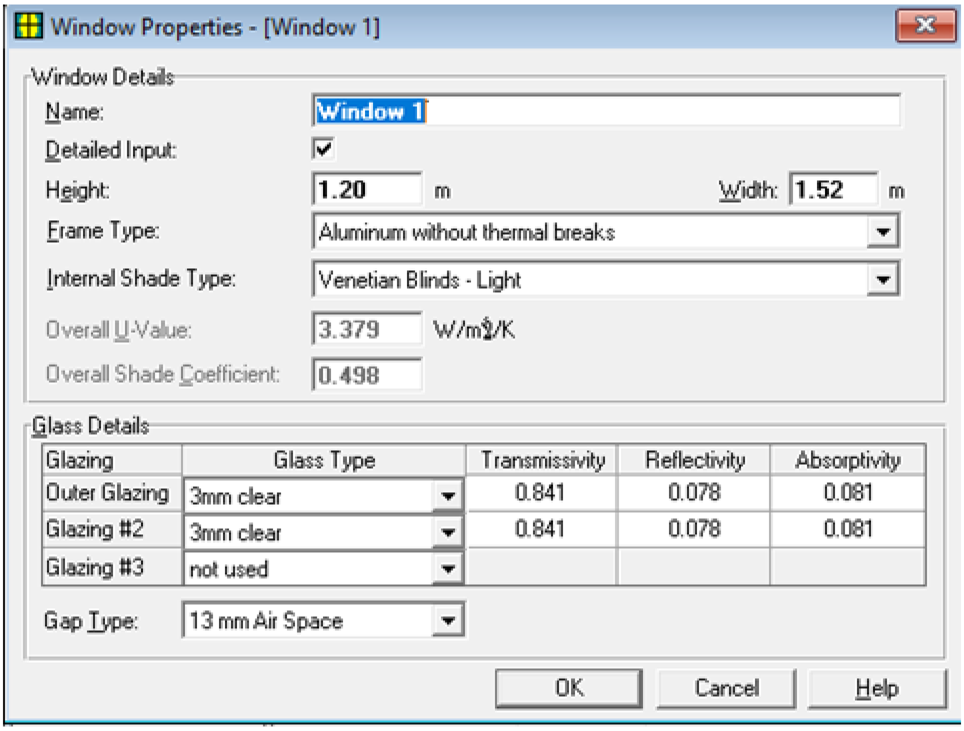


Figure 7: Windows consisting of Double clear glass

After completing entering all the required data, we get the final report that shows us the program's calculations of the building's cooling loads after insulating the external walls and using the double glazing system, which is shown in the table 3.

Table 3: Zone Design Load Summary

Zone Design Load Summary for Default System

Project Name: khaire 4 08/21/2024

Prepared by: LIBYA 01:34a

Zone 1	DESIGN COOLING			DESIGN HEATING		
	COOLING DATA AT Jul 1700 COOLING OA DB / WB 40.3 °C / 24.1 °C			HEATING DATA AT DES HTG HEATING OA DB / WB 3.9 °C / 0.4 °C		
	OCCUPIED T-STAT [illegible]			OCCUPIED T-STAT 21.1 °C		
ZONE LOADS	Details	Sensible (W)	Latent (W)	Details	Sensible (W)	Latent (W)
Window & Skylight Solar Loads	20 m²	898	-	20 m²	-	-
Wall Transmission	123 m²	2118	-	123 m²	2382	-
Roof Transmission	221 m²	10244	-	221 m²	7034	-
Window Transmission	20 m²	990	-	20 m²	1161	-
Skylight Transmission	0 m²	0	-	0 m²	0	-
Door Loads	0 m²	0	-	0 m²	0	-
Floor Transmission	221 m²	0	-	221 m²	0	-
Partitions	56 m²	1921	-	56 m²	0	-
Ceiling	0 m²	0	-	0 m²	0	-
Overhead Lighting	2441 W	2441	-	0	0	-
Task Lighting	0 W	0	-	0	0	-
Electric Equipment	180 W	180	-	0	0	-
People	25	1795	1502	0	0	0
Infiltration	-	7213	-1014	-	0	0
Miscellaneous	-	0	0	-	0	0
Safety Factor	10% / 10%	2780	49	0%	0	0
>> Total Zone Loads	-	30580	537	-	10577	0

Table 4 shows the cooling loads of the external walls, windows, and roof according to direction. It offers comprehensive computations for every surface including area U-values shading coefficients solar loads and cooling transmission. This information aids in improving HVAC system design and comprehending the thermal behavior of building envelopes.

Table 4: Cooling Loads external walls, windowns, and roof

TABLE 1.1.B. ENVELOPE LOADS FOR SPACE "library" IN ZONE "Zone 1"						
	Area (m²)	U-Value (W/(m²-°K))	Shade Coeff.	COOLING TRANS (W)	COOLING SOLAR (W)	HEATING TRANS (W)
N EXPOSURE						
WALL	43	0.332	-	165	-	247
WINDOW 1	9	3.379	0.498	453	491	531
WINDOW 2	2	3.372	0.498	119	129	139
S EXPOSURE						
WALL	37	1.543	-	820	-	979
WINDOW 1	4	3.379	0.498	181	120	212
WINDOW 2	5	3.372	0.498	238	158	279
W EXPOSURE						
WALL	44	1.543	-	1133	-	1156
H EXPOSURE						
ROOF	221	1.851	-	10244	-	7034

Table 5: Case 1 and Case 2 Results

	Case1 values	Case2 values	
Parameter	Base case	AI-based KNN Enhanced Roof System (KNN-ERS)	Total cooling load reduction rate
U value(wall)	1.893(W/(m²-°K))	0.332(W/(m²-°K))	82.4%
Wall transmission	3138 (W)	2118 (W)	32.5%
Window solar load	885 (W)	898 (W)	1.44%
Window transmission	1495 (W)	990 (W)	33.7%
Total cooling load	32242(W)	30580 (W)	5.15%

The results for the case 1 and case 2 can be summarized and compared in table 5. A 32.5% reduction in wall transmission cooling load resulted from the walls U-value dropping dramatically from 1.893 W/(m²-°K) to 0.332 W/(m²-°K) a decrease of 82.4 percent. The window solar loads stayed nearly constant with a slight increase of 1.44% while the window transmission cooling load decreased by 33.7. Energy efficiency was demonstrated by the 5. 15% decrease in the total cooling load which went from 32242 W to 30580 W. The efficacy of the KNN-ERS in maximizing thermal performance is demonstrated by these outcomes.

DISCUSSION

The significant impact of efficient insulation and passive cooling techniques on improving the thermal performance of buildings in hot dry climates. By incorporating solutions such as insulated foundations, double glazing, shading, and, underfloor ventilation, buildings can significantly reduce cooling loads, improve energy efficiency, and enhance indoor comfort. For Libya, and Tripoli in particular, implementing these strategies could lead to a more sustainable and energy-efficient built environment, reducing reliance on mechanical cooling systems, lowering electricity costs, and relieving stress on the national power grid. These results highlight the importance of investing in energy-efficient building practices in hot climates for both economic and environmental benefits.

The insulated clay hollow blocks with polystyrene, insulated clay blocks for construction, and building facade with external thermal insulation panels installed is represented in Figure 8, Figure 9, and Figure 10 respectively.

Figure 8: Insulated Clay Hollow Blocks with Polystyrene

Figure 9: Insulated Clay Blocks for Construction

Figure 10: Building Facade with External Thermal Insulation Panels Installed

CONCLUSION & RECOMMENDATIONS

The goal of this study is to demonstrate the usefulness of re-introducing passive cooling techniques to diminish cooling energy consumption in building. The results of this study highlight that passive strategies are effective for reducing the cooling load in mechanically air-conditioned buildings. Furthermore, we chose to study AI-based KNN Enhanced Roof System (KNN-ERS) that would be accessible, easy to implement, and effective for reducing the cooling load in the present and future buildings. The energy simulation used evaluates different passive cooling technologies in terms of the rate of cooling load reduction. The results of simulations show that applying external thermal insulation to the building walls leads to a noticeable reduction in the cooling load compared to the basic case by 32.5%. In addition, the use of double glazing technology reduces the thermal load by 33.7%. Using this simulation the maximum cooling load (occurring in July) can be reduced by about 5.15% using KNN-ERS passive technique.

The study's results identify a group of recommendations for designing a low cooling energy building, which are summarized below:

1-Understanding thermal properties of building materials is essential for evaluating thermal performance of a building. Therefore, architects should select insulation materials that are great at resisting the flow of heat (low U-value and high R-value).

2- According to the simulation results, an exterior insulation layer is a more effective location for insulation materials to reduce the cooling load.

3- The size, placement and type of glass work with the insulation to significantly reduce solar absorption and thus reduce the building's cooling load.

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