ISVS e-journal, Vol. 10, Issue. 1
January, 2023

Effects of Building Envelopes on Energy Consumption in the Domestic Buildings in Bahrain

Saad Fawzi Al-Nuaimi[1,] & Wafa AlMadani[2]
Department of Architecture Engineering, College of Engineering[1]
University of Diyala, Iraq.
Department of Engineering, College of Applied Studies,
University of Bahrain, Bahrain [2]
dr.saadalnuaimi@uodiyala.edu.iq [1]
walmadani@uob.edu.bh [2]

Abstract

All over the world, the demands and the needs for energy has increased over the years, which increases the cost of energy simultaneously. In this situation, it is important to reduce energy consumption. Reducing energy has to start at the global level through macro and micro environments reaching the level of buildings and users.

Many research have tried to tackle the problem of the effect of buildings on the consumed energy inside the buildings, because they can affect the consumed energy. For example, In the Kingdom of Bahrain, the buildings consume the major part of over-all energy consumption, which is around 80% from the total energy produced. Specifically, for the residential dwelling sector, it may reach 54.5% of the entire energy, at the annual rate of increase at 8%.

In Bahrain, the largest part of energy consumption has been for making internal environments comfortable by using mechanical and electrical air-conditioning systems in buildings. Therefore, the "building envelope" can be one of the most effective parts, which could reduce the use of energy inside the buildings, if constructed of proper "walls, openings and roofs".

This research examines the issue of the effect of a building envelope and how it can be utilized for reducing energy consumption in Bahrain. The goal is to assess the effects of the inner layers of the walls, which usually act as the main part of the building envelope. It employs the simulation program "e-QUEST 3-64" to calculate the changing effects of the inner layer materials as finishing material on the consumed energy.

This research takes Bahrain as a case study because of the availability of information, which can be used for the simulation program. A sample case for the building envelope has been designed by using 25 cm thick brick walls with the outside layer plastered with cement and painted white. The effects of many parameters of the inner layer materials such as the material thickness, colors and the texture are fixed to investigate the influence of using different inner layers to the consumed energy in the dwellings.

The research concludes that the inner layer has a significant effect on the consumed energy in dwellings. It turned out that *plywood is the best inner layer; it will decrease about 8 % of energy consumed and thereby reduce the cooling demand by 11%. The findings will help the architects to implement the best inner layers on energy conservation.*

Keywords: Building envelope, dwellings and energy, simulated energy, energy consumption, inner layer and energy.

Introduction

The increase in energy consumption has become very notable in recent times. The lack of energy and earth-wide temperature rise will be very compelling to deal with energy consumption. Indeed, as Yilmaz (2007) says, the productive utilization of energy has become the main point of contention for energy strategies.

From 1998, the energy use in the Kingdom of Bahrain has risen. It was 5773 GW and has become 10689 GW in 2007 according to the official statistics (BMEW, 2005). This shows that the building structures consume (around 80%) most of the electricity-based energy in Bahrain.

It is reported that the domestic dwellings in Bahrain use around 55% of the total energy consumption. According to statistics, there is an annual rate of increase of this sector at around 8%. Studies point out that buildings use more than half the energy in the buildings to create acceptable comfort levels (IEA, 2007, Srivastava-Modi, 2011).

The enormous amount of energy utilized in buildings is for cooling and ventilation. As is known, heat moves by conduction through the building envelope (external walls and roofs) and create the problem of energy in structures (Al-Homoud, 2004). In the domestic dwellings in Bahrain, 51% of energy is utilized for cooling. In this situation, the well-designed structures can produce huge saving in energy and cost related to air conditioning (Al-Nuaimi, 2014).

Thus, the warm layer of the building envelope is sandwiched between different characteristics such as the indoor temperature and the open-air climate. The building materials of the building envelope affect the room air temperature and accordingly, the utilization of energy. The properties of the building materials determine the sunlight-based heat gain, heat transmission, heat capacity and air invasion (Fazio, et al., 1997).

The study of Givanni has identified these qualities as thermal properties of the building envelope which are connected with the warm conductive, the coefficient surface connectivity, heat limit and the properties of the surface radiation; reflection properties, emissivity, and absorption properties (Givanni Sagravatti,et.al, 2022). These ought to be notable and appropriately viewed as during the initial plan stage to accomplish building warm comfort and reduce the energy utilization required (Al-Qadhi, 2008; Al-Saadi, 2006).

This research investigates the effect of various internal finishing materials; the thermal investigation effect is focused on the commonly used materials inside the dwellings in Bahrain. The common materials are: stones (rocks), porcelains (ceramic), cement plastering, chipboard (particle or fiber board), gypsum plastering (stucco), granites (intrusive rocks), marble rocks (metamorphic), terrazzo (mosaic tiles), gypsum boards (dry wall), clay bricks, and plywood boards.

Research Limitations

Numerous past investigations have examined how to reduce energy utilization by re-conceptualizing buildings and structures. They have ranged from the global level to urban planning, buildings, and building envelopes to internal building components. However, there is inadequate research examining the impact of the building envelopes.

This study is focused on the effect of the building envelopes on energy utilization in the dwellings in Bahrain. It examines the contribution of various materials in reducing the energy utilization in buildings. It uses different inner surface materials in building envelopes to determine how they contribute to energy use in the dwellings for air-conditioning.

A simulation model is imitated to assess the effect of internal surfaces of the envelope on energy utilization. In order to eliminate the other factors that affect energy utilizations, following have been taken into account.

- The area of the structure.
- Bahraini environmental characteristics: warm and humid in the summer season and cold and humid in the winter season.
- The normal materials which have been used in the residences in Bahrain.

Following parameters are made constant in order to ensure that the study focuses on the impact of changing surfaces on energy utilization. These permanent parameters are:

- The shape and material properties of the main walls, roofs and floors.
- The properties of the material-color and texture.
- The surface cost and development cost.
- The thicknesses of the inner surface materials.

Review of Literature

During the war in Ukraine, the crisis of energy became more important than ever before (Sagravatti et. al, 2022). Many studies have been done in the field of the energy consumptions to ascertain the energy consumption in public buildings. For example, Yang Liu et.al. (2019) has simulated the different structural elements in China. They have studied the effects different variables such as the walls, windows, roofs, structure, and the ratio of openings to the walls for the large scale of public buildings in Wuhan in China. By using the simulation program Design Builder software, the study has found the annual energy consumptions in these types of buildings. However, it has not ascertained the effects of the inner layer materials in the residential buildings which is the most significant aspect in the Arabian Gulf.

Mohamed (2020) has also examined energy consumption, comparing between three types of residential buildings, single story, duplex and an apartment in Tripoli Lybia. The study has used the ‘energy-plus’ simulation program to simulate and find the cost of energy consumptions inside these residential buildings. The study has found the apartments to be the most energy efficient and then the duplex and the single floor residential building. This study is focused on the residential type and neglects all other factors like materials and other building characteristics.

Al-Shargabi, (2022) has carried out a systematic literature review for 185 previous studies for the effect of building’s characteristics on energy consumption. It finds that all the studies had examined the outer envelope effects such as the buildings elements. They have focused on the building type, the characteristics of the building, as predicted variables. They point out that the characteristics of the inner envelope, has received less attention.

Al-Nuaimi (2022) has investigated the simulated effect of building orientation on energy consumption in the Kingdome of Bahrain. He has used the climate information for the Kingdome of Bahrain, and has found the best and worst orientations for the buildings in terms of energy consumption. The study also does not examine the effects of the inner layer materials and their role in energy consumption.

It is notable that there have been no studies investigating the effect of the inner layer of the building envelopes on energy consumption in the domestic buildings.

Research Methodology

This research has employed quantitative data according to the deduction methodology. It employs a the E-Quest simulation program to generate data for the consumption of energy inside the buildings in Bahrain. It uses climate data and energy data as related to Bahrain using Bahrain as a case study. Bahrain is a typical case of the climate situation in the Arabian Gulf and hence could provide indications as to how the use of materials in in the inner surfaces of the envelopes could be employed to manage and reduce energy consumption the domestic buildings.

The E-QUEST Modeling Program

There are a number of programs that can be used in this research. There are also many variables that can be considered during the choice cycle. For example, speed and cost, precision, reproducibility, responsiveness, ease of use, climate information accessibility, input intricacy and result quality (Al-Saadii, 2006; ASHRAE, 2021; Hong, Chou and Bong, 2000).

The research uses one of the most popular and quick modelling programs for energy simulation which is the e-quest program. E-QUEST is one of the best energy simulation programs which can model the buildings and produce accurate results (Capehart, 2007).

> "Energy modelers and engineers all over the world use it. One big contributing factor to its popularity is its cost. It is free and it is built on the DOE 2 simulation engine. The other benefit of e-QUEST is that it can be used at every stage of a building's development, from the early designs to final stages".
>
> (DOE and Hirsch, 2021)
>
> E-QUEST modelling and simulation program
>
> "Can construct a building envelop within the program. From there you can run simple simulations or very complex models. There are three input wizards in e-QUEST modelling that all have differing levels of complexity, or it can use the detailed DOE-2 interface. They wizards are as follows: Schematic Design Wizard (simple inputs), Design Development Wizard (detailed input) and Energy Efficiency Wizard. Each wizard has extensive default inputs that are based off California Title 24 building energy code. Long-term average weather data (TMY, TMY2, TMY3, etc.) for 1000+ locations in North America are available via automatic download from within e-QUEST".
>
> (Clevenger and Knox, 2013)

The e-QUEST modelling and simulation program could support many graphical figures. It could provide accurate simulated results with comparisons and analysis reports.

The Weather Conditions for the E-Quest Modeling Program

Climate information is typically accessible as crude information designs for a long time, ordinarily 20-30 years in non-industrial nations. This crude information is improper for the energy reproduction programs. A regular climate year, addressing numerous long periods of climate information must be chosen for the energy investigation. This deterrent has obstructed the utilization of energy reproduction programs in agricultural nations in the examination of building warm plan.

The consumed simulation program e-QUEST requires the accompanying information with fluctuating subtleties:

- Climate and topographical information.
- Building actual information, interior burdens, and functional attributes.
- The characteristics of the equipment and HVAC system.

The Building Envelope

To define the terminology of the building envelope according to the previous definitions, the following descriptions can be used as a guideline for the research:

> "The terminology of Building envelope refers to those building parts that encase molded spaces and through which nuclear power is moved to or from the outside environment"
>
> (Turner and Doty, 2007:10).
>
> "The nuclear power move rate is the heat gain which can be kept up with in an indoor temperature lower than the open air temperature"
>
> (Turner and Doty, 2007:12).

Material Properties for e-QUEST

The e-QUEST program has all the material properties built in the program; they can be changed according to special requirements. This research will use the standard materials properties.

> "The most important properties are three; which can be used to characterize the thermal qualities of a material: conductivity, thickness, specific heat".
> (Doebber, 2004: 27)

The Study Model

This research uses the smallest functional simulated model for investing the effect of the inner layer of the building envelope. The simulated model is used in the e-QUEST simulation program as a single space used as a dwelling unit in Bahrain. The model is constituted of three cubic meters with only one wooden door with 2.2-meter height and 1-meter width. The opening is 1-meter width by 1-meter height and has single glazing. The thermal assessment is focused on the inner layer of the base case envelope. It is constructed as a concrete roof with a concrete floor while the wall is also of concrete blocks. All the selected building materials and their properties are commonly used in Bahrain, as shown in the Figs. 1 and 2.

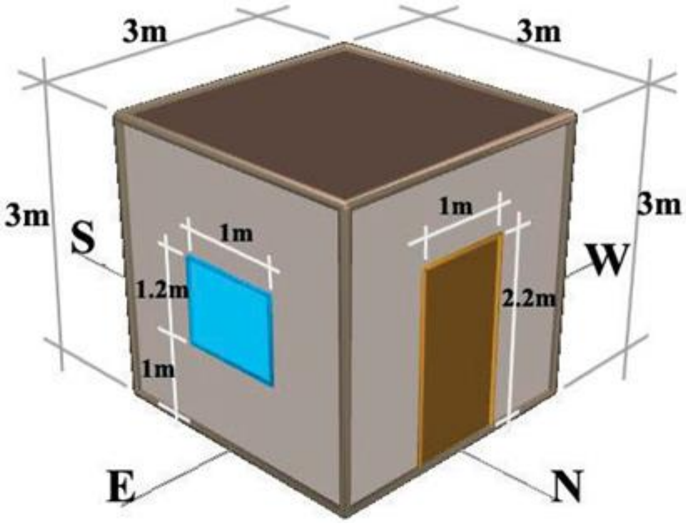


Fig. 1: A perspective of the research model
Source: authors

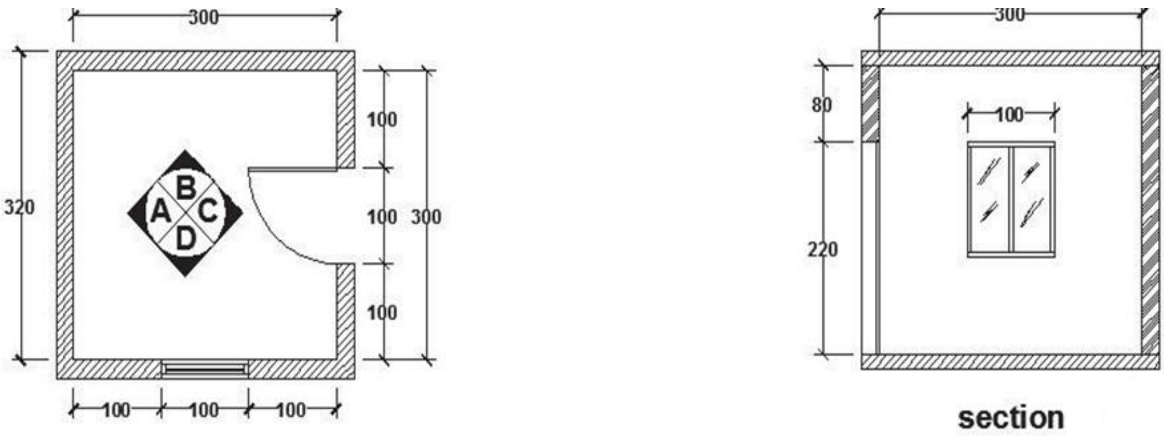


Fig. 2: The Research Model - plan and section
Source: Authors

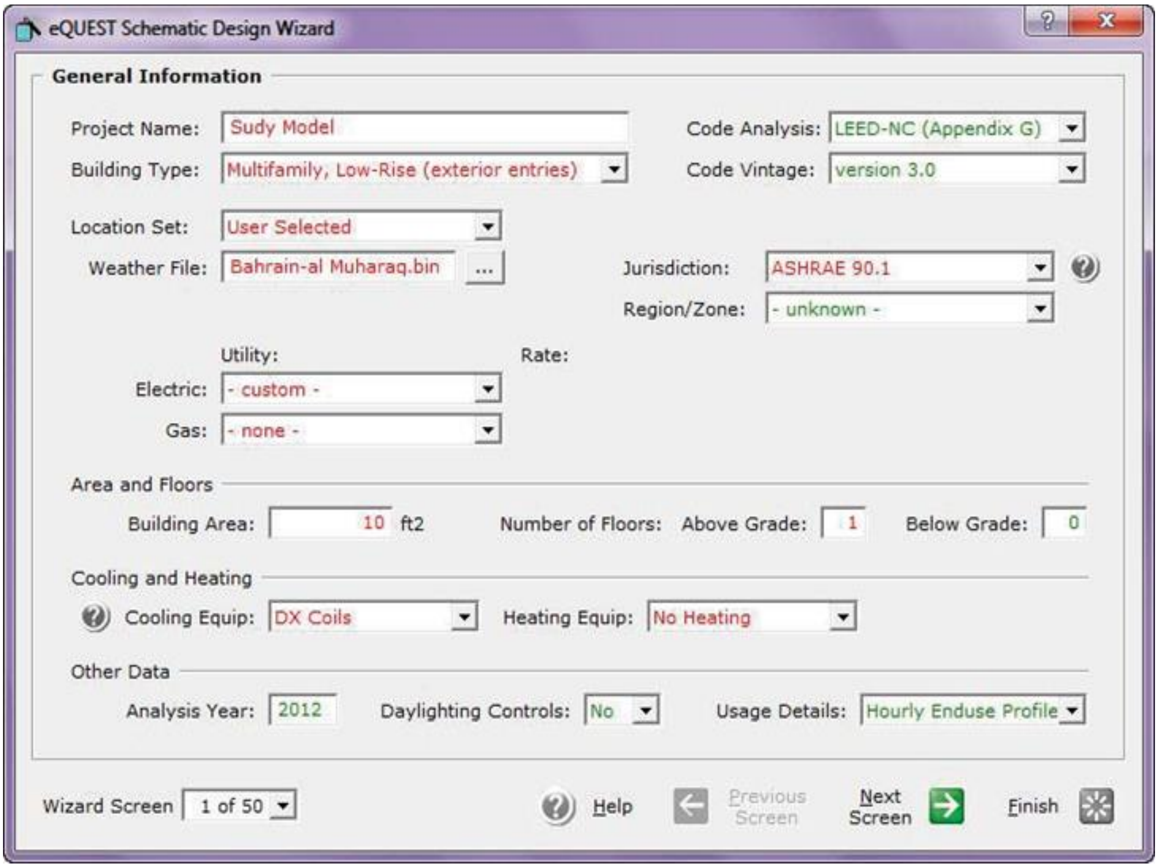
Interior Layer Materials

The research uses the base case study as a reference to investigate the effect of changing only the inner layer while the other parameters are fixed. The commonly used internal building envelope layers are as follows:

- Stones (rocks).
- Porcelains (ceramic).
- Cement plastering.
- Chipboard (particle or fiber board).
- Gypsum plastering (stucco).
- Granites (intrusive rocks).
- Marble rocks (metamorphic).
- Terrazzo (mosaic tiles).
- Gypsum boards (dry wall).
- Clay Bricks.
- Plywood boards.

The selected materials are used in the e-QUEST program with properties as sown in Fig 3. The impact of the inner layer of the designed model envelope is changed each run time to investigate the effect of the inner material on the consumed energy in the building, while the other parameters are fixed as same as in the base case model.

Fig. 4 shows the input data for the construction of building envelope properties. Fig. 5 shows the material properties which are used for the simulation model available in the e-QUEST simulation program. Fig. 6 shows the construction materials for the base case model which is the same for all the simulated cases and only the inner layer material properties are modified according to the used material.


eQUEST Schematic Design Wizard

General Information

Project Name: Sudy Model
Building Type: Multifamily, Low-Rise (exterior entries)
Code Analysis: LEED-NC (Appendix G)
Code Vintage: version 3.0
Location Set: User Selected
Weather File: Bahrain-al Muharaq.bin
Jurisdiction: ASHRAE 90.1
Region/Zone: - unknown -
Utility: Electric: - custom -
Utility: Gas: - none -
Rate:

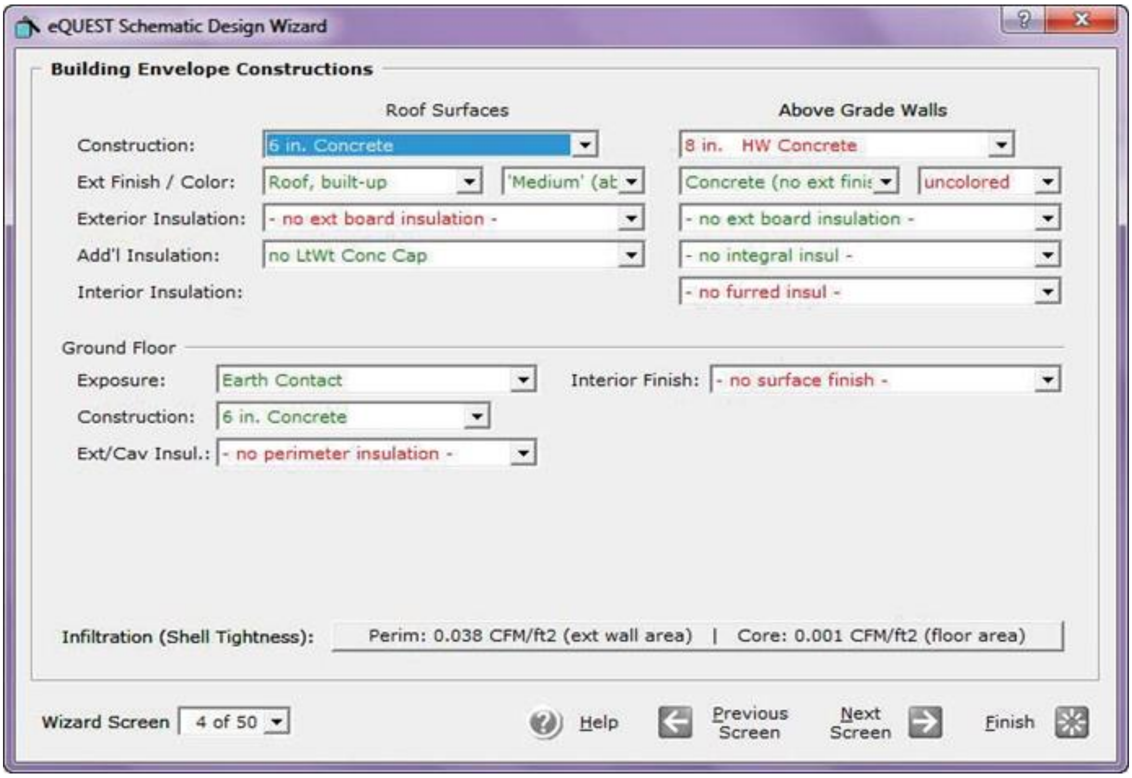
Area and Floors
Building Area: 10 ft2
Number of Floors: Above Grade: 1
Below Grade: 0

Cooling and Heating
Cooling Equip: DX Coils
Heating Equip: No Heating

Other Data
Analysis Year: 2012
Daylighting Controls: No
Usage Details: Hourly Enduse Profile

Wizard Screen: 1 of 50

Fig. 3: The required data for the program of base case model
Source: Authors



Building Envelope Constructions

	Roof Surfaces	Above Grade Walls
Construction:	6 in. Concrete	8 in. HW Concrete
Ext Finish / Color:	Roof, built-up 'Medium' (ab	Concrete (no ext finis uncolored
Exterior Insulation:	- no ext board insulation -	- no ext board insulation -
Add'l Insulation:	no LtWt Conc Cap	- no integral insul -
Interior Insulation:		- no furred insul -

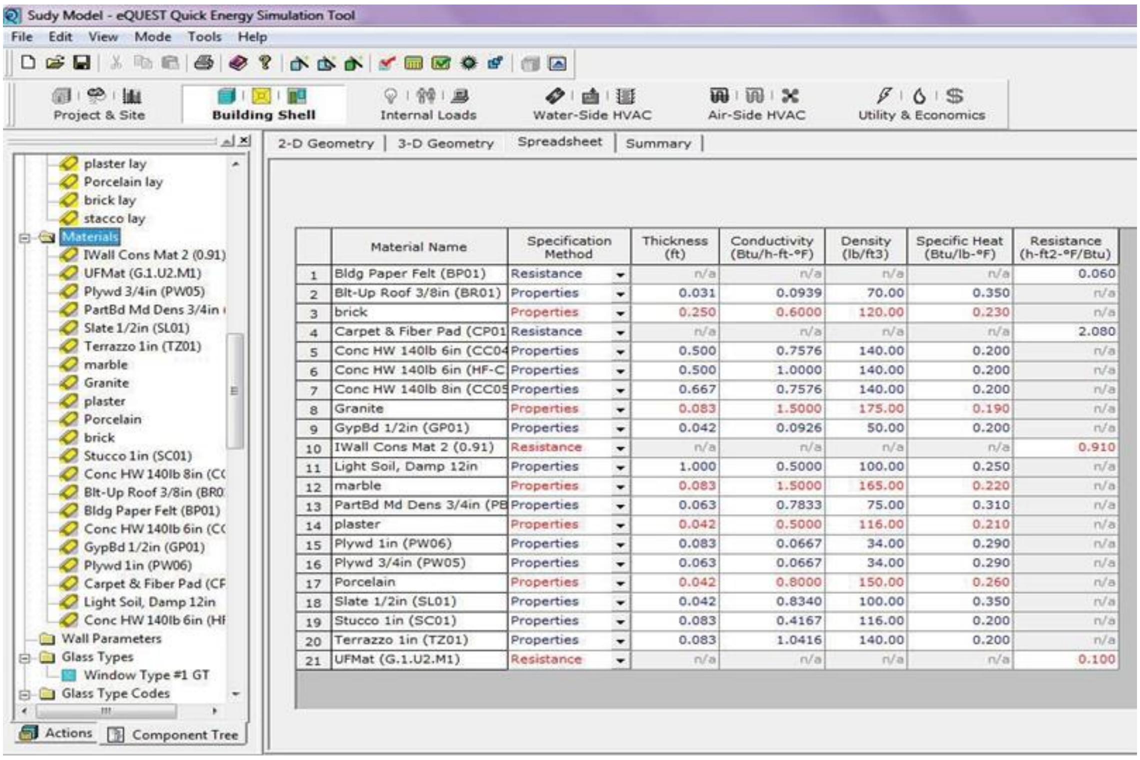
Ground Floor

Exposure: Earth Contact
Interior Finish: - no surface finish -
Construction: 6 in. Concrete
Ext/Cav Insul.: - no perimeter insulation -

Infiltration (Shell Tightness): Perim: 0.038 CFM/ft2 (ext wall area) | Core: 0.001 CFM/ft2 (floor area)

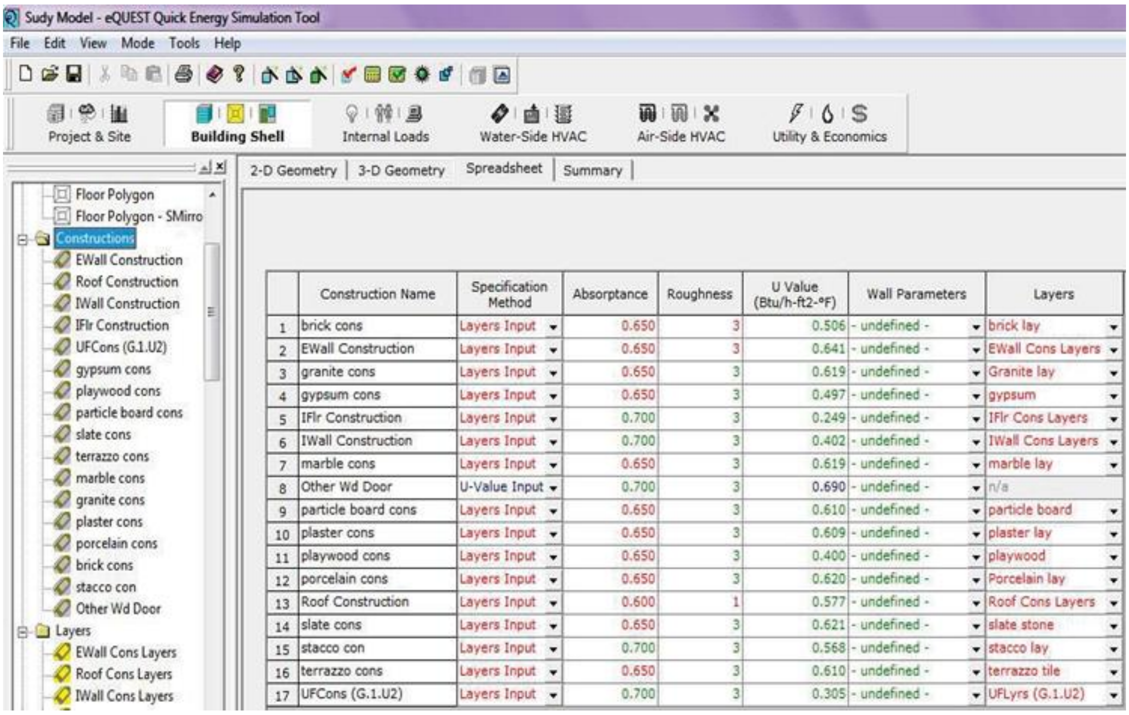
Wizard Screen 4 of 50

Fig. 4: The envelope construction required data for the simulated model
Source: Authors



	Material Name	Specification Method	Thickness (ft)	Conductivity (Btu/h-ft-°F)	Density (lb/ft3)	Specific Heat (Btu/lb-°F)	Resistance (h-ft2-°F/Btu)
1	Bldg Paper Felt (BP01)	Resistance	n/a	n/a	n/a	n/a	0.060
2	Blt-Up Roof 3/8in (BR01)	Properties	0.031	0.0939	70.00	0.350	n/a
3	brick	Properties	0.250	0.6000	120.00	0.230	n/a
4	Carpet & Fiber Pad (CP01	Resistance	n/a	n/a	n/a	n/a	2.080
5	Conc HW 140lb 6in (CC04	Properties	0.500	0.7576	140.00	0.200	n/a
6	Conc HW 140lb 6in (HF-C	Properties	0.500	1.0000	140.00	0.200	n/a
7	Conc HW 140lb 8in (CC05	Properties	0.667	0.7576	140.00	0.200	n/a
8	Granite	Properties	0.083	1.5000	175.00	0.190	n/a
9	GypBd 1/2in (GP01)	Properties	0.042	0.0926	50.00	0.200	n/a
10	IWall Cons Mat 2 (0.91)	Resistance	n/a	n/a	n/a	n/a	0.910
11	Light Soil, Damp 12in	Properties	1.000	0.5000	100.00	0.250	n/a
12	marble	Properties	0.083	1.5000	165.00	0.220	n/a
13	PartBd Md Dens 3/4in (PB	Properties	0.063	0.7833	75.00	0.310	n/a
14	plaster	Properties	0.042	0.5000	116.00	0.210	n/a
15	Plywd 1in (PW06)	Properties	0.083	0.0667	34.00	0.290	n/a
16	Plywd 3/4in (PW05)	Properties	0.063	0.0667	34.00	0.290	n/a
17	Porcelain	Properties	0.042	0.8000	150.00	0.260	n/a
18	Slate 1/2in (SL01)	Properties	0.042	0.8340	100.00	0.350	n/a
19	Stucco 1in (SC01)	Properties	0.083	0.4167	116.00	0.200	n/a
20	Terrazzo 1in (TZ01)	Properties	0.083	1.0416	140.00	0.200	n/a
21	UFMat (G.1.U2.M1)	Resistance	n/a	n/a	n/a	n/a	0.100

Fig. 5: Material qualifications used in the simulated model
Source: Authors



	Construction Name	Specification Method	Absorptance	Roughness	U Value (Btu/h-ft2-°F)	Wall Parameters	Layers
1	brick cons	Layers Input	0.650	3	0.506	- undefined -	brick lay
2	EWall Construction	Layers Input	0.650	3	0.641	- undefined -	EWall Cons Layers
3	granite cons	Layers Input	0.650	3	0.619	- undefined -	Granite lay
4	gypsum cons	Layers Input	0.650	3	0.497	- undefined -	gypsum
5	IFlr Construction	Layers Input	0.700	3	0.249	- undefined -	IFlr Cons Layers
6	IWall Construction	Layers Input	0.700	3	0.402	- undefined -	IWall Cons Layers
7	marble cons	Layers Input	0.650	3	0.619	- undefined -	marble lay
8	Other Wd Door	U-Value Input	0.700	3	0.690	- undefined -	n/a
9	particle board cons	Layers Input	0.650	3	0.610	- undefined -	particle board
10	plaster cons	Layers Input	0.650	3	0.609	- undefined -	plaster lay
11	playwood cons	Layers Input	0.650	3	0.400	- undefined -	playwood
12	porcelain cons	Layers Input	0.650	3	0.620	- undefined -	Porcelain lay
13	Roof Construction	Layers Input	0.600	1	0.577	- undefined -	Roof Cons Layers
14	slate cons	Layers Input	0.650	3	0.621	- undefined -	slate stone
15	stacco con	Layers Input	0.700	3	0.568	- undefined -	stacco lay
16	terrazzo cons	Layers Input	0.650	3	0.610	- undefined -	terrazzo tile
17	UFCons (G.1.U2)	Layers Input	0.700	3	0.305	- undefined -	UFLyrs (G.1.U2)

Fig. 6: Construction properties used in the study model
Source: Authors

To find the effect of the inner layer material on the consumed energy of the model, many different inner layer materials popularly used in the Kingdom of Bahrain have been assessed. These are displayed in the Table1.

Table 1: The Properties of the inner layer material
Source: e-Quest materials library

No.	The Materials	Thickness Inch	Density lb/ft3	Specific heat btu/lb-°F	Conductivity btu/h-ft-°F
1	Slate stone finishing	½ in	100	0.4	0.83
2	Porcelain finishing	½ in	150	0.3	0.80
3	Plaster finishing	½ in	116	0.2	0.50
4	Particle board finishing	¾ in	75	0.3	0.78
5	Stucco finishing	1 in	116	0.2	0.42
6	Granite finishing	1 in	175	0.2	1.50
7	Marble finishing	1 in	165	0.2	1.50
8	Terrazzo tile finishing	1 in	140	0.2	1.04
9	Gypsum finishing	½ in	50	0.2	0.09
10	Brick finishing	3 in	120	0.2	0.60
11	Plywood finishing	¾ in	34	0.3	0.07

The results after running e-quest:

The program has produced the following results.

1- The first computer run shows the yearly-consumed energy for the reference case model “base model” in Bahrain as introduced in the Table 2. The consumed energy by space cooling has taken the biggest part of the total consumed energy. It is about 58% of the total consumed energy as displayed in the Fig. 7.

Table 2: Consumed energy by the base model.
Source: Authors

consumed energy in base model	
Ele. (kWh)	
Space Cool	2984
Vent Fans	796
Pump	0.11
Mis. Equipment.	1015
Area Lights	368
Total	5162

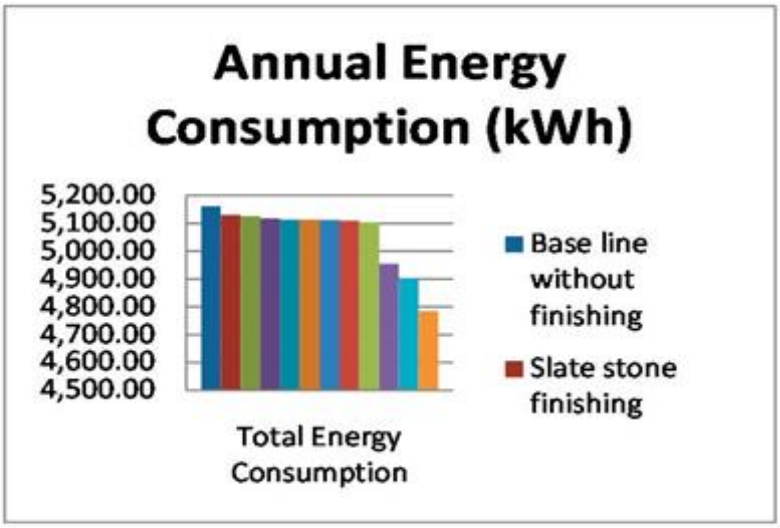


Fig. 7: Annual consumed energy inside the base case model
Source: authors

2- The table 3 shows the annual energy consumption for different inner layer materials for dwellings in Bahrain. It shows the variety of inner finishing materials and how they have impacted the energy utilization inside the review model as follows:

  a- The use of plywood as an inner material reduces energy consumption 7.6% related to the reference model.
  b- The use of brick as an inner layer material reduces energy consumption 5% related to the reference model.
  c- The use of gypsum board as an inner layer material reduces energy consumption 4% related to the reference model.
  d- The range of energy reduction in using all other inner layer materials is between 0.6% and 1.2% related to the base model.

Table 3: Consumed energy by (kWh) for different inner layer materials of the envelope.
Source: Authors

Used Materials	Annual Consumed energy (kWh)
Base line without material	5,162
Slate stone	5,130
Porcelain	5,127
Plaster	5,117
Particle board	5,114

Stucco	5,113
Granite	5,112
Marble	5,109
Terrazzo tiles	5,104
Gypsum boards	4,954
Brick	4,902
Plywood boards	4,785

3- Fig. 8 shows the best three materials that can be used for the inner layer of the building envelope. These materials are: plywood, concrete blocks and gypsum as related to the reference model.

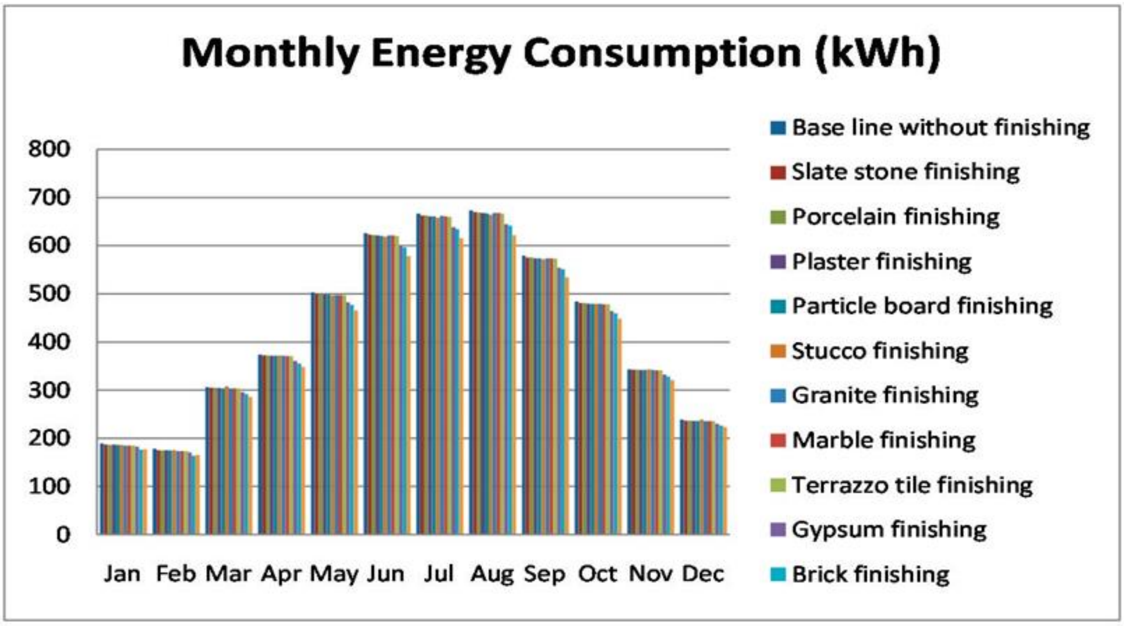


Fig. 8: Annual energy consumption for the different inner layer materials.
Source: authors

4- Fig. 9 and the table 4 show the window of e-QUEST simulation program with the monthly consumed energy for the internal layer of the building envelope.

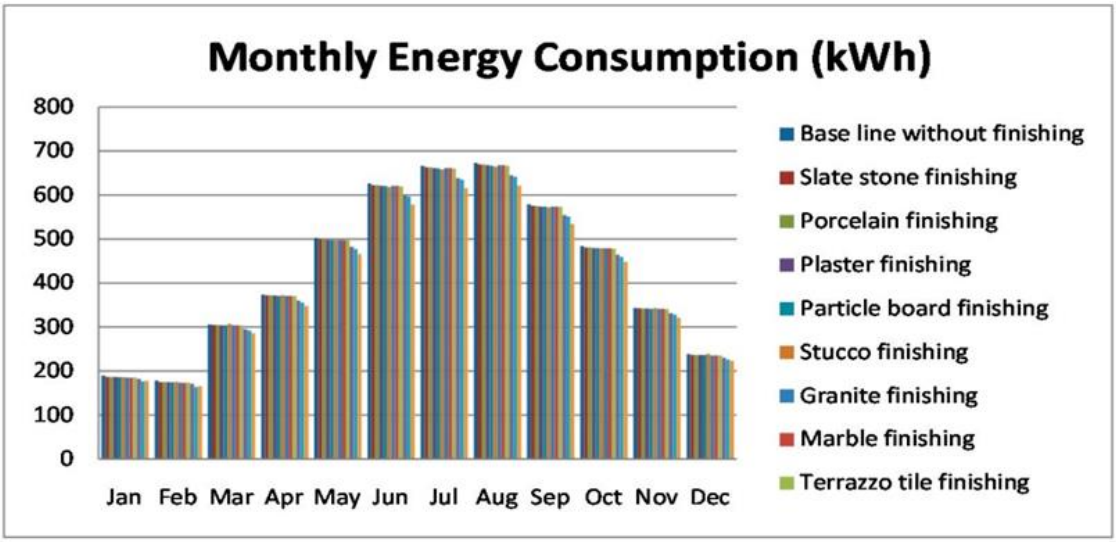


Fig. 9: Energy consumption for the different inner layer materials.
Source: Authors

Table 4: Monthly numerical consumed energy (kWh) for different inner layer Materials
Source: Authors

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Tot.
Base case	190	178	306	374	503	626	667	673	579	484	343	239	5,162
Slate stone	187	175	305	372	500	623	663	670	576	481	343	237	5,130
Porcelain	187	175	305	372	499	622	663	669	575	481	342	237	5,127
Plaster	187	175	304	372	498	621	661	668	574	480	342	236	5,117
Particle board	186	175	304	371	498	621	661	667	574	479	342	236	5,114
Stucco	186	175	308	372	497	618	658	664	572	479	343	239	5,113
Granite	185	173	304	371	498	621	661	668	574	479	342	236	5,112
Marble	185	173	304	371	497	621	661	668	574	479	342	235	5,109
Terrazzo tile	185	174	304	371	497	620	660	667	573	478	341	235	5,104
Gypsum	183	171	296	360	482	600	638	645	554	464	332	230	4,954
Brick	176	168	292	356	477	596	635	641	551	459	328	226	4,902
Plywood	177	166	286	348	466	579	616	622	535	488	321	223	4,785

5- Fig. 10 shows the annual demand for the energy consumed inside the base case model. It shows that it will consume around 80% for internal air cooling.

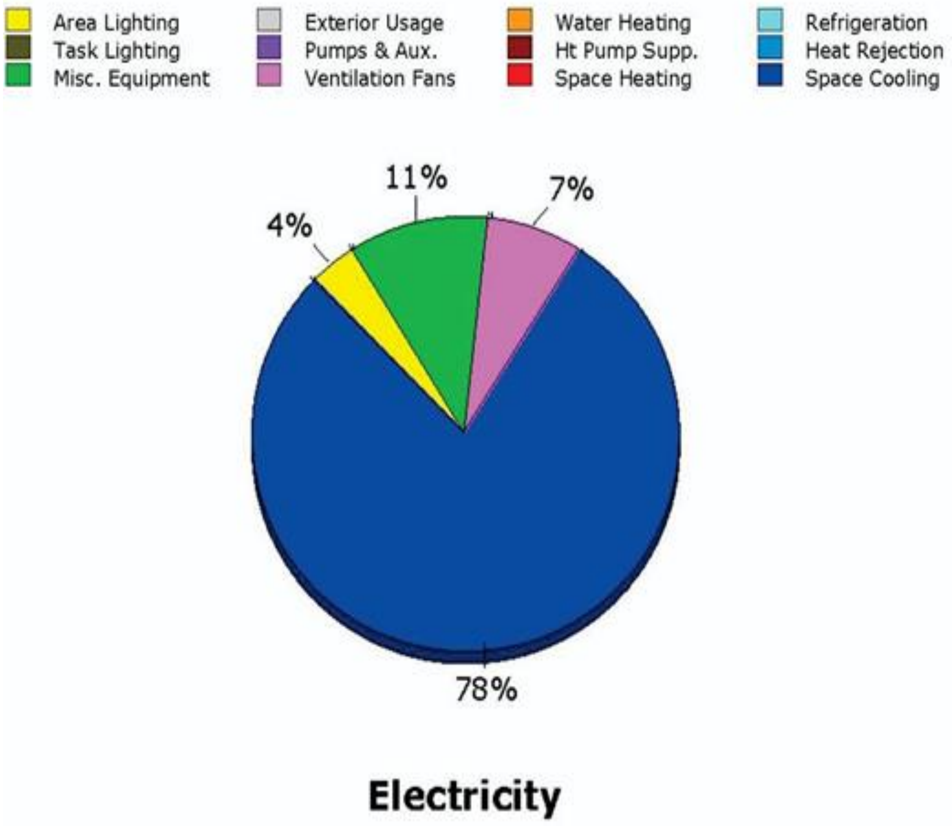
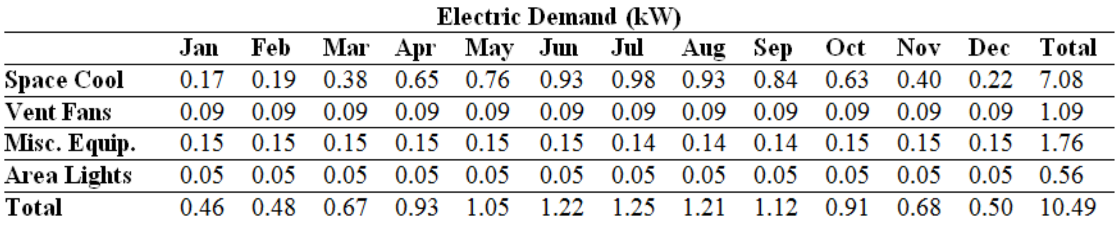


Fig. 10: Annual maximum needs for the reference model (Base model)
Source: authors

6- Related to the base simulated models, the consumed energy has been reduced around 8% by using the plywood material, 5% by using blocks and 4% by using gypsum boards as the inner layer for the building envelope.

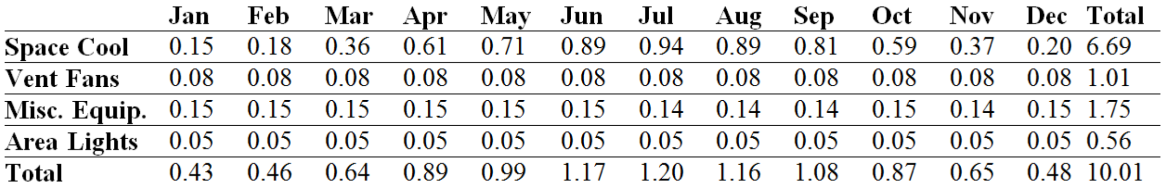
7- The peak of the monthly demand by the end use for the base model is shown in the Table 5, while the Table 6 shows the demand of energy inside the building with the inner layer material as gypsum. The demand for energy in the previous case was less than the base case model by 4%. The use of clay brick as an inner layer material demands less energy in the model at around 7% related to the base case model, as shown in the Table 7. The use of plywood as an inner layer will make the demand for the energy less by around 8% related to the base case model as shown in the Table 8.

Table 5: Monthly Maximum demand for reference point (Base model).
Source: Authors



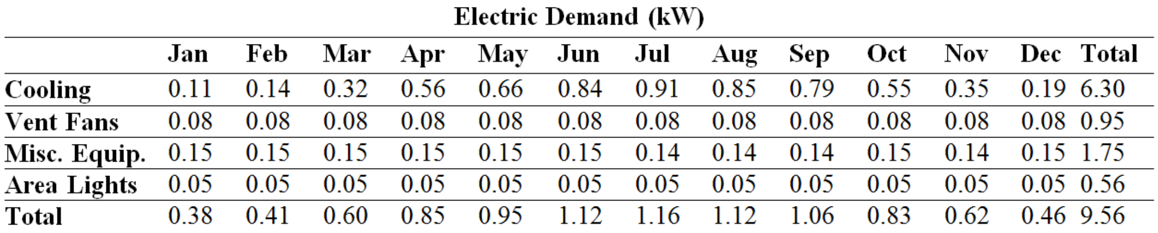
Electric Demand (kW)													
	Jan	**Feb**	**Mar**	**Apr**	**May**	**Jun**	**Jul**	**Aug**	**Sep**	**Oct**	**Nov**	**Dec**	**Total**
Space Cool	0.17	0.19	0.38	0.65	0.76	0.93	0.98	0.93	0.84	0.63	0.40	0.22	7.08
Vent Fans	0.09	0.09	0.09	0.09	0.09	0.09	0.09	0.09	0.09	0.09	0.09	0.09	1.09
Misc. Equip.	0.15	0.15	0.15	0.15	0.15	0.15	0.14	0.14	0.14	0.15	0.15	0.15	1.76
Area Lights	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.56
Total	0.46	0.48	0.67	0.93	1.05	1.22	1.25	1.21	1.12	0.91	0.68	0.50	10.49

Table 6: Maximum monthly needs for gypsum as an inner layer of the building envelope.
Source: Authors



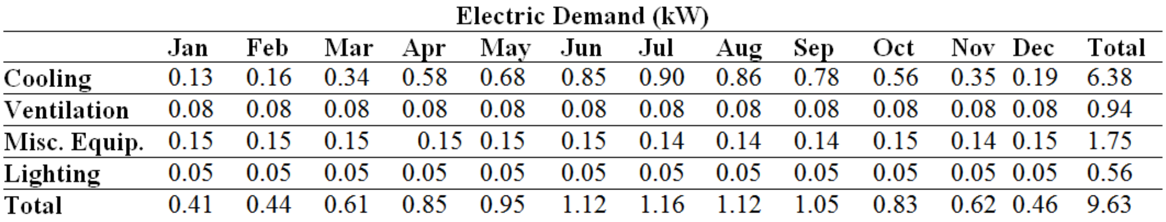
	Jan	**Feb**	**Mar**	**Apr**	**May**	**Jun**	**Jul**	**Aug**	**Sep**	**Oct**	**Nov**	**Dec**	**Total**
Space Cool	0.15	0.18	0.36	0.61	0.71	0.89	0.94	0.89	0.81	0.59	0.37	0.20	6.69
Vent Fans	0.08	0.08	0.08	0.08	0.08	0.08	0.08	0.08	0.08	0.08	0.08	0.08	1.01
Misc. Equip.	0.15	0.15	0.15	0.15	0.15	0.15	0.14	0.14	0.14	0.15	0.14	0.15	1.75
Area Lights	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.56
Total	0.43	0.46	0.64	0.89	0.99	1.17	1.20	1.16	1.08	0.87	0.65	0.48	10.01

Table 7: Monthly needs for consumed energy by using brick as an inner material
Source: Authors



Electric Demand (kW)													
	Jan	**Feb**	**Mar**	**Apr**	**May**	**Jun**	**Jul**	**Aug**	**Sep**	**Oct**	**Nov**	**Dec**	**Total**
Cooling	0.11	0.14	0.32	0.56	0.66	0.84	0.91	0.85	0.79	0.55	0.35	0.19	6.30
Vent Fans	0.08	0.08	0.08	0.08	0.08	0.08	0.08	0.08	0.08	0.08	0.08	0.08	0.95
Misc. Equip.	0.15	0.15	0.15	0.15	0.15	0.15	0.14	0.14	0.14	0.15	0.14	0.15	1.75
Area Lights	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.56
Total	0.38	0.41	0.60	0.85	0.95	1.12	1.16	1.12	1.06	0.83	0.62	0.46	9.56

Table 8: Monthly maximum needs for Plywood as a finishing material
Source: Authors



Electric Demand (kW)													
	Jan	**Feb**	**Mar**	**Apr**	**May**	**Jun**	**Jul**	**Aug**	**Sep**	**Oct**	**Nov**	**Dec**	**Total**
Cooling	0.13	0.16	0.34	0.58	0.68	0.85	0.90	0.86	0.78	0.56	0.35	0.19	6.38
Ventilation	0.08	0.08	0.08	0.08	0.08	0.08	0.08	0.08	0.08	0.08	0.08	0.08	0.94
Misc. Equip.	0.15	0.15	0.15	0.15	0.15	0.15	0.14	0.14	0.14	0.15	0.14	0.15	1.75
Lighting	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.56
Total	0.41	0.44	0.61	0.85	0.95	1.12	1.16	1.12	1.05	0.83	0.62	0.46	9.63

8- When the inner layer of the building envelope was modified, the consumed energy inside the model related to the base case model was reduced as shown in the Fig. 11 as follows

- In the case of using plywood, the energy reduction was 10%.
- In the case of using clay brick, the energy reduction was 7%.
- In the case of using gypsum board, the energy reduction was 5.5%.

Fig. 12 shows the comparison between the selected four uses: the base model, the model using gypsum, the model using brick and the model is using the plywood.

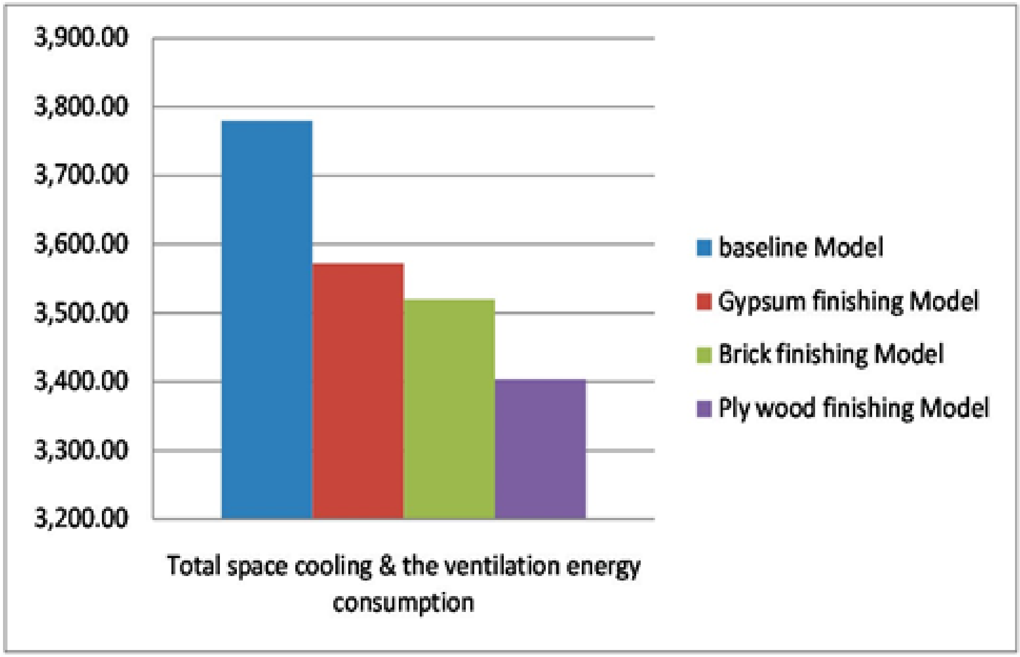
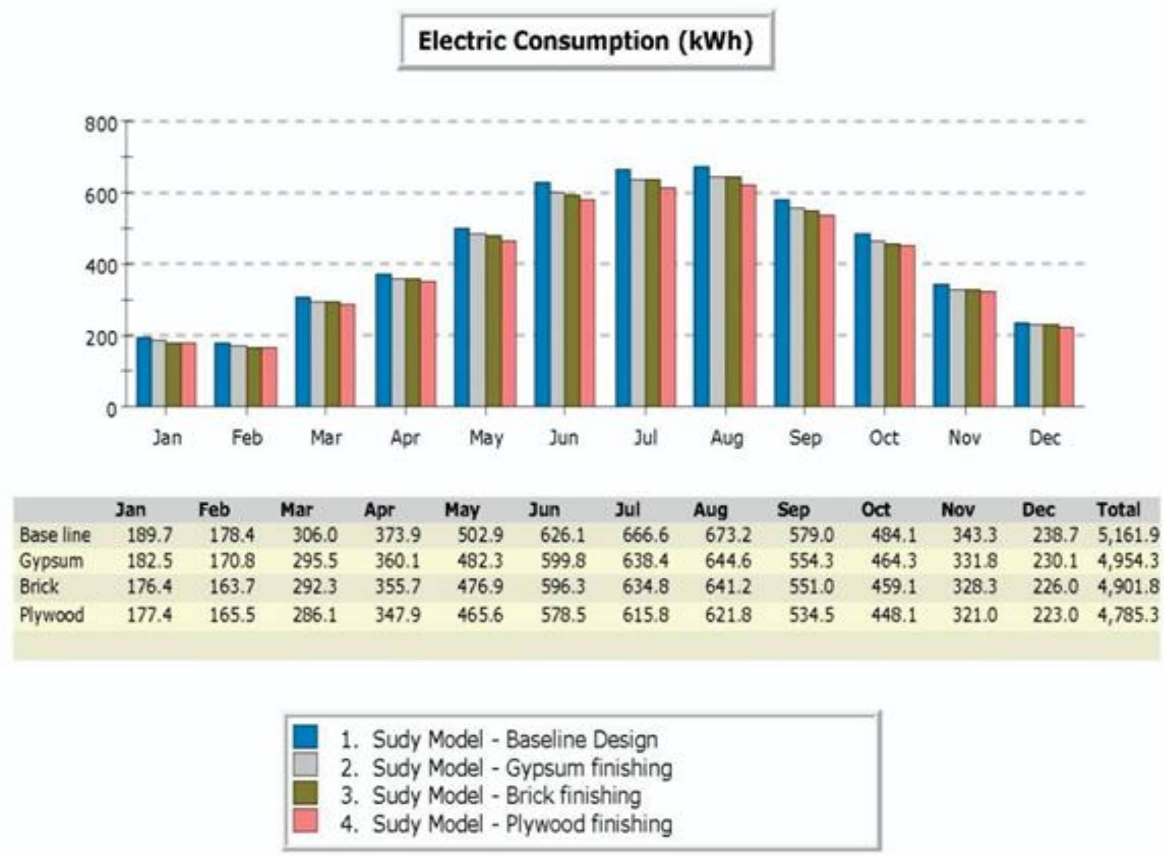


Fig. 11: Annual energy consumption to cool and ventilate the space.
Source: authors



	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Total
Base line	189.7	178.4	306.0	373.9	502.9	626.1	666.6	673.2	579.0	484.1	343.3	238.7	5,161.9
Gypsum	182.5	170.8	295.5	360.1	482.3	599.8	638.4	644.6	554.3	464.3	331.8	230.1	4,954.3
Brick	176.4	163.7	292.3	355.7	476.9	596.3	634.8	641.2	551.0	459.1	328.3	226.0	4,901.8
Plywood	177.4	165.5	286.1	347.9	465.6	578.5	615.8	621.8	534.5	448.1	321.0	223.0	4,785.3

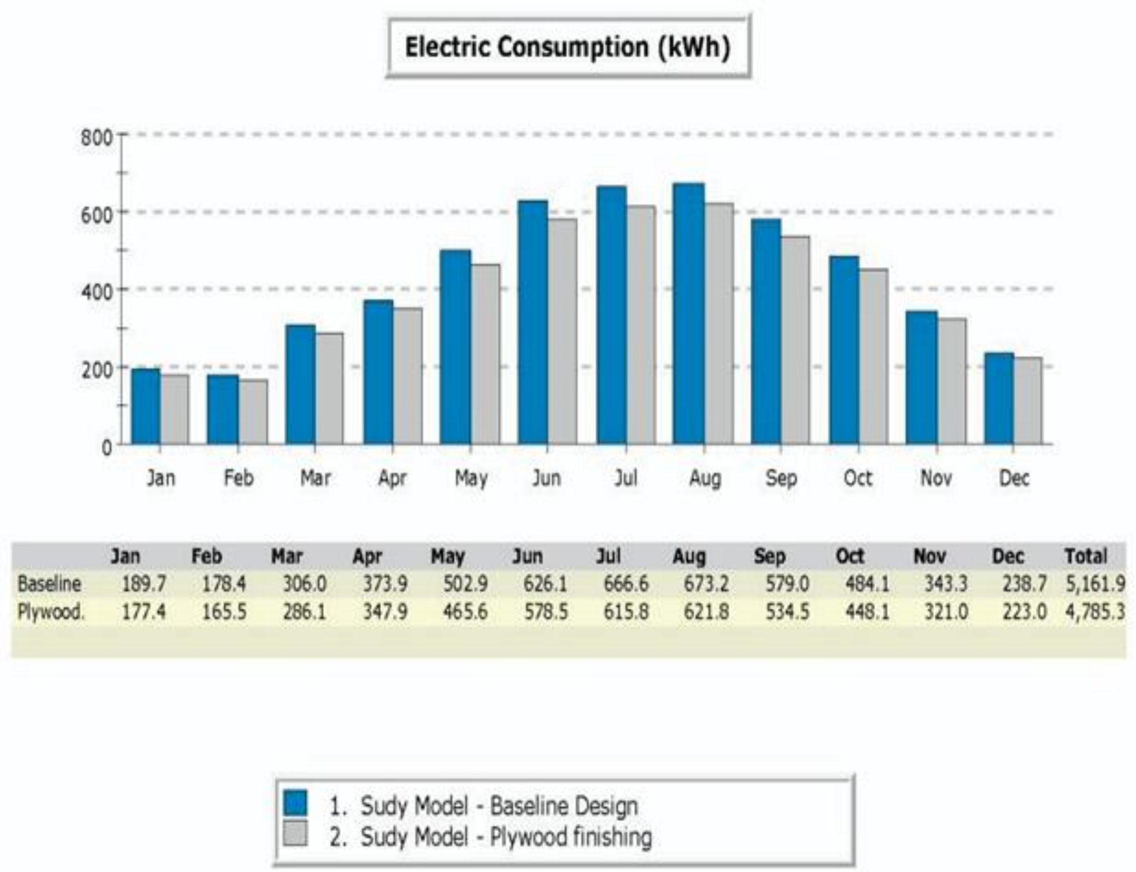
Fig. 12: Monthly energy consumption for the selected inner layer materials
Source: Authors

9- The energy consumption inside the model used for air-conditioning and ventilation for each different inner layer of the building envelope shows different amounts of energy consumptions related to the base model, as shown in the Table 9.

Table 9: Monthly energy consumption for cool and ventilate the spaces
Source: Authors

		Jan	Feb	Mar	Apr	May	Jun	Jul	Au	Sep	Oct	No	Dec	Total	Less
Reference model base case model	Cool	7	12	118	196	317	445	484	485	401	300	165	56	2,984	
	Fans	68	61	68	65	68	65	68	68	65	68	65	68	796	
	Total	75	73	185	261	384	510	551	553	466	367	231	124	3,780	
Ply wood	Cool	4	7	107	178	288	406	442	443	365	273	152	49	2,715	9 %
	Fans	59	53	59	57	59	57	59	59	57	59	57	59	688	13.5%
	Total	62	60	166	235	347	462	501	501	422	331	209	108	3,403	10%
Brick	Cool	2	5	113	186	299	423	461	462	381	283	159	52	2,823	5.5%
	Fans	59	53	59	57	59	57	59	59	57	59	57	59	696	12.5%
	Total	61	58	172	243	358	480	520	521	438	342	216	111	3,520	7%
Gypsum	Cool	5	9	113	187	301	423	461	462	381	285	159	53	2,839	5%
	Fans	62	56	62	60	62	60	62	62	60	62	60	62	734	8%
	Total	67	65	175	248	364	484	523	524	442	347	219	115	3,573	5.5%

10- The base reduction of energy consumption was when the inner layer of the building envelope was plywood. Monthly energy consumption for the plywood related to the base model was shown in the Fig. 13. This means that the wooden material is the best material for dwellings in Bahrain as an inner layer to reduce energy consumption.



	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Total
Baseline	189.7	178.4	306.0	373.9	502.9	626.1	666.6	673.2	579.0	484.1	343.3	238.7	5,161.9
Plywood.	177.4	165.5	286.1	347.9	465.6	578.5	615.8	621.8	534.5	448.1	321.0	223.0	4,785.3

Fig. 13: Monthly energy consumption for the reference model using plywood
Source: Authors

Conclusions

This research investigated the effect of the commonly used materials focused on three different finishing materials for the internal surfaces of the building envelopes which had been selected from among eleven different used materials. The e-QUEST simulation program was used to simulate the effect of changing the inner layer material while all other variables for the simulated model were fixed. These common materials show different effects for reducing the consumed energy inside the simulated model (related to the baseline model as a simulated dwelling in Bahrain).

The conclusions are as follows:

- The material of the inner layer for the building envelope is a very effective parameter for reducing energy consumption in the dwellings in Bahrain.
- There is a wide range of reducing the consumed energy by changing the material of the internal layer of the building envelope.
- The best internal material to be utilized as an inner layer for building envelope of the dwellings in the kingdom of Bahrain is plywood; it consumes less energy which is around (0.08); clay brick is (0.05) and the gypsum material is (0.04). Other effect of the simulated materials consume at a range between the values of (0.06) to (0.012) less from all consumed energy according to the base model.
- The best inner layer for the common materials in Bahrain could be listed from the best to the lowest effect as the following; plywood; clay brick; and the gypsum.
- According to the simulated model, the total monthly demands of the electricity for the material of gypsum board as an inner layer is 10.01 KW, while for the clay brick, it is 9.63 KW) and for plywood, it is 9.56 KW.
- The total monthly energy consumption for the space cooling with the required ventilation related to the base model has been reduced as follows: 0.1 from the consumed energy when using plywood, 0.07 when using the clay brick material and 0.055 when using the gypsum material.

Finally this research finds that there is a real effect of the inner layer materials on energy consumption in the domestic buildings in Bahrain.

References

Al Nuaimi, S.F. (2013) The impact of different shading percentages on energy consumption and electricity's bills for different orientations in Bahrain. Journal of advanced science and engineering research, v.3, no.2: pp.120-135.

Al-Nuaimi S. F. (2022) A Simulated Evaluation of Energy Consumption Related to the Orientation of a Dwelling in Bahrain, ISVS e-Journal, Vol. 9, No.4: pp. 1-14.

Alnuaimi, S.F. & Mohammed, W.M. (2021) Living cool: An approach for Architectural "COOL ROOF" to Decrease the Electricity Consumption in Iraq. In IOP Conference Series: Materials Science and Engineering vol. 1076, no. 1: pp. 012016). 2nd international Scientific Conference of Engineering Sciences (ISCES 2020).

Al-Nuaimi, S.F. & Mohammed, W.M. (2022) Creating Preventive Spaces: A strategy for designing environmental urban spaces to deter the pandemics. ISVS e-journal, V. 9, No. 3: pp.1-20.

Al-Nuaimi, S.F., & Kh. A. Khamis (2014) Thermal Impact of Different Interior Finishing Materials On Energy Consumption in Bahrain. Journal of Energy Technologies and Policy, 4 (3), pp.30-49.

Al-Saadi, S. N. (2006) Envelope design for thermal comfort and reduced energy consumption in residential buildings. A thesis presented to the King Fahd University of Petroleum and Minerals Saudi Arabia, Master of Science in architectural engineering.

Al-Zubari W. K,, El-Sadek A. A., Al-Aradi M. J., & Al-Mahal H. A. (2018) Impacts of climate change on the municipal water management system in the Kingdom of Bahrain: Vulnerability assessment and adaptation options. Clim Risk Manag [Internet]. pp. 95 - 110. Available from: https://linkinghub.elsevier.com/retrieve/pii/S2212096317301250

Al-Shargabi A. et.al. (2022) Buildings' energy consumption prediction models based on buildings' characteristics: Research trends, taxonomy, and performance measures, Journal of Building Engineering, Volume 54, 104577, ISSN 2352-7102, https://doi.org/10.1016/j.jobe.2022.104577.

Capehart, B. L. (Ed.) (2007) Encyclopedia of energy engineering and technology (Vols. 1). Boca Raton, FL: CRC Press. . International journal of civil and environmental engineering, vol.6, no. 12:pp.1147-1153. Available from: https://publications.waset.org/vol/72.

Clevenger, C. & Knox, M. (2013) A Tutorial and introduction to e-QUEST, Department of Construction Management, 291 W Laurel St., Guggenheim Hall, Colorado State University, Fort Collins, Colorado 80523. https://ecs.syr.edu/centers/SustainableEngineering/modules/1353_Clevenger.pdf

DOE & Hirsch. J. J. (2021) Energy and thermal performance tools, funding research by department of Energy, US, https://www.archtoolbox.com/energy-and-thermal-performance-tools. . International journal of civil and environmental engineering, vol.6, no. 12:pp.1147-1153.

Doebber, I. R. (2004) Investigation of concrete wall systems for reducing heating and cooling requirements in single family residences. Unpublished Internet Resource; Computer File Date of Entry, (Blacksburg, Va.: University Libraries, Virginia Polytechnic Institute and State University).

Dornelles, K. A., & Roriz, M. (2004) Thermal inertia, comfort and energy consumption in buildings: A case study in Sao Paulo State - Brazil. International Journal for Housing Science and Its Applications, Vol-28 (No.2), pp.153-162.

Sagravatti, G. & Tagliapietra, S. (2022) National energy policy responses to the energy crisis, working paper submitted to Italy, Bruegel. https://www.bruegel.org/dataset/national-energy-policy-responses-energy-crisis

Hong, T., Chou, S. K., & Bong, T. Y. (2000) Building simulation: an overview of developments and information sources. Building and Environment, Vol-35(No.4), pp.347-361. http://www.dynamic-ews.com/Tariffs/Electricity%20Tariffs/Bahrain.pdf.

Inc, W. A. (2012) Weather data 2012. International journal of civil and environmental engineering, vol.6, no. 12, pp.1147-1153. Available from: https://publications.waset.org/vol/72. http://www.weatheranalytics.com/index.html

Kevin, L. et. al (2021) ASHRAE handbook principles of heating, ventilating, and air-conditioning systems and equipment, Atlanta, ninth edition.

Mohammed, W. M. & Al Nuaimi, S. (2020) Investigate the Sustainable Efficient Spaces in Islamic Inheritance Houses. IOP Conf. Ser.: Mater. Sci. Eng. V. 881 012029, 3rd International Conference on Sustainable Engineering Techniques (ICSET 2020) 15 April.

Nuaimi, S. F. A., & Khamis, K. (2009) The Efficiency of Concrete Block for Domestic Dwellings in Bahrain. Gulf University Journal Vol-1(No.1), pp.119-139.

Rallapalli, H. S. (2010) A Comparison of EnergyPlus and e-QUEST Whole Building Energy Simulation Results for a Medium Sized Office Building. Arizona state university.

Srivastava-Modi, S. (2011) Evaluating the Ability of e-QUEST Software to Simulate Low-energy Buildings in a Cold Climatic Region.

Turner, W. C., & Doty, S. (2007) Energy management handbook (6th Ed). Lilburn, GA: Fairmont Press. Distributed by CRC Press/Taylor & Francis. Civil and Environmental Research, vol.3, no.3: pp.61-75

Umbark, Mohamed, Alghoul, Samah & Dekam, Elhadi (2020) Energy Consumption in Residential Buildings: Comparison between Three Different Building Styles. Sustainable Development Research (ISSN 2690-9898 e-ISSN 2690-9901). Volume 2. pp 1.

Yang Liu, Shiqing Zou, Hongyu Chen, Xianguo Wu, & Wenman Chen (2019) Simulation Analysis and Scheme Optimization of Energy Consumption in Public Buildings, Advances in Civil Engineering, vol. 2019, Article ID 6326138, 13 pages. https://doi.org/10.1155/2019/6326138.