A Simulated Evaluation of Energy Consumption Related to the Orientation of a Dwelling in Bahrain

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Abstract

Today, the problem of energy consumption is a major challenge for many countries, especially those with harsh climatic conditions. This is compounded further by the deficiency of knowledge about the effect of the coordinate orientation of houses that can save energy. The energy which can be used inside the dwellings for the air conditioning can be reduced if the designer use the correct orientation for the dwelling itself.

This research aims to simulate the effect of the orientation of a single virtual residential unit located in Bahrain from 0° to 360° with an increment of 15° on energy consumption. The "Eco Designer" program was utilized to calculate the energy evaluation for each dwelling for different orientations.

The research reveals that; 1) The best and the worst orientation for the dwelling's elevation is when it is oriented to face the Southeast with angles (345°, 360°, 0°, and 15° clockwise from the North) and (120°, 135°, and 150° South-East), respectively; 2) The energy consumption is 14692 kWh; 3) The energy consumption per square meter is 102.40 kWh/m^2

Keywords: Simulated energy consumption, energy in dwellings, energy consumption, energy consumption in hot humid zone, hot humid zone.

Introduction

In hot and humid climates, the energy demand is represent half of the used energy in the urban during the peak load. This energy normally is used for supplying the buildings to offer internal comfortable spaces by cooling these spaces, especially during the summertime. "The pressure placed on energy resources to satisfy inhabitants' indoor comfort requirements is mounting due to accelerated urbanization rates in developing countries" (Elnabawi MH.,2021).

Therefore, many studies have to reduce waste by using energy inside the buildings generally (Abanda FH, Byers L.,2016) , and residential units in particular (Ettahir A, Bourass O.2019, Ashmawy; R.E, Azmy NY. ,2018) as they consume the largest energy in the different sectors of the urban fabric of the city. The previous studies have been conducted in different types of climates, and the focus has been on the hot dry climates generally. In this research, areas with cold-dry climates in winter and hot-humid in summer are addressed.

Research Aims

The aim of this research is to reduce the waste of energy by using the necessary electrical energy to adapt the residential buildings during the different seasons of the year in hot-humid areas. The research objectives are:

(1) Studying the effect of the different orientations of the single residential building on the consumption of electrical energy within the residential space.
(2) Finding the best approach to the lowest consumption of electrical energy.
(3) Finding the angles in which the amount of energy consumed inside the individual residential building is changed.

Literature review

Many different studies had been done to reduce the energy consumption in Bahrain and many other countries. Some of these studies try to reduce the energy consumption throw different elements as followings:

- **Reduce the energy consumption by the roof of the building:**

Many previous studies study the effect of the roof on energy consumption for example; the study presented in an international conference "living cool: An approach for architectural COOL ROOF to decrease the electricity consumption in Iraq" (AlNuaimi, S.F. and Mohammed, W.M., 2021,). This study focused on the reducing the energy by using the concept of "cool roof" and fixed all other parameters.

While other study which had been submitted to the "fourth international conference on Engineering and Technology for Sustainable Development in Indonesia". This study studied the best construction material can be used to reduce the energy consumption (Dr. AlNuaimi, S. Fawzi,2022).

A study in Bahrain tried to find the effect of green roof technology to reduce the energy consumption and the bills of the used electricity inside the Bahraini houses, by using the artificial grass on the top of the roof (Al Nuaimi, S.F., 2013). "The concept of unnatural roof garden to reduce energy consumption and electricity bills for houses in Bahrain"

- **Reduce the energy consumption by the Building materials:**

Many studies tried to find the effects of the building materials and finishing on energy consumption, Such as; (Nuaimi, S. and Khamis, A., 2013) "Energy saving in buildings in Bahrain: Suitability of concrete blocks". This study analyzed the effect of building materials for the buildings in Bahrain on energy consumption, and how can be increasing the ability of building insulation by using the concrete block.

A study had been published in an international journal the title of this study was "Thermal Impact of Different Interior Finishing Materials on Energy Consumption in Bahrain" (Al-Nuaimi, S.F., Kh. A. Khamis, 2014). The study analyzed different materials which are using in Bahrain as common finishing materials inside the residential buildings.

- **Reduce the energy consumption by the Building attachments:**

A research titled "Shading Percentage Effects on Energy Consumption for Bahraini Residential Buildings" had been studied the effect of the shading on energy consumption in Bahrain (Al Nuaimi, S.F., 2012). And this study reached for many conclusions, one of these conclusions was as much as the building is shaded the energy will be decrease inside the buildings in Bahrain.

All previous studies analyzed and found the effects of many variables on the energy consumptions, but no one of these previous studies find the effect of building orientation on energy consumption in Bahrain. For that reason this research will use the simulation program to find the effect of building orientation on energy consumption in Bahraini dwellings.

Research Methodology

The research employs a quantitative method that depends on quantitative data collection. These data have been generated through a simulation software program, and have been analyzed by a statistical analysis method to test the relationship between the variables of the research.

The Kingdom of Bahrain was chosen as a study area that represents hot and humid type of climate, as it has a hot-humid climate in summer and is cold-dry in winter. The housing sector in Bahrain was focused on as it represents the largest energy-consuming sector. A previous study had been conducted on the built housing units in Bahrain; these dwellings have been constructed by the Ministry of Housing. The study calculated the models' repetitive in all areas in Bahrain to find the most frequent model to use as a case study. For the purpose of knowing the importance of building orientation, it was necessary to know the result of changing the direction of the simulated building (dwellings) by fixing all variables and changing the orientation only.

The "eco-designer" program has been used to simulate the existing building by creating a virtual one with a real dimension similar to the original. It is a computer simulation program used to know the effect of various variables on the consumed energy inside buildings during the design process. The program was provided with climatic information related to the Kingdom of Bahrain and the elected architectural form. The program was operated starting from the North (0°) direction in a clockwise direction and ending with the (345°) North-west orientation. Each time, the building's orientation (15°) was changed clockwise.

After completing the results of the simulation process for each orientation, which amounted to 24 cases, a change in the consumption of energy was found according to the change of the orientation of the building.

The Simulation Computer Program

"Many simulation programs and tools are available nowadays to aid designers to execute new technologies and evaluate innovative ideas to increase energy savings in their proposed designs. These building energy simulation programs have different features and a range of capabilities" such as the following: (Hong T, Chou S., Bong T.,2000; Rallapalli HS.,2010).

- "General geometry modeling zone internal loads".
- "Building envelope properties".
- "Daylighting and solar infiltration".
- "Ventilation and multi-zone airflow".
- "Renewable energy systems".
- "Electrical systems and equipment".
- "HVAC systems and equipment".
- "Environmental emissions".
- "Economic evaluation".
- "Climate data availability".
- "Results reporting and validation".
- "Calculate the envelope heat gains or loss".
- "Space heat and cooling load".
- "Evaluate indoor thermal conditions".
- "Predict energy performance of buildings and analyze the life cycle costing".

The "Eco-designer" simulation program is an environmental software tool from Autodesk (Kawamoto S, Aoyagi M, Ito Y.,2005),it is software designed to include all environmental criteria as well as technical and economic criteria from the design of the product or service. The software allows designers and urban designers to combine technical quality and environmental quality. Eco-designer allows the designers not only to reduce the environmental impacts but also to better know the designed products and services.

Architectural and urban designs usually joined the design of the project with the existing contextual climate to improve comfort environments. “Today; integration of energy management into the early stages of architectural design, as a function of ecological/sustainable consciousness, is a paradigm of the contemporary architecture and of crucial concern”(Sadeghi P, D. Utzinger M., 2012).

All building variables had been fixed and only orientation is changeable each (15°) for the (360°). Thus, the fixed variables for the designed model are building dimensions, building materials, building function, glazed and solid areas, and building design.

The Climate of Bahrain

“Bahrain is an archipelagic consisting of 33 natural islands and many artificial islands” (The Bahrain Authority for Culture and Antiquities, online report, 2022. Al-Nuaimi, S.F., Mohammed, W.M. and Ismael, N.T., 2019). With a total length of 161 km and an area of 779.95 km², it is the smallest Arab country in terms of area. Bahrain has a hot-humid climate because Bahrain is located near the equator and is surrounded by water. The climate in Bahrain is characterized by hot summers and relatively mild winters. The average air temperature fluctuates between 14°C and 41°C.

There are only two clear seasons: winter runs from November to April and summer lasts for the rest of the year, with January being the coldest month, while the temperature peaks in August. Rain in Bahrain is scarce and irregular and shows high spatial and temporal fluctuations. The average rainfall is about 80 millimeters per year (mm/year), while evaporation exceeds rainfall by more than ten times during the year. The average monthly relative humidity is about 67%, with the average daily maximum ranging from (78%) to (88%). It is also characterized by a high number of hours of brightness, which reaches its highest limit of 12 hours. Winter in Bahrain is characterized by a moderate temperature of about 20.8 °C. Northwesterly winds dominate Bahrain in this season, and sometimes humid and warm southeasterly winds. Rain falls in this season, with an annual average of 74 mm, and the rainfall rate may change from year to year (Al-Zubari WK, El-Sadek AA, Al-Aradi MJ, Al-Mahal HA.,2018).

The Case Study

The research used the Kingdome of Bahrain as a case study to show the results of the building orientation on energy consumption inside the dwellings in hot and humid climate. “Rapidly rising Bahraini population figures, expected to increase by 33% by 2030 compared to 2015” will produce increases in the amount of energy demand in dwellings (Bahrain in 2030 report,2021) “The average amount of electricity consumed by the residential sector between 2010–2018 was 47.9% of all electricity supplied by the country”(F. ANDS. ,2013); “this means that the sector consumed almost half the electricity, while the other half was consumed by three different sectors” (Bahrain Electricity and Water Authority ,2021); Residential 46.9%, commercial 36.6%, industrial 16.1%, agricultural 0.4%.

The ministry of housing in Bahrain has statistics for the number of dwellings that had been built according to several standard models. Each location has a number of standard dwellings with a total unit was 15099 units in more than twenty-five different locations in Bahrain as presented in Table 1.

Table 1: Numbers and locations of dwelling units built in Bahrain by the ministry of housing
Source: (Ministry of housing/ Kingdom of Bahrain, 1999).

NO.	ZONE	DISTRICT	DWELLINGS NUMBER
1	MUHARRAQ AND HIDD	MUHARRAQ	122
2		BUSAYTIN	101
3		ARAD	669
4		HIDD	121
5	UM AL-HASSAM	UM AL-HASSAM	165
6	JIDDHAFS	JIDDHAFS	196
7		SANABIS	178
8		KARRANAH	20
9	NORTHERN REGION	ALDURAZ	40
10		ALBUDAIYA	20
11	SITRA	SITRA	165
12	AALI	A'ALI	740
13	ISA TOWN	ISSA TOWN	4668
14	RIFFA AND SOUTHERN REGION	WEST RIFFA	56
15		EAST RIFFA	1216
16		ASKER	55
17		JAU	46
18		ALDUR	8
19	WESTERN REGION	ALJASSRA	67
20		DUMISTAN	62
21		ALZALLAQ	52
22	HAMAD TOWN	LAWZI DIST.	2012
23		RAWDAH DIST.	1486
24		WADI DIST.	922
25		NUZHA DIST.	1910
26	Total		15099

Previous studies have examined projects' design samples regarding the 15099 houses (Al Nuaimi SF.,2012)). They found the maximum repetitive model in these projects. Afterward calculating all the dwellings units' models "they were 58 different house samples" in all Bahraini districts (Ministry of housing, Bahrain,1999). "The study found that sample number 21 is the most common building sample. Sample number 21 is a building with two floors containing one living room, one hall, three bedrooms, one kitchen, two toilets, one store, a garden, and a garage for one car" as shown in Fig. 1 and Fig. 2 (Nuaimi S.F. Al.,2013).

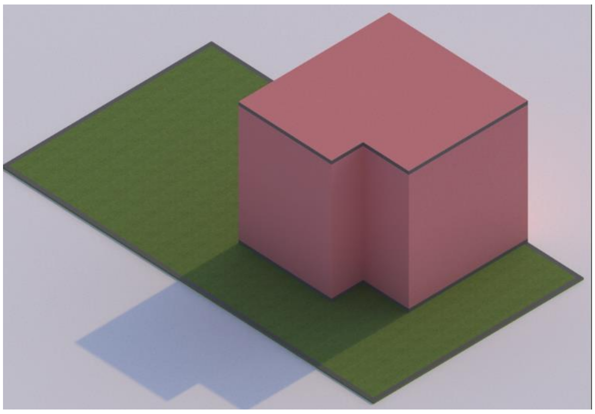
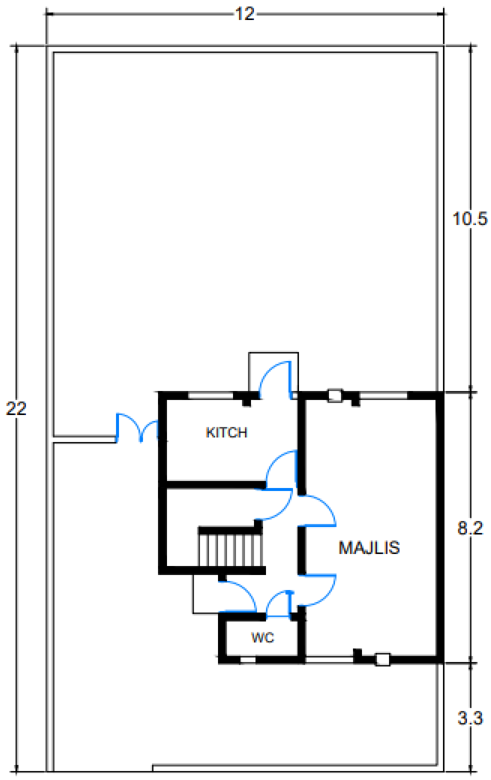


Fig. 1: The shape of the dwelling unit (the sample number 21)
Source: (Al-Nuaimi S., Khamis K., 2014)



(a)

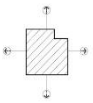
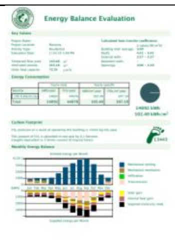
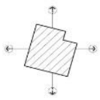
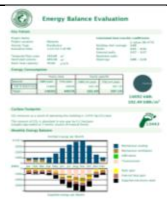
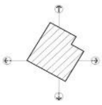
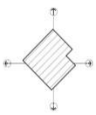
(b)

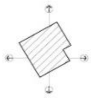
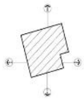
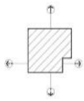
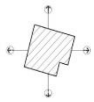
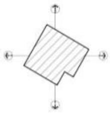
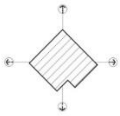
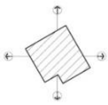
Fig. 2: The (a) ground and (b) first-floor plan for the case study residential building
Source: Al-Nuaimi S.F., Khamis KA., 2013

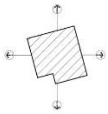
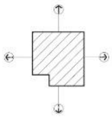
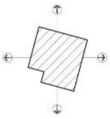
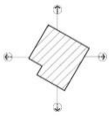
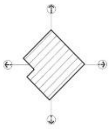
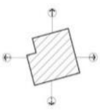
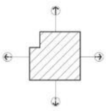
Results

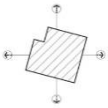
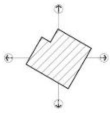
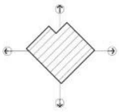
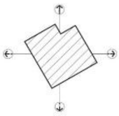
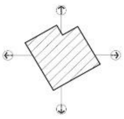
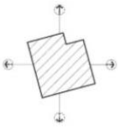
When the program was run, the Table shows the results of energy evaluation for different orientations for the virtual dwelling units simulated by using the simulation program. The dwelling`s orientation varies from 0° until 345° with an increment of 15°. The total yearly energy consumption in kWh and the total yearly energy consumption per square meter are calculated for each orientation. Fig. 3 shows the energy balance evaluation for North or 0o dwelling`s orientation that was calculated by using the Eco-designer program. Energy balance evaluation involves yearly energy consumption, emitted and supply energy in each month, and heat transfer coefficients. Fig. 4 shows the change in total yearly energy consumption in kWh (left y-axis) and total yearly energy consumption per square meter in kWh/m2 (right y-axis) to the orientation of the virtual dwellings. The change in total yearly energy consumption (in kWh and kWh/m2) has the characteristic of a sinusoidal graph.

Table 2: The simulation results of the energy consumption in dwellings units by using the Eco-designer program
Source: Author.

Station	**Orientation**	**Dwelling's Orientation**	**Simulated "Energy evaluation"**	**Total yearly "Energy consumption"**	**Total yearly per square meter**
1.	"North" 0°			14692 kWh	102.40 kWh/m²
2.	"North-East" 15°			14692 KWh	102.40 KWh/m²
3.	"North-East" 30°			21011 KWh	146.44 KWh/m²
4.	"North-East" 45°			21011 KWh	146.44 KWh/m²

5.	"North-East"	60^{o}			21011 KWh	146.44 KWh/m^2
6.	"North-East"	75^{o}			14859 KWh	103.56 KWh/m^2
7.	"East'	90^{o}			14859 KWh	103.56 KWh/m^2
8.	"South-East"	105^{o}			14859 KWh	103.56 KWh/m^2
9.	"South-East"	120^{o}			21076 KWh	146.89 KWh/m^2
10.	"South-East"	135^{o}			21076 KWh	146.89 KWh/m^2
11.	"South-East"	150^{o}			21076 KWh	146.89 KWh/m^2

12.	"South-East"	165°			14969 KWh	104.33 KWh/m^2
13.	"South"	180°			14969 KWh	104.33 KWh/m^2
14.	"South-West"	195°			14969 KWh	104.33 KWh/m^2
15.	"South-West"	210°			21040 KWh	146.64 KWh/m^2
16.	"South-West"	225°			21040 KWh	146.64 KWh/m^2
17.	"South-West"	240°			21040 KWh	146.64 KWh/m^2
18.	"West"	255°			14970 KWh	104.34 KWh/m^2

19.	“North-West”	270°			14970 KWh	104.34 KWh/m^2
20.	“North-West”	285°			14970 KWh	104.34 KWh/m^2
21.	“North-West”	300°			21059 KWh	146.77 KWh/m^2
22.	“North-West”	315°			21059 KWh	146.77 KWh/m^2
23.	“North-West”	330°			21059 KWh	146.77 KWh/m^2
24.	“North-West”	345°			14692 KWh	102.40 KWh/m^2

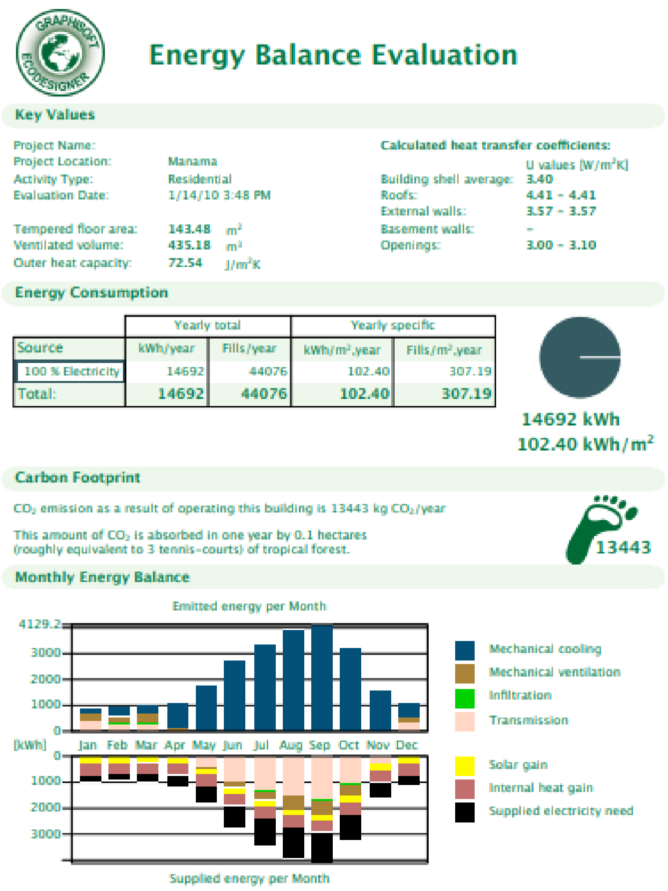


Fig. 3: The energy balance evaluation for North or 0° orientation.
Source: Author.

Discussion

After running the "Eco-Designer program"; all the needed information and environmental data for the uses of the program were fixed for all cases, in order to study the result of changing the orientation of the simulated dwelling unit on the amount of energy used inside it for air-conditioning purposes. The climate of Bahrain was determined and the three-dimensional shape of the block housing unit that represents the most frequent sample among the rest of the housing models used in Bahrain was selected. In addition, the type of activity inside the unit was determined by the residential function, and the building materials and finishes used inside and outside the building were determined.

To determine the outcome of changing the orientation of the dwellings on the energy used for heating and cooling purposes inside the housing unit, the program was run 24 times (at varying angles every 15°) starting from the North direction with a North angle (0°, 360°) and this angle increases every (15°) in a clockwise direction. The results showed that there is an actual change in the amount of energy consumed inside by changing the direction, but these changes are not effective every (45°), meaning that the change will be in eight directions only and that the rest of the changes are almost identical.

As the results showed that the change in the amount of energy consumed in this study case starts from the orientation of the building is at an angle (30° North - east), then it does not change in the angles ((45° and 60°) North - east) after that it changes when the orientation of the building is at an angle (75° North-east) and does not change in the angles ((90°) East and (105°) South-east).

The results also showed a clear discrepancy in the amount of energy spent within the housing unit, and the trend during which the least energy consumed annually was (14,692 kWh) centered around the North (0°, 360°) N, (15°) N.E and (345°) N.W) and the largest amount Total annual energy consumption (21076 kWh) consumed when the building is oriented ((120°, 135°, 150°) South-east). The Figure 4 shows the change in total yearly energy consumption in kWh (left y-axis) and total yearly energy consumption per square meter in kWh/m2 (right y-axis) to the orientation of the virtual dwellings.

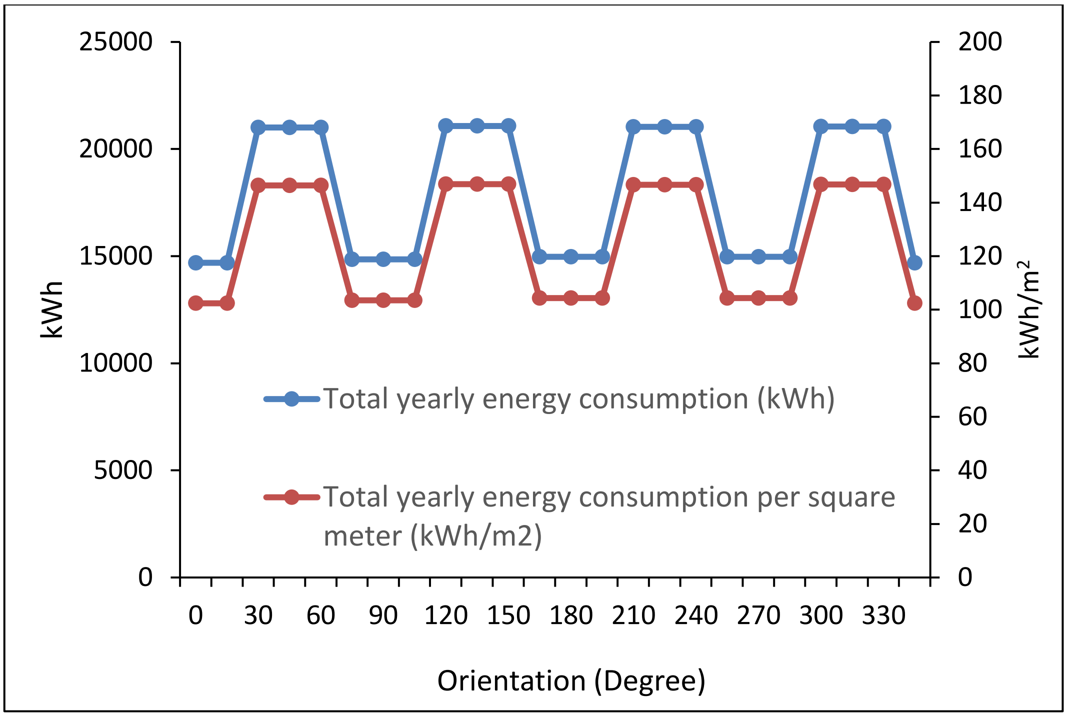


Fig. 4: The change in total yearly energy consumption in kWh (left y-axis) and total yearly energy consumption per square meter in kWh/m^2 (right y-axis) to the orientation of the virtual dwellings (x-axis).
Source: Author.

Conclusions

For the selected virtual dwelling units, with real dimensions which were used in the kingdom of Bahrain; the research reached concluded the following:

- The best orientation for the dwelling's elevation is when it is oriented to face the orientation south-east with angles (345° "North-West"), (360, 0° "North"), and (15° "North-East"). The research calculated the energy consumption and finds the total yearly energy consumption was 14692 kWh and the energy consumption for each square meter is 102.40 kWh/m^2.

- The worst orientation for the dwelling's elevation is South-east with angles (120° "East-South"), (135° "East-South") and (150° "East-South") clockwise from the North). The research calculated the energy consumption and finds the total yearly energy consumption was 21076 kWh and the energy consumption for each square meter is 146.89 kWh/m^2.

- The energy consumption inside the dwellings is changed each 45° starting from the angle (345° north-west).

- The effective building orientations according to energy consumption are changing each (45°) starting from (345° "North-West"), (30° "North-East"), (75° "North-East"), (120° "South-East"), (165° "South-East"), (210° "South-West"), (255°"South-West") and (300° "North-West").

Recommendations

The research makes the following recommendations:

1- The reducing of energy consumption is very important in all sectors especially in houses and villas.
2- The building orientation is very important in decreasing the consumed energy inside the buildings, so; the designer must study the building orientation whenever design a building.
3- The architects, urban designers and urban planner must reduce the energy consumptions in the buildings from the design stage.
4- Future studies must be done for real projects within their real locations in the urban design with the real surroundings, for real reduce in energy consumptions.

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