

Resident Behavior and Activity Pattern Influencing Electrical Consumption in Household Air Conditioners in Tripoli - Libya

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Abstract: Air conditioning systems are essential in the Libyan residential buildings. This study focuses on the resident behavior and activity pattern that affecting electrical consumption related to the air conditioning systems, as part of applying energy efficiency standards and labels program. The data were collected using a questionnaire prepared for this purpose. Questionnaires were distributed on more than 150 families living in Tripoli-Libya, to determine the average number of air conditioners installed in each building, types of air conditioners, operating hours for each type, the average cooling capacity in (Btu/h), as well as the consumption rate during hot months. 103 responses out of 150 were collected and statistically analyzed using Excel sheet, while 10 incomplete responses were rejected. Results showed that more than 31 air conditioning brand names with different manufacturers and sizes are installed. Also, it was found that the average operating hours during the cooling period is 12.9 hours/day, with average annual operating hours for each type is about 1430 hours/year. In terms of air conditioner cooling capacity, the most commonly used air conditioners are with a cooling capacity of 12,000 Btu/h, and about 1926 hours/year. Then the 18,000 Btu/h with about 1880 hours/year. While the lowest used air conditioners are with a cooling capacity of 9000 Btu/h are about 1214 hours per year. It is also evident that the most relatively acquired types are the cheapest air conditioning systems regardless the energy efficiency criteria.

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تأثير سلوك ونشاط السكان على استهلاك الطاقة الكهربائية في أجهزة التكييف المنزلية بمدينة طرابلس - ليبيا

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ملخص: تعد أجهزة تكييف الهواء المنزلية أحد المتطلبات لتلطيف درجات حرارة المساكن المعاصرة، الأمر الذي زاد من اقتناء تلك الأجهزة، وخاصة خلال فصل الصيف. تركز هذه الدراسة على تأثير سلوك ونشاط السكان على استهلاك الكهرباء فيما يتعلق بمكيفات الهواء المنزلية. كما تعتبر هذه الدراسة جزءاً من تطبيق معايير وملصقات كفاءة الطاقة لأجهزة التكييف، والبرامج التوعوية لنشر ثقافة ترشيد استهلاك الطاقة. وقد تم جمع البيانات عن طريق توزيع استبيانات على عدد 150 عائلة داخل نطاق بلدية طرابلس الكبرى، حيث تم تجميع عدد 103 رداً عن الاستبيان واستثناء 10 لعدم اكتمال المعلومات المطلوبة. تم تحليل البيانات باستخدام برنامج (Excel) لتحديد متوسط عدد أجهزة التكييف للمنزل الواحد وأنواع أجهزة التكييف المستخدمة وعدد ساعات التشغيل لكل نوع ومتوسط السعة التبريدية للمكيفات المستخدمة بوحدة التبريد البريطنانية (Btu/h)، وكذلك معدل استهلاك أجهزة التكييف في فصل الصيف. أظهرت نتائج الدراسة أن أكثر من (31) اسماً لشركات مصنعة مختلفة وبأحجام متعددة يتم استخدامها. كما وجد أن متوسط ساعات التشغيل خلال فترة التبريد هو 12.9 ساعة/ يوم. ومتوسط ساعات التشغيل السنوي لكل نوع من الأنواع حوالي 1430 ساعة/سنة. أما عن قدرة المكيف، فإن المكيفات الأكثر استخداماً هي ذات سعة تبريد 12000 Btu/h بحوالي 1926 ساعة/سنة، و 18000 Btu/h بحوالي 1880 ساعة/سنة. بينما الأدنى استخداماً للمكيفات هي ذات سعة التبريد 9000 Btu/h بحوالي 1214 ساعة بالسنة. كما يتضح من خلال النتائج أن أجهزة التكييف المنفصلة الأقل سعراً في أسواق مدينة طرابلس هي الأكثر استخداماً في المباني السكنية.

Keywords: Electric power, domestic sector, air-conditioning.

1. INTRODUCTION

Air conditioning units in hot areas are essential in all dwellings, according to contemporary lifestyle. Air-conditioning is expected to reach 5.6 billion units by 2050, with incomes in emerging market economies more than tripling what it was in 2016 (1.6 billion units) in global cooling electricity demand [1].

The interest of researchers and engineers in the issue of energy use in residential buildings and the possibility of reducing their consumption, where heating, ventilation and air conditioning systems (HVAC) are considered to play an important role in ensuring the comfort of individuals, and it is among the largest energy-consuming equipment electrical in buildings [2].

1.1. Air conditioning situation

In the middle east and north Africa (MENA), for example, residential buildings consume more than 50% of the total energy consumption for air conditioning in State of Kuwait [3]. On the other hand, Tripoli is classified within the hot dry climate, and the energy consumption in the residential sector represents 36% of the total energy consumption, where approximately 50% of it goes for cooling buildings [4].

Optimal operation of the existing air conditioning equipment contributes in reducing the use of air conditioning energy in buildings. Optimal operation can be applied with small modifications in the existing air conditioning systems [5]. To study the electrical consumption of residential air conditioning systems, it is necessary to obtain an accurate usage scheduling description. On this basis, several studies have been conducted, including song's survey and others in 2017 for 10 dwellings in Shanghai, China with continuous measurements [6]. The results of this survey showed that the electricity consumption is mainly influenced by the type of work and lifestyle of occupants, as well as their time in the building. Where the energy consumption on weekdays is significantly different from weekends, to increase the time people are present at home [7]. In addition, Wang and Others, in 2015 developed and analyzed heating ventilation and air conditioning load models, for different types of residential and commercial buildings, using EnergyPlus simulation and analysis software. However, they considered that the HVAC operate electric devices longer period than the residential buildings, representing a high percentage of total energy consumption in buildings [8]. The high summer temperatures and the intensive use of refrigeration and air conditioning has a significant impact on raising the residential electrical consumption, exacerbating the problem of load-throwing during the cooling period, and it is important to use high-efficiency air conditioners to reduce electricity consumption [9].

Vakiloroaya et al., in 2014 reviewed and demonstrated several different techniques and methods that improve the performance of heating, ventilation and air conditioning systems (HVAC) in order to reduce energy consumption. Where reducing energy consumption of heating, ventilation and air conditioning systems became increasingly important due to the high cost of fossil fuels and environmental concerns [2].

Maguoz, in 2019 studied the impact of the use of high-efficiency air conditioners by applying the energy efficiency standards and labels to reduce the electricity consumption in Libyan buildings and reducing electrical bill. [9]. Also Alabani and Tawil, in 2019 showed that the study on the possibility of applying energy efficiency standards and labels programs for domestic air conditioning devices in Libya, Where a 10-year strategic plan was developed during 2020-2030 to estimate the expected savings in energy consumption with increasing the energy efficiency of household air conditioners [10].

1.2. Energy consumption situation in Libya

In Libya, the energy sector witnessed an increasing growth during the period from 2003 to 2010, where the produced energy in gigawatt-hours (GWh) in 2003 was about 18,943 GWh, and it rose to 32,558 GWh in 2010, and it was The percentage increase in the last year between 2009 and 2010 to 7.2%, as energy production increased from 30,337 GWh in 2009 to 32,558 GWh in 2010, and the energy sold was about 20,602,217 GWh. 43% of this energy was produced by gas stations, 37% from dual-cycle plants, and 20% from steam plants [11].

The residential sector is considered as one of the most important and largest sectors consuming electrical energy in Libya. The percentage of consumption in this sector reached about 31% of the total energy sold for the year 2010 as shown in Figure (1). The consumption of this energy is often through electrical appliances and household. According to the distribution of energy consumption of the residential sector in Libya shown in Figure (2), domestic air conditioners consume about 18.35% of the total energy consumed in the sector [12]. This occupies the second in terms of residential consumption after lighting and which is relatively large. As most homes in Libya contain air conditioners that are operated for long periods during summer time. Also, it is difficult to schedule its operation automatically, with low settings of thermostat in the air conditioner. As this causes the compressor to work continuously with no stopping, consequently leads to high rate of energy consumption.

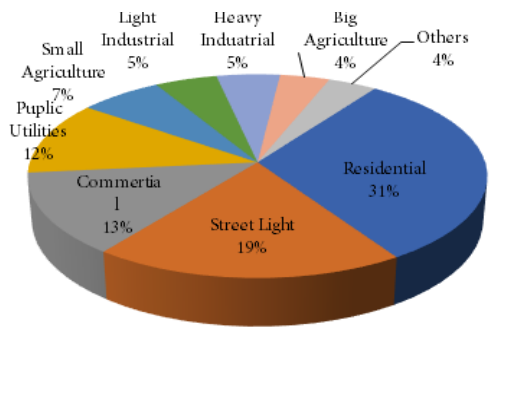


Figure (1). Distribution of electricity sold in Libya [11].

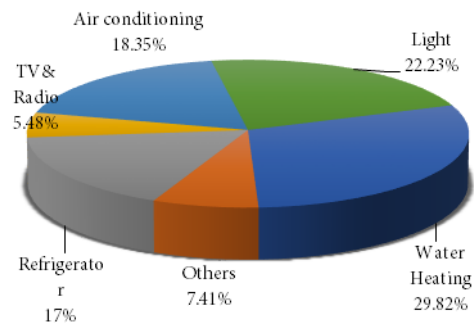


Figure (2). Distribution of electricity by domestic use in Libya [12].

1.3. Energy efficiency standards

Human welfare increases with the use of electrical devices including air conditioning, which resulted in a steady increase in electrical energy consumption. Hence, it is necessary for energy specialists to think about ways and find solutions to reduce the energy consumption of these devices without affecting their actual performance. One of these solutions, is the application of energy efficiency standards and labels programs for electrical appliances, including air conditioning, which has been applied in many countries of the world.

Energy efficiency standards and labels are used to reduce the energy requirements of new devices, this is done by reducing the demand for low-efficiency devices in the market, by choosing relatively more efficient devices [13]. These programs set standards and labels for each product. With this, the minimum standards allowed for the product to enter the market and provide the necessary information on energy performance and energy efficiency benefits in the label and place it on the product to help the consumer make the right choice when buying, by comparing the cost of purchasing the product with the savings resulting from the application of energy efficiency standards for the product in the long run the long.

These programs are more effective when developed in the form of a national program or a comprehensive plan at the level of state institutions, and under the supervision of decision-makers in the state. This program has proven effective in raising the energy efficiency of electrical appliances and reducing their energy consumption in many of these countries. According to the 2012 World Energy Council (WEC) survey, air conditioner labels are mandatory in 52 countries (2/3 of the assessed countries) and planned in 10 countries, while Libya is not included for this survey [14].

Despite the importance of these programs in reducing energy consumption, especially with the shortage of energy supplies and the significant expansion of the use of such devices in Libyan society, and the role of these programs in reducing energy consumption in general and in the residential sector in particular, the application of such programs in Libya is still early. due to the lack of minimum control over the entry of these devices in terms of their energy efficiency, the lack of application of laws relating to the specifications of imported electrical devices, and the lack of awareness in the Libyan society of the importance of rationalizing energy consumption by choosing the most efficient products in the market increases the difficulty of implementing these programs. Also, the randomness of the electrical appliances market in Libya and the failure to determine the cost of increasing the cost in introducing the energy efficiency feature of these devices is one of the important matters that must be studied in order to design a successful

standards and posters program. The following are several procedures that consumers should follow when purchasing air conditioners, which are [14]:

- a. Make sure the air conditioner has an energy efficiency sticker, and that it's highly efficient.
- b. The higher the energy efficiency level on the card to the green leads to more efficient the device's electricity consumption.
- c. Choose the right cooling capacities for room size. So, more air conditioner capacity is more than needed, leads to more waste of energy consumed.

The application of energy consumption rationalization measures is also a behavior that results in saving and reducing the amount of energy consumption. This can be achieved through the behavioral and operational practices of the population, one of the most important measures that contribute to reducing energy consumption during use and after the purchase of the appropriate air conditioner, as well as in old devices installed without taking into account the efficiency of the product:

- a. Setting the air conditioner temperature at (24°C) as the optimum temperature for convenient cooling.
- b. Turn off the air conditioner when you leave.
- c. Clean the air conditioner filter every two weeks.
- d. Windows and doors are closed when the air conditioner is turned on.
- e. The technologies and equipment that increase energy efficiency and reduce consumption can also be used, such as (AIRCOSAVER), which reduces energy consumption by about 30%, according to the manufacturer [15].

2. METHODOLOGY

This study aims to investigate the pattern and rates of usage for residential air conditioners. The study is on hot months (from April to the November) including operating hours for each type, where maximum air temperatures in Tripoli ranges from 43 °C to 47°C [16]. These rates will be used in estimating the energy consumption and developing plans for energy savings by applying energy efficiency standards and labels for air conditioning systems. Developed plans can contribute in preparing beneficial specifications that control the Libyan market, in terms of importing high-efficiency air conditioning units. Moreover, application of plans will spread the culture of energy consumption rationalization.

A questionnaire was designed and distributed to be filled by occupants of residential buildings within Tripoli city. Data was collected for air conditioning units traded in Libyan market. In terms of determining:

1. The average number of air conditioning unit per dwelling.
2. Types and rate of usage for air conditioning systems in the Libyan market.
3. The brands of air conditioning units used.
4. Average capacity of the air conditioning units used, in the British refrigeration unit (Btu/h).
5. Area of residential buildings using air conditioning units.

Questionnaires were distributed electronically and hard copied to 150 residents in Tripoli city. 113 responses were received, 10 responses out of 113 were rejected as required information were incomplete, and 103 responses were analyzed using excel sheet.

3. Results

3.1. Average number of air conditioners per house

Figure (3) shows the percentage and number of air conditioners used, as follows: (36%) owns

one air conditioner, (33%) owns 2 air conditioners, (14%) owns 3 air conditioners, (7%) owns 4 air conditioners, (5%) owns 5 air conditioners and (4%) owns 6. While average of installed air conditioners are 2 to 3 air conditioners per house.

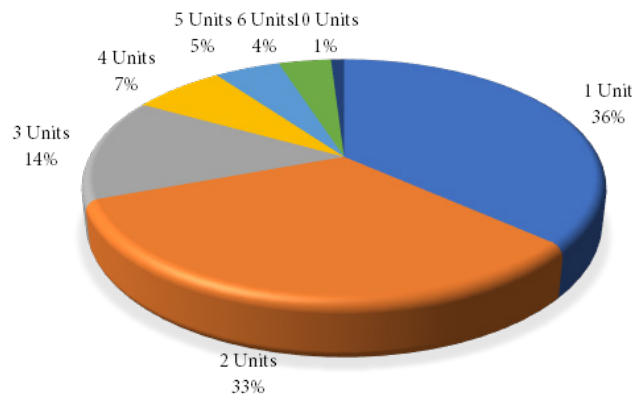


Figure (3). The percentage of ownership of air conditioners (AC).

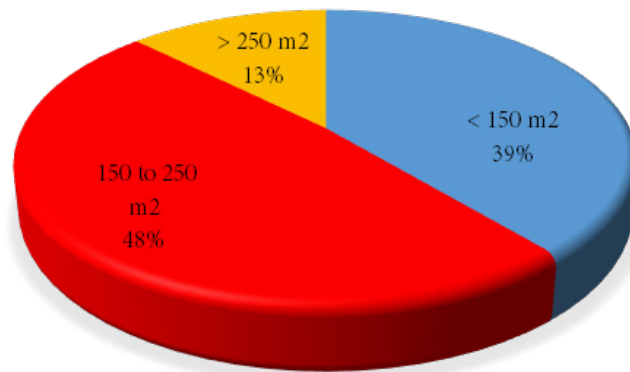


Figure (4). The houses area in Tripoli city.

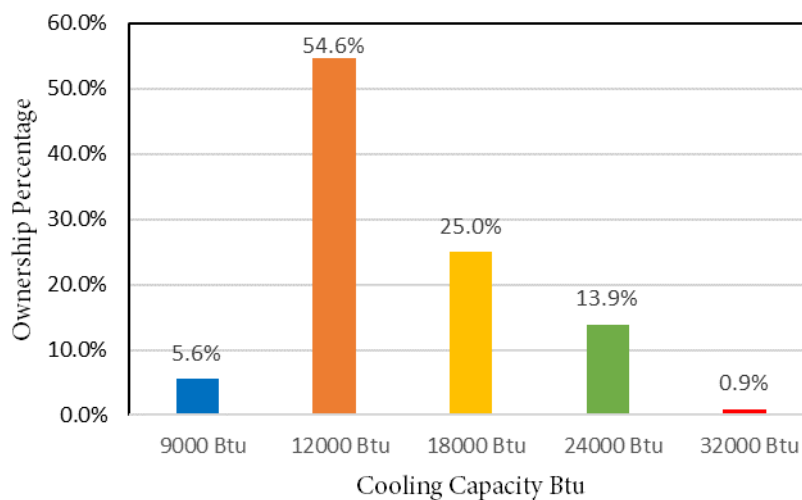


Figure (5). The percentage of air conditioners used according to cooling capacity.

Figure (4) shows that 39 % of houses area are less than 150 m² and 48.5% of houses are ranged between 150 to 250 m². While 13% are the houses with an area of more than 250 m².

Hence, more than one air conditioner is needed to cover the cooling load during cooling

period for all houses.

Figure (5), shows the higher usage of air conditioning systems by dwelling according to the cooling capacity are 12000 Btu and 18000 Btu, with usage percentages of about 54.6% and 25, respectively. While the lowest are 32000 Btu and 9000 Btu, with usage percentages of about 0.9% and 5.6%, respectively.

3.2. Types of air conditioners used

Figure (6) shows the higher used types of air conditioning units imported from different manufacturers and capacities. Whereas, only air conditioners with 1% and more were mentioned from more than 31 brand names collected by the questionnaires.

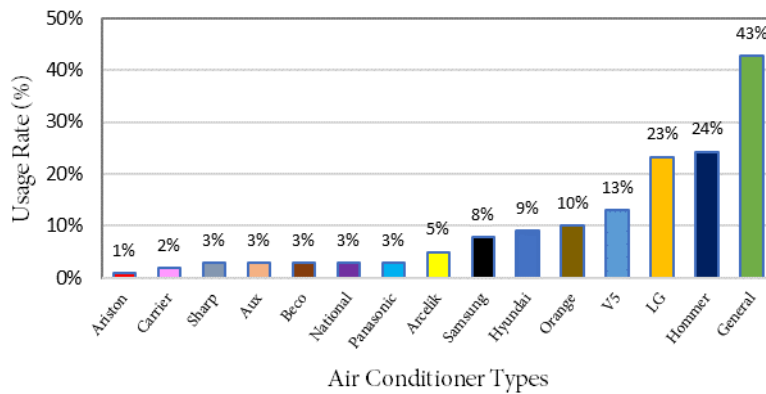


Figure (6). The most commonly used air conditioners and the percentage of use per type.

From Figure (6), it is obvious that, GENERAL, HOMMER and LG are the most air conditioners used by the Libyan houses among the types listed with percentages of about 44%, 24% and 23%, respectively. While the lowest least air conditioner used are ARISTON and Other types with a percentage 1% and less.

Table (1) shows the cost of air conditioners for each type sorted by capacity unit (Btu/h). It is obvious that the cost of most used air conditioners, with capacity of (Btu 12000) ranges from 1,125 to 2,000 Libyan Dinar (L.D).

Table (1). Air conditioner prices by Tripoli market.

Air conditioner type	Country of manufacture	Price D.L.	
		12000 Btu	18000 Btu
General	China	1200	1700
V5		1500	2200
ORANGE		1125	1600
AUX		1300	1950
HOMMER		1750	2450
LG	South Korea	1950	2760
SAMSUNG		1750	2400
ARCELIK	Turkey	1370	2750
BEKO		1370	2750
PANASONIC	Japan	2000	3000

While air conditioners with capacity of (Btu 18000), ranges from 1,600 to 3,000 L.D. Also,

the lower the air conditioner cost, the more installed air conditioner in the Libyan house. This indicates that efficiency is not one of the criteria in the Libyan market, consequently not a priority for the importer rather than the lower cost for the buyer. The efficiency standards that achieve highest reduction in electricity consumption and higher economic is not considered, when choosing air conditioners. This is as a result of lower cost of air conditioner with lower efficiency and low electricity prices in Libya. Raising the efficiency of devices requires a higher primary cost as a result of development and improvement that make air conditioners operate with the lowest possible electric power and higher performance factor. Results have shown that the lowest-priced types in the Tripoli market are the most acquired.

3.3. Average daily operating hours

Figure (7). shows the average daily operating hours of air conditioners from April to November. The average daily operating hours are about 13 hours/day, and the highest operating time is in August, with about 18.5 hours/day, and the lowest operating time is in April, with about 6.8 hours/day.

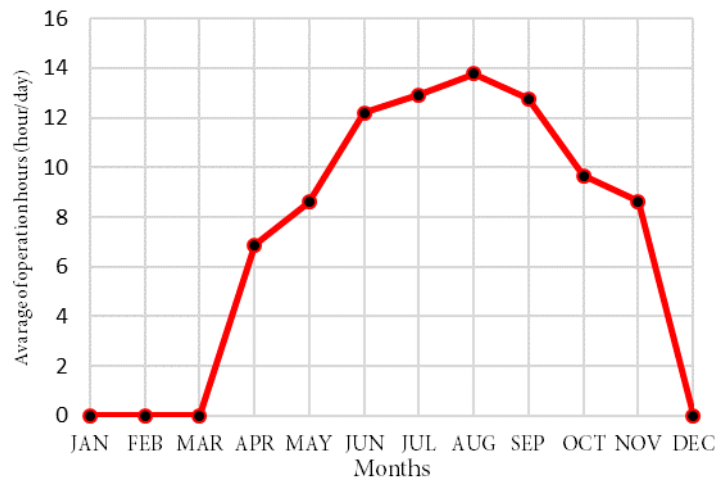


Figure (7). Average daily air conditioners operating hours per month.

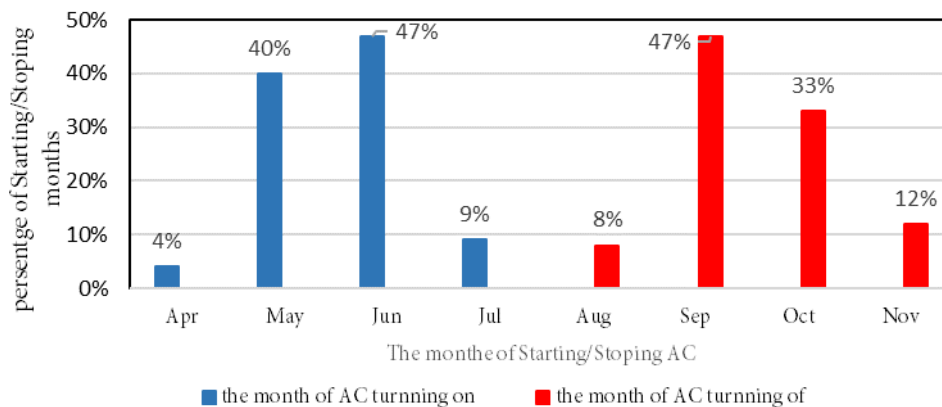


Figure (8). The behavior of families in choosing the cooling period.

Figure (8) shows residents' behavior of when air conditioners are turned on and off. Results showed families start using cooling from April to July, where most of families, start using cooling in May and June with percentages of 40% and 47%, respectively. While turning off air conditioners starts from the end of from August to November, and most of family's end cooling in September and October percentages of 47% and 33%, respectively. This affects the cooling period from one family to another, as their cooling period varies from 2 to 8. months, and an average of 4.9 months per year. The increase in operating hours of air conditioners leads to an increase in the consumption of electrical energy, according to the relatively high temperatures in the summer, that tend people to use air conditioners. Also, 50.1 % families set the cooling temperature to 24 °C, which is good to contribute in reducing energy consumption during use.

Start operating some of these devices varies between families, as some of them start operating the air conditioner on cooling mode from April until November in which the temperatures are relatively higher than the rest of the months.

3.4. Annual average operating hours

Figure (9) shows the average annual operating hours, for each type of air conditioners, as the highest annual operating hours for air conditioners were for AUX type, followed by HOMMER and then BEKO with average operating hours of 2440, 2360 and 2230, respectively.

The lowest operating rate recorded among the types of air conditioners was for ARBIA, SHARP and VESTEL, with annual operating hours of 153, 245 and 277, respectively. On the other hand, the average operating hours for all types installed was about 1430.

Figure (10) shows that the average annual operating hours according to the cooling capacity of the air conditioner (from 9000 to 32000 Btu/h). The highest average annual operating hours are for the air conditioners

capacity of 12000 Btu/h and 18000 Btu/h with 1926 and 1880 hours respectively, while the lowest operating hours are for air conditioners with a cooling capacity of 9000 Btu/h is 1214 hours per year.

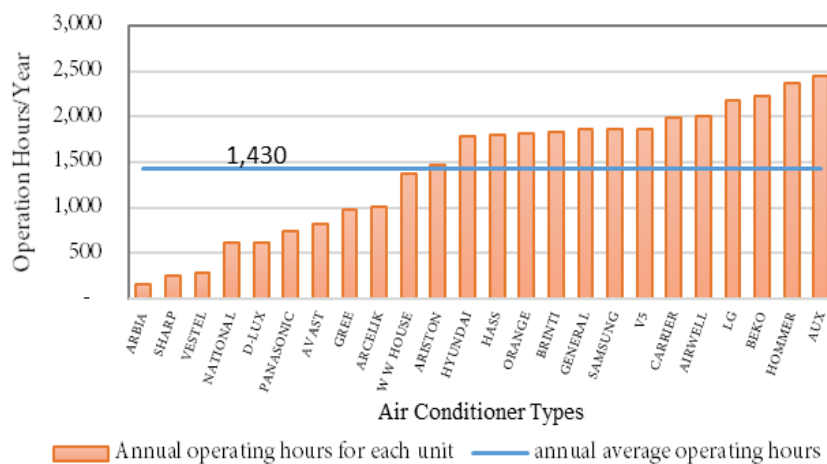


Figure (9). The number of operating hours during the cooling period for each type of device.

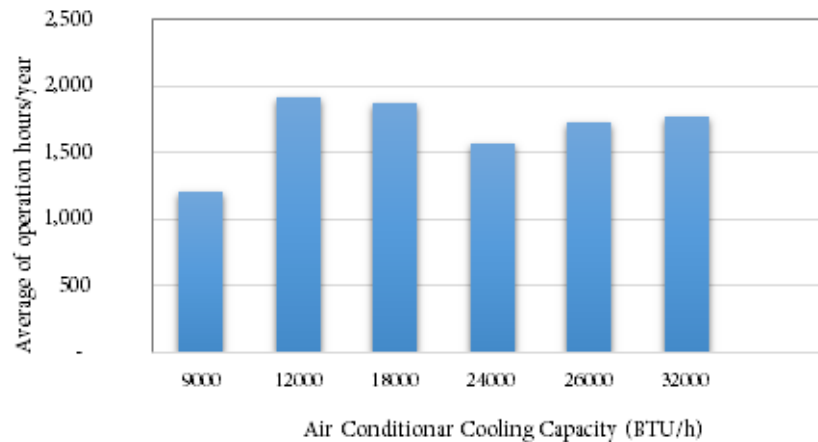


Figure (10). Average of annual operating hours by air conditioner capacity.

4. CONCLUSION

This study collects data on residential air conditioning systems. Data collected by distributing questionnaires for 150 dwellings within Tripoli city. Collected data should determine the average of air conditioners used per house, types of air conditioners, operating hours for each type, and the average capacity of air conditioners, in the British Refrigeration Unit (GMT/hours).

From data collected and analyzed, it was found that there are various manufacturers of air conditioners with different sizes installed in the targeted housing in Tripoli-Libya. Results showed that (General), (LG) and (HOMMER) brands had the highest percentage of usage with 44%, 24% and 23% respectively. In comparison, the lowest percentage of equal use among several types were (ARISTON) to (CARRIER), with a percentage of (1%) and (2%) respectively. The average operating hours during the four cooling period were 12.9 hours/day. The highest operating time was about 18.3 hours/day in August, while the lowest operating time was 6.8 hours/day in April. The highest annual operating hours according to the type of air conditioner were for AUX, followed by HOMMER and BEKO, with an average operating hour of 2440, 2360 and 2230, respectively. On the other hand, the lowest operating hours for air conditioners were for ARBIA, SHARP and VESTEL, with operating hours of 153, 245 and 277 hours, respectively. Also, the average operating hours for all types were about 1430 hours. In terms of air conditioner capacity, the most commonly used air conditioners were with a capacity of 12000 Btu/h and 18000 Btu/h with 1926 and 1880 hours respectively, while the lowest operating hours were for air conditioners with a capacity of 9000 Btu/h is 1214 hours per year.

The study also showed that the lower air conditioners cost of housing-based types was the most installed in the Libyan house. This related to the efficiency that is not one of the criteria in the Libyan market, consequently not a priority for the importer, rather than the cost of air conditioner. In order to reduce electricity consumption, executives should follow programs that urge the development and restrict the supply of low-efficient air conditioners that imported without labels indicating energy efficiency standards. Also, the behavioral and operational practices of consumer, will contribute to reducing energy consumption during operation. Consequently, it is important to educate the consumer about the proper choice of air conditioners according to economic and environmental basis.

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