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ORIGINAL ARTICLE

Analysis of energy consumption for residential building- A case study in Libya

Abdusalam Yehmed Alafya[1] · **Ali O. M. Maka**[2]

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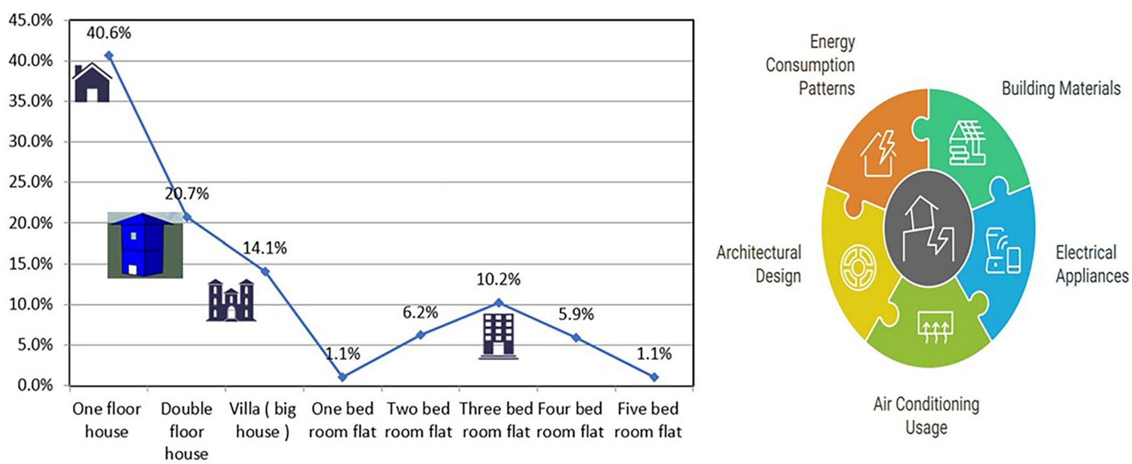
Abstract

An energy-efficient building maximises the utilisation of resources by providing comfortable living conditions to occupancy inside; while consuming the lowest amount of energy required. Building materials and electrical appliances used in a structure affect how power is consumed; hence, a building's characteristics are essential for further development. Notwithstanding, throughout the year, either in cold or hot weather, buildings are designed to provide comfort for their residents. Households in Libya turn on their air conditioning throughout the day to decrease the impact of the summertime weather, so the rise of temperature. That significantly demands more energy from the grid, and during peak energy demand might cause a deficiency in power generation. In residential houses, air conditioning units consume a large volume of Libya's electricity consumption, approximately 36% of the total electricity generated. Therefore, to obtain an overview of the amount of power required for cooling in Libyan homes; an investigation was created with an emphasis on air conditioning usage, followed by modelling of energy consumption. This work aims to minimise the amount of electricity required from a design perspective. It used surveys and modelling to determine the cooling requirements of different types of architectural buildings (ABs). Besides, the investigation indicated there is a substantial excessive waste of energy in the dwelling when using air conditioning units (ACUs). The analysis deduced consumption patterns of Libyan households are high in electricity, whereas approximately 40.6% of the respondents live in a one-floor house, which needs further consideration. At the same time, it addresses the challenges of electricity demand from the architectural viewpoint.

Graphical abstract



Keywords Libyan homes · Energy consumption · Load profile · Occupancy behaviour · Modelling and analysis

Abbreviations

AC	Air Conditions
ACUs	Air Conditioning Units

Extended author information available on the last page of the article

Al	Aluminium
Abs	Architectural Buildings
DHW	Domestic Hot Water
IES-VE	Integrated Environmental Solutions-Virtual Environment
EC	Energy Consumption
GECOL	General Electrical Company of Libya
HVAC	Heating Ventilating Air Conditioning
MICS	Multi-Indicator Cluster Survey
STD	Standard Division
MAE	Mean Absolute Error
LDs	Libyan Dwellings
LPM	Load Profile Model
PVC	Polyvinyl Chloride
PD	Peak Demand
RB	Residential Building
RMSE	Root Mean Square Error
HEB	Household Energy Behaviour
HED	High Energy Demand
LCBEs	Libya Construction Building Envelopes
TLH	Typical Libyan House
OB	Occupants Behaviour
UNs	United Nations

1 Introduction

Energy in houses is fundamental for used in numerous functions, hence used for heating and cooling, powering appliances and electronics, etc. Therefore, understanding how energy can be consumed and conserved in a home is vital to assist you in managing costs and reducing environmental impact [1, 2]. A significant amount of the globe's energy needs is provided to household energy consumption, which is important to the whole energy environment [2, 3]. By making strategies can be leveraged by decreasing energy bills, reducing carbon footprint, and creating a further sustainable home [4]. Also, energy demonstrating is mainly employed for supportive knowledgeable decision-making. Energy can contribute to a better understanding of energy use and the main parameters that affect consumption within a built environment [5].

In Libya, conventional buildings provide a comparatively comfortable temperature during the winter, especially during the summer season. These buildings have a high thermal capacity and are naturally ventilated. They have a courtyard available to them. However, "modern" construction is developing quickly these days, and the buildings' thermal quality is neglected. Since there aren't enough rules in place, the majority of modern structures lack thermal insulation and have extremely poor air tightness [6]. The electricity/energy sector in Libya, similar to other countries, energy is crucial to the countries for social and economic well-being. Electricity is a vital energy source since it covers people's needs between fulfilling energy requirements and attaining progress from the viewpoint of productive processes [7, 8]. In order to decrease peak demand (PD) in the building, however, architects, engineers, and designers can collaborate to achieve this by carefully choosing architectural specifications and component sizes [9].

In many countries, including the Middle East, parts of Africa, and the United States, to name a few; hence, cooling can be responsible for more than 70% of the peak household

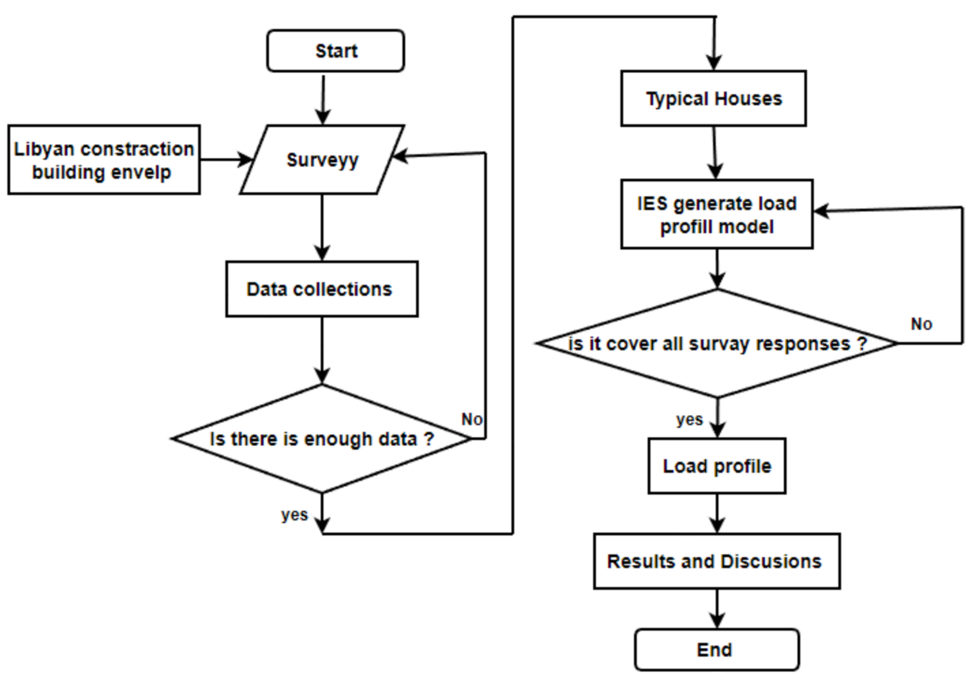


Fig. 1 Flow chart of research methodology

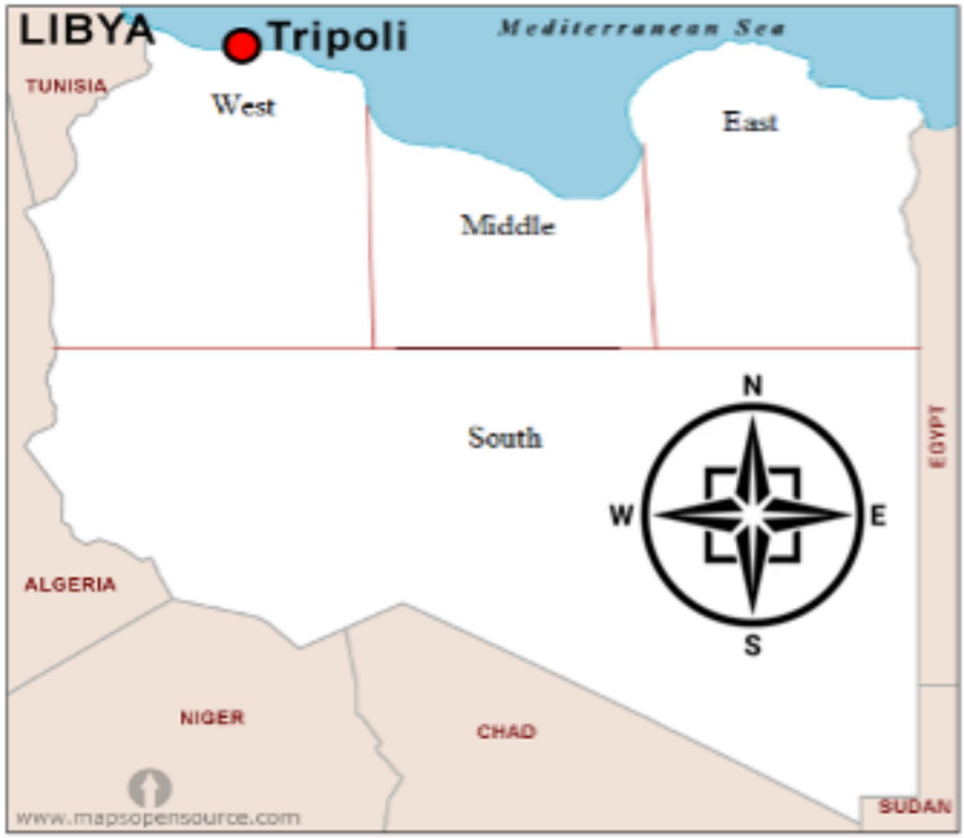


Fig. 2 Map of Libya and the four regions considered west, middle, east and south reigns

electricity consumption on especially hot days. Increasing AC loads into effect extra strain on the electrical system and necessitates more electricity production and transmission capacity to meet peak demand (PD) as well as higher total electricity needs [10]. It is worth noting that the Libyan electricity consumption data of residential buildings (RB) is estimated to consume more than 36% of the generated electricity yearly [11–14]. Thus, that value is relatively high and requires more investigation, subsequently recommending an appropriate solution and feasible to save money used in the expansion of building other electricity sources.

According to the results of research done by Alghoul et al. [15]; hence, various industries use electricity in Libya, including residential, commercial, industrial, street lighting, and agriculture. It's deduced that the housing sector is the largest portion of these sectors, about 32%, followed by the industrial sector, approximately 21%. Elsahati et al. [16] investigated the demand for electricity in Libya, which is classified by the type of user, such as residential and agricultural. Nonetheless, several essential factors that impact demand, such as variable weather patterns, building infrastructure, and (HVAC) systems, are neglected. Numerous studies are being conducted on heating, ventilation, and air conditioning (HVAC) components, to determine at different (HVAC) systems, how much energy they use, as well as how to simulate and model it.

Mohamed et al. [17] examined domestic energy usage and household energy behaviour (HEB) in Libya. Based on a survey of households, the study underscores the possibility of decreasing energy consumption by enhancing household behaviour and using extra-efficient appliances. It deduced that public outreach efforts by the government

Table 1 Compares the Libyan type of dwelling in the current study questionnaire and MICS report

MICS report [23]		Current study		
Type of building	Percentage	Type of building	Percentage	STD
Villa or modern house	17.3%	Villa or modern house	14.1%	1.6
Regular house	65.5%	Regular house	61.3%	2.1
Flat	14.3%	Flat	24.5%	0.1
Other*	3%	Other	–	–

*The different types of domestic buildings

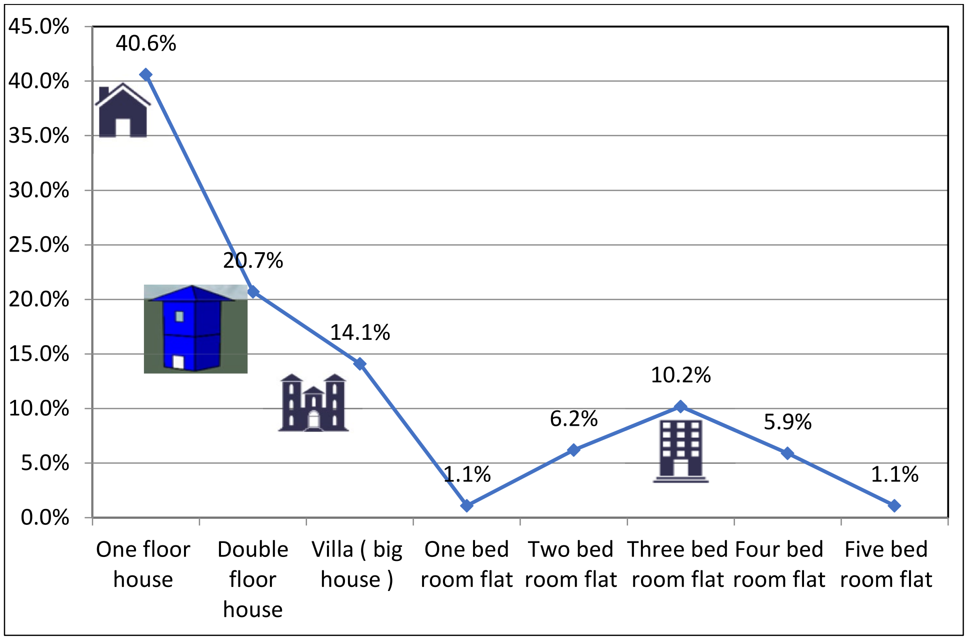


Fig. 3 Distribution of Libyan living buildings

and local communities in regard to ways to conserve energy could potentially reduce the growing demand for resources for energy. The study by El Bakkush [18] used a tool called integrated environmental solutions-virtual environment (IES-VE). To investigate the thermal performance of the building in various configurations, taking into account changes to the building's orientation, construction materials and fenestration. Remarkably, it emphasises the necessity of considering energy efficiency and the environment when designing buildings, especially in areas with harsh climates such as Libya. Another research study by Ndiaye and Gabrielb [19] analyses electricity consumption in residential dwellings. Therefore, nine variables were considered, including the house status (owned or rented), the number of occupants, the average weeks of vacation annually, the type of fuel used for the heating system, and the type of fuel utilised in the pool heater. Also, the type of fuel used to heat the domestic hot water, the type of air conditioning system, the available or not of an air conditioning system, and the number of hours of air changes. The consequence was that the above mentioned variables were essential to optimal the electricity consumption better. A study by Zaho et al. [20] incorporated the collection of data, case studies, statistical analysis and modelling approach; hence, to explore the complex interactions between resident behaviour and building technology concerning energy consumption. It underscores the significance of resident behaviour and building technology in determining energy usage patterns, advocating for a holistic method to energy efficiency in residential buildings. In another study by Ndiaye [6] a mixed-methods technique was used in the study, mixing qualitative interviews with quantitative questionnaires. The key objective of the thermal comfort study is to evaluate the thermal comfort of conventional homes in Libya. Hence, thermal comfort norms for Libya indicate the potential to reduce energy consumption in the upcoming home compared to the modern home in each of the country's three climate zones, using roughly 80% less energy in wintertime and 60% less in summertime. Research conducted by Mora et al. [21] assessed residential energy usage, concentrating on the function of occupancy profiles in energy and considering domestic hot water (DHW) and heating. However, the study aims to understand how occupancy profiles influence energy consumption in residential buildings, particularly in Mediterranean climatic conditions. The outcomes have deduced a significant reliance on DWH and heating on energy consumption.

Based on the aforementioned literature, we elicit that further analysis needs to be carried out in Libyan electricity computation dwellings to comprehend the high energy demand and find convenient solutions. Understanding people who deal with energy inside their houses leads to proper planning in design and construction. Hence, the ACUs are used widely to cool the building from the heat. Indeed, this reflects more energy demand from the national grid at peak load. Thus, it is worthwhile to consider how these attributes affect general energy usage and demand in Libya and whether they can be enhanced.

It is worth noting that the metrological environment in Libya is hot in the summer, particularly in the country's south reign and along the coast, where humidity levels are high. That required to use AC unit to cool down the condition inside the building. In contrast, the winter season is cold and requires heating conditions inside the building. The heating of Libyan houses/buildings is usually either AC or

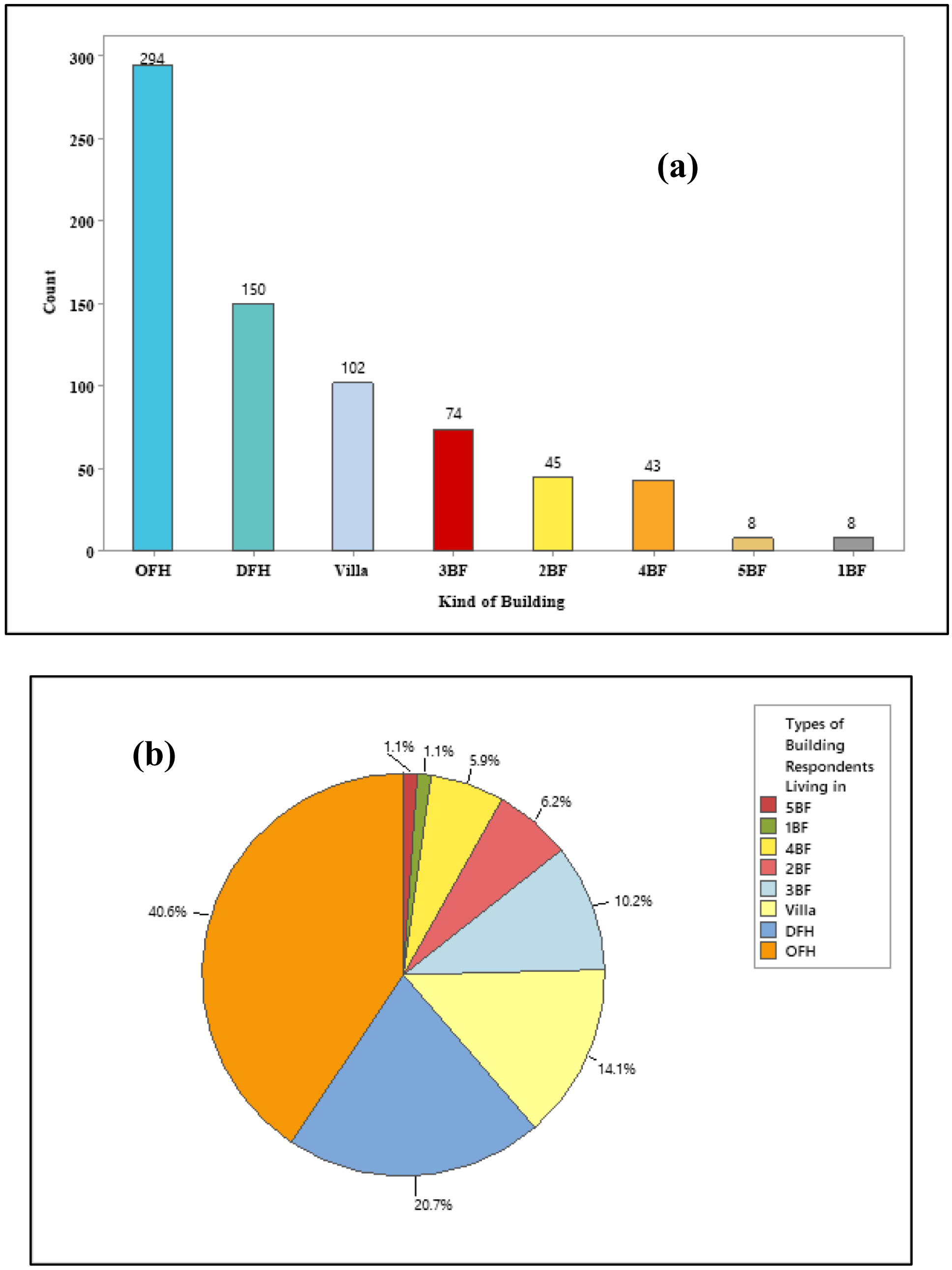


Fig. 4 Building type usually inhabitants live in, **a** type of building with the number of respondents, **b** percentage of sample buildings

electrical heater unit. The significance of this study is to assist various stakeholders, i.e., general electrical company of Libya (GECOL) as the supplier, the government as policy maker and inhabitants as energy users. However, in developing strategies to ensure that building materials for obtainable and planned schemes are conscious of the influence on cooling loads where, user comfort, and subsequent peak electricity demands. It is to investigate the relationship between the Libyan residential sector's peak load and air-conditioning. Also, to investigate the energy consumption profile of typical residential buildings in Libya. In doing so, we considered both survey and IES-VE modelling software tools to be used to achieve the goal of this study. This study basically consists of six key sections. Therefore, it commences with an introduction section summarising the background of Libyan energy consumption of residential buildings. The methodology and work steps are details and narrated modelling approach in the second Section. The validation of comparing the results with another result is presented in Section Three. Section Four contains the outcome/results and discussions that analysed the modelling and survey. Finally, the summaries of conclusions and outlines of future works are in section five.

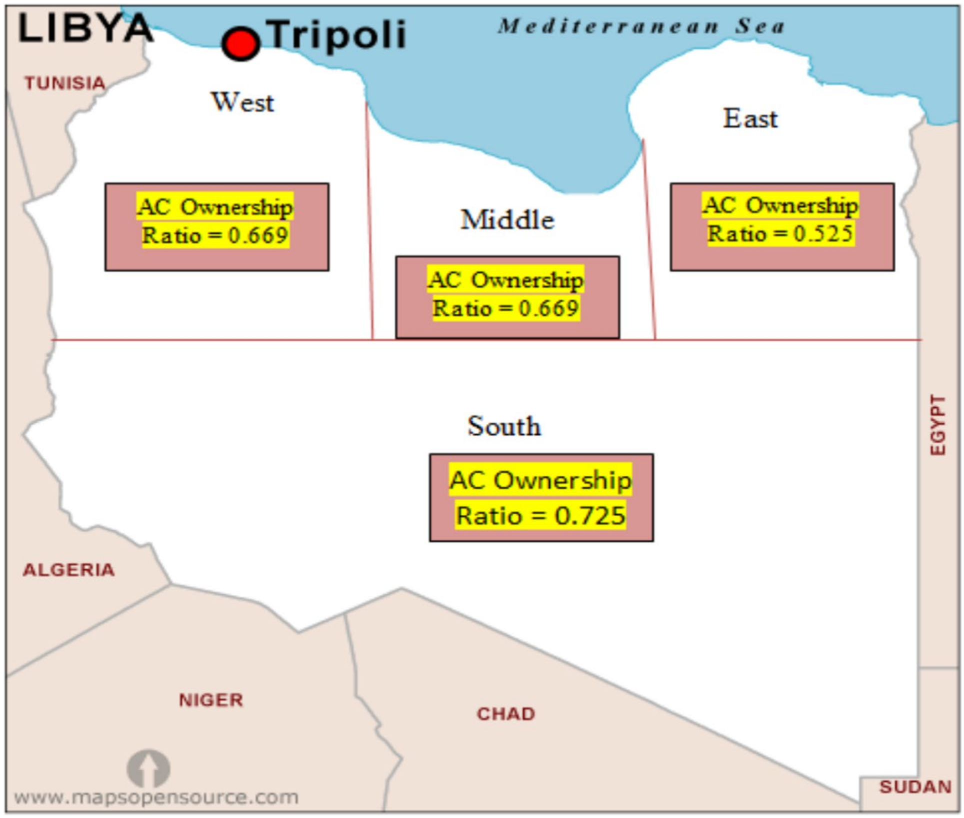


Fig. 5 Overall AC Ownership for each region of Libya

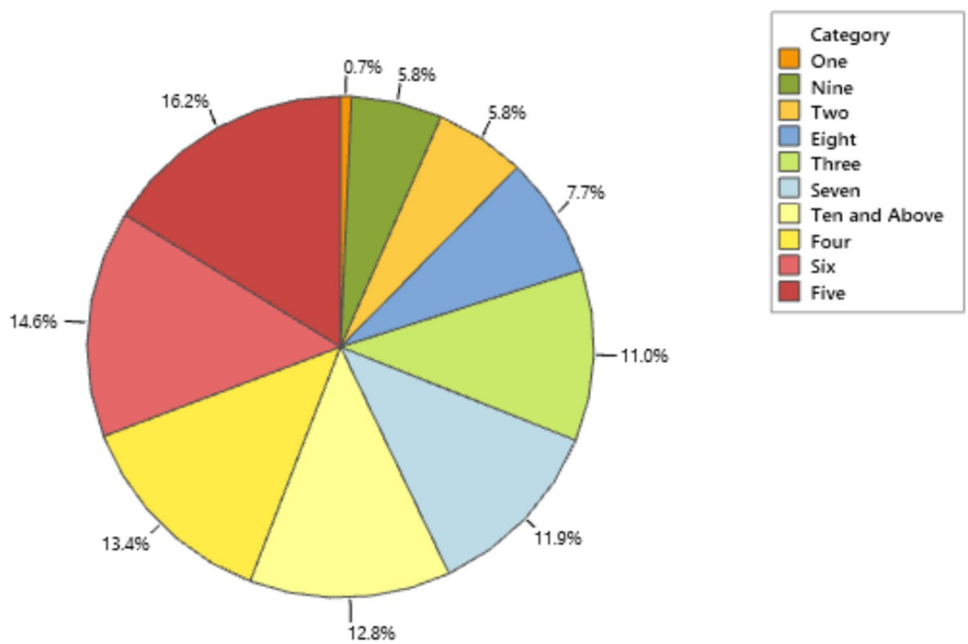


Fig. 6 The percentage of occupants living in the sample's property

2 Methodology

This work commenced by designing a survey of building householders based on Libyan construction building envelopes (BEs). To explore the high energy demand (HED), the survey was distributed online to cover all of the Libyan territory, to obtain the reasons behind this demand and try to find a solution. The behaviour of occupancy and reply came from all

Table 2 Details the number of people in a specific type of building

No of People	One	Two	Three	Four	Five	Six	Seven	Eight	Nine	≥ Ten	Total
One floor house	3	19	32	45	57	44	31	25	10	28	294
Double floor house	1	1	6	7	24	26	22	13	21	29	150
One bedroom flat	–	1	1	1	2	–	–	1	2	–	8
Two-bedroom flat	–	6	15	10	8	2	3	–	–	1	45
Three-bedroom flat	–	10	16	20	5	8	8	3	1	3	74
Four-bedroom flat	1	3	5	10	9	9	3	1	–	2	43
Five-bedroom flat	–	1	1	–	–	2	1	–	–	3	8
Villa (big house)	–	1	4	4	12	15	18	13	8	27	102
Total	5	42	80	97	117	106	86	56	42	93	724

regions of the country, which was the key factor considered in this study investigation.

The response data collected from that survey was used to facilitate an understanding structure of typical Libyan houses. Hence, from typical houses, data is fed to the load profile model and generated in IES-VE software. Also, the model should cover the entire survey responses in order to get a load profile cascade. Subsequently, that leads to a drowning in the shape of load profiles of Libyan houses. The discussions of the results gained from the survey and model are considered. Figure 1 elucidates the flow chart of the steps for research methods.

2.1 The survey

The survey is based on core/sub-questions with multiple-choice answers for the participant to choose their response. This type of questionnaire was used to help the participants determine appropriate answers, where they are from different levels of education. The questionnaire approach was used to provide a broad overview of household dwellings in Libya. It is important to understand people's behaviour by knowing how they manage energy inside their house. That helps engineers in future during the stages of designing houses to consider various factors. So, by including their occupancy and air conditioning usage, for comparative analysis with energy usage. The surveys were distributed, and the total number of responses achieved was about 724, representing the resulting data.

2.2 IES-VE software

This programme is IES-VE software is used to examine the energy use of a building. So, it is used to predict energy consumption and award relevant energy performance credits. This can be applied during construction or after the build has been completed. The output tends to be graphical, which must be interpreted to understand such data. It is popular software for engineers in the field it is used to assess a building expenditure of energy by energy modelling and physics.

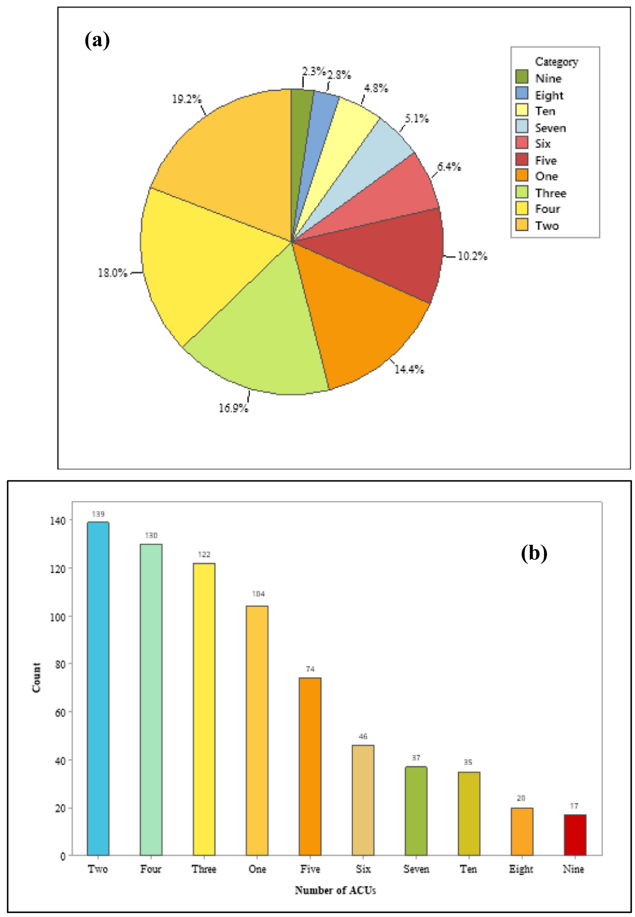


Fig. 7 Respondent's descriptions **a** the percentage of ACUs in sample property, **b** the number of ACUs in the survey

2.3 Area of study

Historically, the taxonomy of Libya into three main territories Tripoli, Benghazi and Fezzan. In that territory, there are many administration taxonomies, so-called municipal, based on population distribution and geographic location. Accordingly, this study is divided into four geographic regions: west, middle, east and South.

Table 3 Number of ACUs in a specific type of building

No of ACUs in Property	One	Two	Three	Four	Five	Six	Seven	Eight	Nine	≥ Ten	Total
One floor house	44	65	65	68	32	10	5	1	3	1	294
Double floor house	7	18	17	29	20	22	18	10	4	5	150
One bedroom flat	6	-	-	-	-	1	-	1	-	-	8
Two-bedroom flat	17	16	9	3	-	-	-	-	-	-	45
Three-bedroom flat	18	26	15	14	1	-	-	-	-	-	74
Four-bedroom flat	9	7	11	4	7	1	-	1	1	2	43
Five-bedroom flat	2	2		1	1	1	-	-		1	8
Villa (big house)	1	5	5	11	13	11	14	7	9	26	102
Total	104	139	122	130	74	46	37	20	17	35	724

Figure 2. shows the location of Libya and four regions. It is important to mention that most inhabitants live in the coastal region.

2.4 Libyan building envelope

The building envelope comprises a roof, wall, windows, sunscreens, exterior doors, water infiltration and shading. Hence, the wall and roof are basically constructed using conventional approaches that can be combined with the insulated wall. Notwithstanding, in Libya, it is essential to have at least one window in each room; nevertheless, based on the owner's desire, the constructor and owner whether windows are made from aluminium (Al), glass or Polyvinyl chloride (PVC)-clad wood frame along with thermal breaks. Permanent sunscreens or "mashribiya" are installed for sun screening and shade. In modern Libyan buildings, however, a waterproof membrane and moisture barrier flashing are constructed in the sloped roof deck to prevent water infiltration via brick hollow walls [22].

3 Validation

The validation is an important stage that verifies the suitability and dependability of designs, procedures, and the gained results. Assessing that technical outputs are reliable, efficient, and suitable for implementation in usage requires this phase. Therefore, the multi indicator cluster survey (MICS). MICS report studied the case of Libya, which represents the Libyan living conditions of the Libyan family, hence the importance of developing the economy [23]. That survey was a national survey that targets national indicators in both rural and urban areas. The report was performed by thirteen national experts and was assisted by experts from the United Nations (UNs) agency's office in Libya. Table 1 details a comparison between the MICS report and the current study survey.

The characteristics of Libyan dwellings (LD) are predicted based on the replies of the people who participated in the survey. The respondents of the current survey are from different geographic in Libya. The Libyan inhabitants mostly lived in regular houses, about 61.3%; the second pattern is flat, where the number of bedrooms in flats was 1,2,4,5 bedroom, representing about 24.5%. In contrast, villas or modern houses are less used representing about 14.1%.

The standard divisions (STD) were estimated between the current study and the MICS report. The analysis indicated a variance of (STD) of the value of regular houses, villas, and modern houses, 1.6 and 2.1, respectively. At the same time, there is a close in the analysis of flat, which was 0.1. Also, further statistical analyses were performed to identify the results and ensure the actual indicators and estimations. The mean absolute error (MAE) was also estimated at 1.8. Also, the root mean square error (RMSE) is predicted to be 0.670. The Eqs. (1, 2) are used in statistical estimation of MAE and RMSE, respectively.

$$MAE = \frac{\sum_{i=1}^{n} \left|p_i - t_i\right|}{n} \tag{1}$$

$$RMSE = \sqrt{\frac{\sum_{i=1}^{n} \left(p_i - t_i\right)^2}{n}} \tag{2}$$

where (ti) is the target value, (pi) is the predicted value, and (n) is the number of samples.

4 Results and discussions

4.1 Distribution of Libyan living

There is a diversity of Libyan buildings; it's different from one area to another and the owner's economic status. The survey results showed that the types of Libyan homes are represented by 41% of one-story houses and those who live in a double-story house were about 21%. Also, 14%

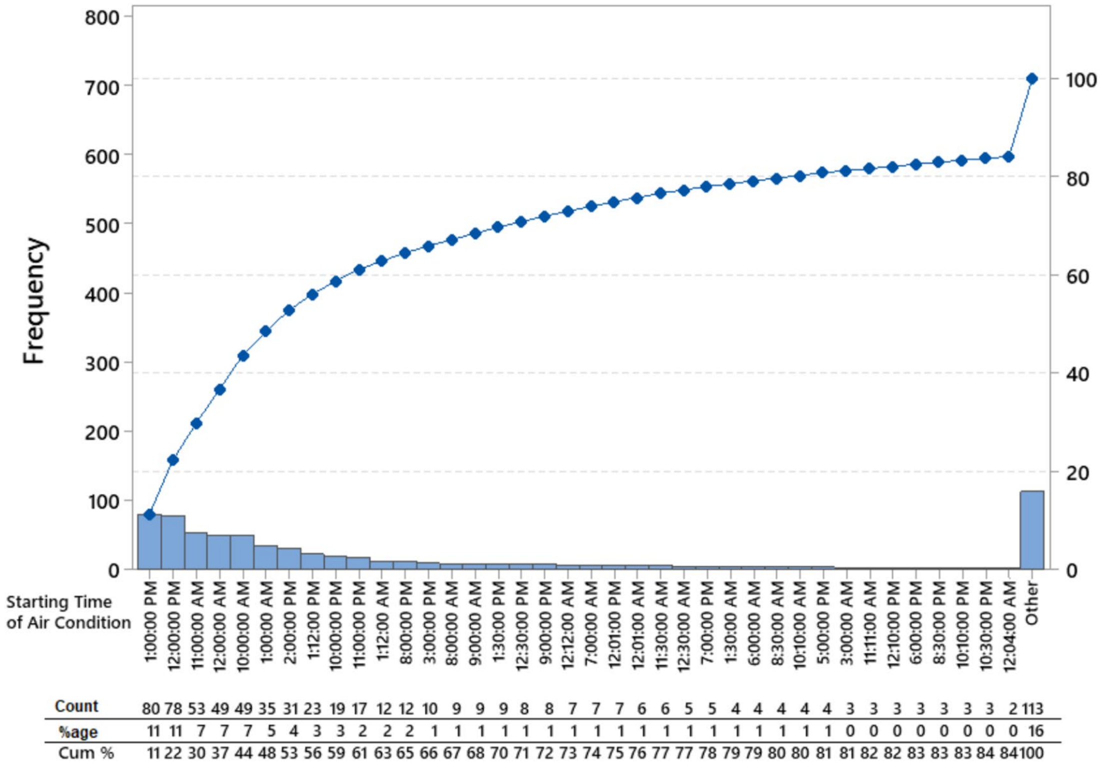


Fig. 8 Pareto chart of starting time of ACUs in summer

responded that they live in a big villa. The rest of the respondents live in flats: 1% in one-bedroom flats, 6% in two-bedroom flats, 10% in three-bedroom flats, 6% in four-bedroom flats and 1% in five-bedroom flats. Figure 3. illustrates Libya houses in terms of the number of rooms and type of building house or flat.

4.2 Type of building where the respondents reside

From the results, as shown in Fig. 4a type of building with the number of respondents and part (b), percentage of sample buildings. Out of 724 respondents, approximately 294 lived in one-floor houses, representing 40.6% of the entire respondents in the survey sample. Although, those remaining, 150, representing about (20.7%), lived in two-floor houses; 102, representing about (14.1%), lived in villas. Moreover, 74 (10.2%) were living in three-bedroom flats, 45 (6.2%) were living in two-bedroom flats, 43 (5.9%) in four-bedroom flats, and 8 (1.1%) were living in both one-bedroom and five-bedroom flats.

4.3 Description of type of building, area of country and number of air conditioning

Based on analysis, it shows that in the East region of the country is the most common living are 'one-floor' houses, 'two-floor' houses and villas. In the mid-region of the country, most respondents in that region occupy common living 'one floor' houses (48 out of 91). Similarly, in the country's southern region, most occupants 69 out of a total of 140 respondents reside in a 'one-floor' house. But, in the country's western region, 'one-floor' houses and 'two-floor' houses were common among the respondents. A total of 157 respondents out of 399 lived in 'one-floor' houses, whereas 83 out of 399 lived in 'two-floor’ houses.

There were various households found to have between one and five ACUs in 'one-floor' houses in the western region of the country; although, the two-floor houses have between six and seven ACUs. In the villas, houses were found to have among eight and ten ACUs installed in their homes. Therefore, this indicates that the country's western region has the highest number of ACUs installed in villas, one-floor houses and two-floor houses. So, these three housing categories had more air conditioning installed.

Figure 5 Indicates overall AC ownership for each region. In order to determine peak electricity load time for the entire population, it was essential to generalisation our sample data

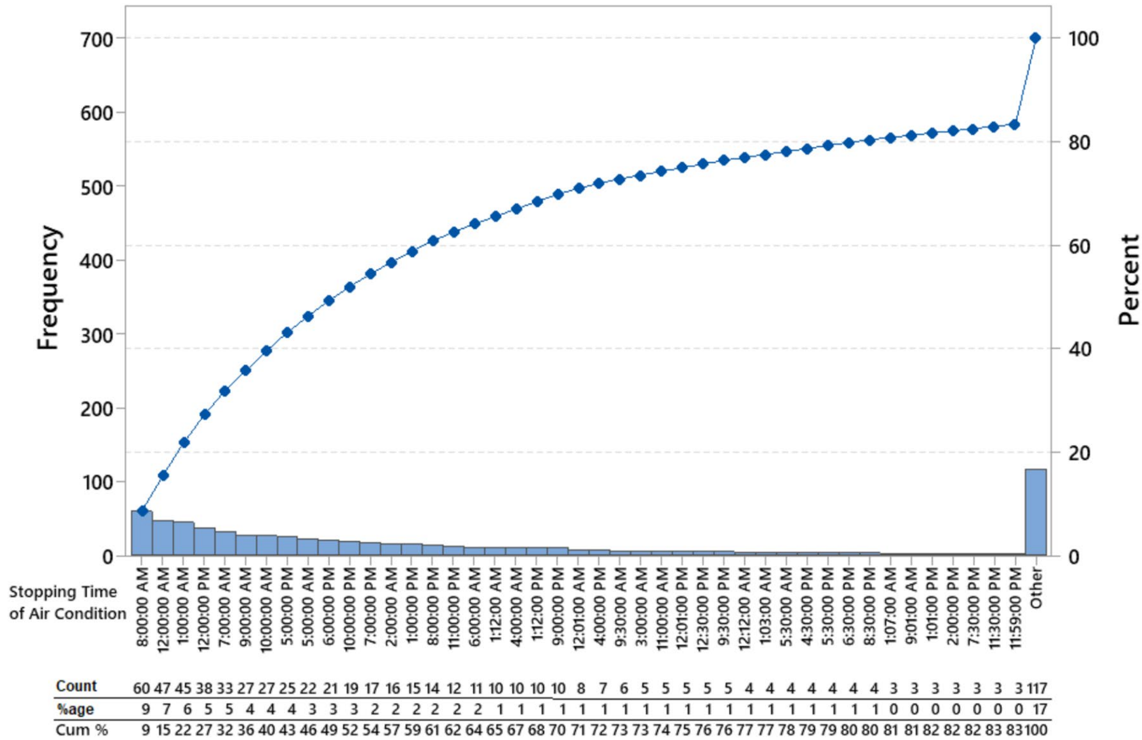


Fig. 9 Pareto chart of stopping time of ACUs in summer

to the entire population. For this, we determined the AC Ownership ratio for our sample size using the following formula for each region (West, East, South and Middle) as given in Eq. (3).

$$\begin{aligned} &\textit{AC Ownership in Regions}\,(\textit{West}/\textit{East}/\textit{South}/\textit{Middle}) \\ &= \frac{\textit{Total No of People Living in the Region}}{\textit{Total No of ACs Owned by People Living in the Region}} \end{aligned} \tag{3}$$

4.4 Number of occupants

Figure 6. demonstrates the respondents' description based on the number of people living in the property. Thus, the total number of respondents was about 724, with 117 representing about (16.2%) of the respondents living in a five-member household, followed by 106 respondents in a six-member household, respectively. Also, 97 (13.4%) respondents lived in a household with four members, while 93 (12.8%) were living in a ten-person and above household. Moreover, 86 respondents (11.9%) were found to be living in a household with seven occupants, while 80 (11.0%) respondents were in a three-member household. Of the remaining respondents, 56 (7.7%) lived with eight people in the household, while 42 (5.8%) lived with two people and nine people in a particular building. Finally, only five (0.7%) respondents were living alone. Table 2 lists more details about the number of people in a specific type of building.

The energy consumption patterns representing factors such as many bedrooms and the number of occupants are directly related to the high consumption volume and include house cooling.

Further assessment of 'one-floor' houses revealed that five-member households were the most widespread with respondents, with 57 respondents inhabiting them, followed closely by four and six-member households at 45 and 46, respectively. Only three respondents live in one member household for the same kind of property.

4.5 Number of air conditioning units (ACUs) in the property samples

The number of AC units is based on the number of people and rooms, where the number of inhabitants rises as the rooms increase. Figure 7a illustrates respondents' descriptions based on the number of air conditioning units on their property. Figure 7b in-vividly, the estimation of the number of ACUs in the survey. Therefore, from a total of 724 respondents, there was about 139 (19.2%) had two ACUs.

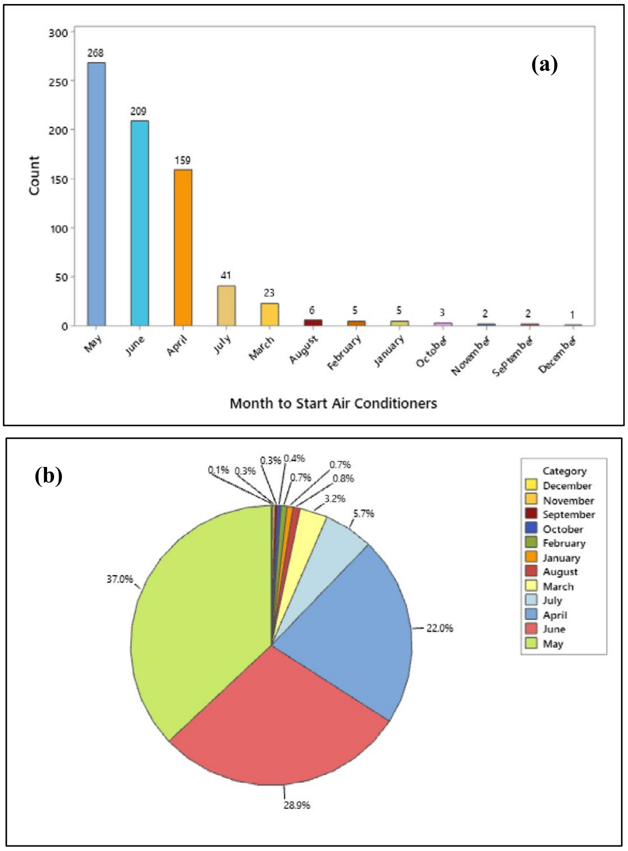


Fig. 10 Respondents reply **a** Starting month for using ACUs, **b** a percentage of start Months for using ACUs

Also, 130 (18%) respondents have mentioned that they have four ACUs, and 122 (16.9%) own three ACUs; however, 104 (14.4%) respondents indicated just having one ACUs on their property. Besides, this indicates that almost two-thirds of respondents (495) which represent (68.5%) had between one and four ACUs installed in their homes. Although the remaining respondents, 74 (10.2%) own five ACUs, whereas 46 (6.4%) showed having six ACUs on their property. Furthermore, 37 (5.1%) own seven ACUs, whereas 35 (4.8%) possess ten or more ACUs on their property. The analysis also indicated that 20 (2.8%) respondents own eight ACUs, while only 17 (2.3%) indicated having nine ACUs.

A further detailed data breakdown of the number of air conditioning units is listed in Table 3. Where was revealed that the majority of respondents who live in 'one-floor' houses had between one and four air conditioning installed. That sign of one-floor houses is more consume of electricity used in the cooling system. In contrast, more than five air conditioning units are typical for villas.

Energy building systems, including illumination, HVAC, etc., have also been proportionally controlled using occupancy information. Numerous studies are being conducted on utilising occupancy information for building management and controls. These applications include straightforward presence-based lighting systems and demand management ventilation shifting to additional complicated frameworks incorporating model predictive control or reinforcement learning [24–26].

The significance of energy saving as it can be considered to optimise energy consumption. Hence, the powerful and famous elements that affect energy consumption are the occupants' behaviours. At the same time, the human being is prime-over that m of indoor energy applications of the dwelling.

4.6 Starting time of ACUs on summer days

Starting and switching off ACUs depends on the weather conditions, when people feel hot and cool. Based on the respondents have shown various times for starting their air conditioning. The Pareto Chart of time is presented in Fig. 8. display plotted by Minitab software as it shows the starting time of the ACUs. Based on the results in the figure, approximately 59% of the respondents mentioned that the start times for their ACUs varied between 11 am and 2 pm. According to the respondents who had three units or more, starting times in one day comprised 84% of the total respondents in the survey, whereas those who had starting times once or twice. It can be anticipated that 84 (11%) respondents started ACUs at 1 pm during the summer season, while 78 (10.8%) started their air conditioning at 12 pm.

This significantly means that the majority of the respondents started their air conditioning unit when the sun was fully up and at its zenith. According to 53 (7.3%) respondents reported starting their air conditioning at 11 am, 49 (6.8%) respondents reported starting their air conditioning at 12 am, whereas another 49 (6.8%) reported starting their ACU at 10 am.

Various factors that affect the magnitude of energy used at home should be considered. However, The number of people in the family, lifestyle, region and environment, the kinds of appliances used, ownership, architectural characteristics of the home, and behaviour of humans significantly affect the amount of energy consumed domestically [27]. Subsequently has been determined that occupant actions and behaviour have a significant role in the variability of energy consumption in buildings [28, 29].

4.7 Stopping time of ACUs in summer days

Respondents have shown there are different times for stopping their air conditioning. A Pareto Chart of the stopping

Fig. 11 Duration of ACUs use

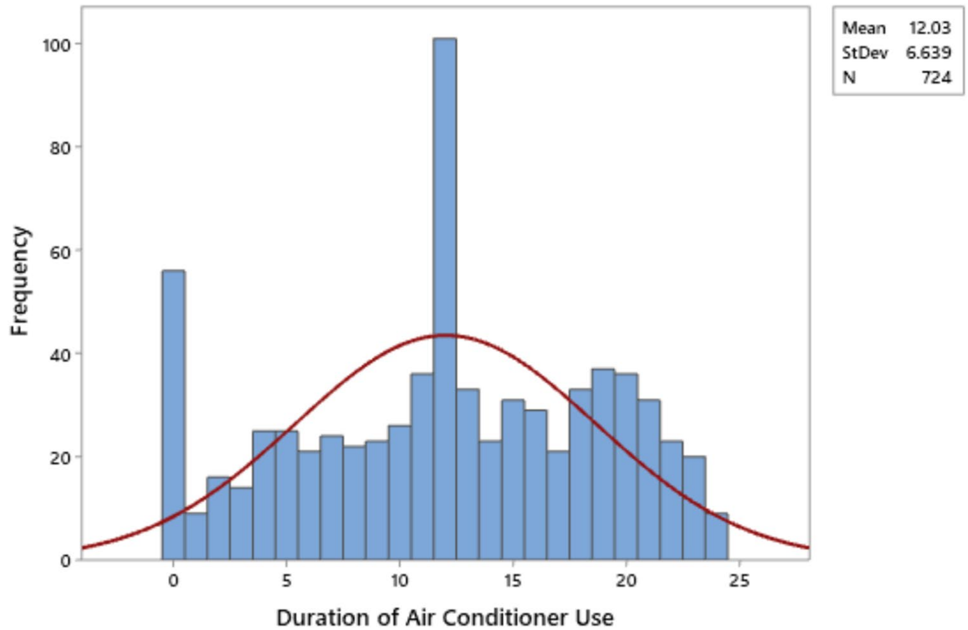


Table 4 A summary of statistical analysis of the duration of air conditioning use

Variable	Total no. of respondents	Mean	St Dev	Min	Mix	No for mode	Median	Skewness
Duration of ACUs use	724	12.03	6.639	0.00	23.983	68	12.0	-0.19

time of the ACUs is used to specify that. Figure 9 illustrated that about 60 (8.3%) respondents normally stopped their ACUs at 8 am in the morning; subsequently, 47 (6.5%) and 45 (6.2%) respondents stopped the ACUs at 12 am and 1 am, respectively. The stop times mentioned thrice or more via the respondents made up about 83% of the total respondents in the survey. Hence, the stop times were mentioned twice or just once by the respondents, which made up approximately 17% of the total respondents. Therefore, for this analysis, these timings were not considered outliers; nevertheless, these could either be through chance or a preference of a specific respondent.

4.8 Starting the month of air conditioning

Based on the environment and geographic region, either desert or coastal inshore region, the use of ACUs relies on where you live. Figure 10a displays details of the overall months during which respondents started utilising their ACUs. Figure 10b shown a percentage of start Months for using ACUs. As in-vividly seen, the majority of respondents stated that they started using their air conditioning between March and July, with particular groupings in April, May and June. Hence, out of 724 respondents, 159 (22.0%) respondents stated they started using air conditioning in April, and 268 (37.0%) respondents started using their ACU in May. Although about 209 (28.9%) respondents started using their ACU in June. The total comprised about 636 (87.9%) respondents who started air conditioning in these three months. This specified the use of ACU coinciding with the start of the summertime, with peak usage occurring during May and June. Nevertheless, a relatively sharp drop in ACU usage use is evident during January and February and then from July onward until December. This is likely due to changing weather and the end of the summertime.

4.9 Duration of ACU use

According to the statistics from typical (starting – stopping) time, the ACUs duration of usage was determined. A histogram was used here to analyse parameters and generated using Minitab software, as shown in Fig. 11. Therefore, the average use of ACUs for 724 respondents was about 12.03 h and a statistical standard deviation of 6.639 h. This specified that 95% of the respondents were using air-conditioning for a duration of 5.4 – 18.7 h. As illustrated, about 101 respondents out of 724 used air conditioning for an average of 12 h, whereas approximately

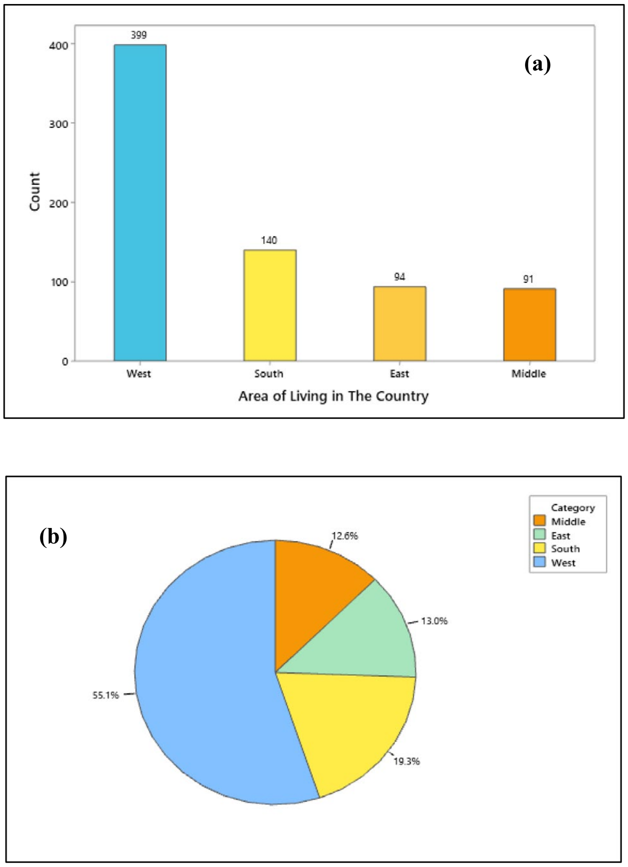


Fig. 12 **a** Living area of respondents, **b** percentage living area of respondents

60 respondents used their air conditioning for less than 1 h.

Table 4 lists a statistical analysis of the duration of air conditioning use. As shown and from the analysis, the duration of usage of ACUe ranged from a minimum of 0 h to a maximum of 23.98 h. The mode value is 12, as about 68 respondents out of 724 used the air conditioning for straight 12 h. The skewness value is -0.19, indicating a symmetric distribution of the data across the whole range of duration of use of air conditioning. The negative value of skewness might be because of high values of no usage or less than one hour of use by respondents.

4.10 Living area of respondents

There was a variance in the response based on their living area, where more shown in the western region. Figure 12a displays and describes the geographical area of the country where the respondents reside at the time of the survey. Figure 12b Percentage of the living area of respondents. Thus, from an entire of 724 respondents about 399 (55.1%) of respondents were living in the western region. At the same time, about 140 (19.3%) respondents were living in the southern region. Consequently, the majority of inhabitants respondents (539) representing (74.4%) were living across the southern and western regions of the country. The remaining respondents, 94 (12.9%), lived in the east, and 91 (12.6%) lived in the middle of the country. Table 5 reveals that one-floor houses are common in almost entirely areas of the country. However, inhabitants in the west favoured two-floor houses making 55.3% of this type of houses.

4.11 Respondents' report based on stopping month of air conditioning

According to the environmental status, ACUs cool indoor buildings during summertime. Figure 13a displays and details the frequency of respondents stopping the air conditioning via month. Figure 13b presents the respondents mentioned in the survey that they initiated stopping their ACU usage from August onward. Through November, the vast majority of respondents, about (671), which represent (92.7%), have stopped their air conditioning usage, while few, just (26) which represent (3.6%), they stop their ACUs in December. However, the peak months when respondents stopped their air conditioning usage are September, October and November.

Therefore, stopping ACUs during these three months represented up to 633 responses, i.e., approximately 87.4% of the total response. It is important to mention that during peak months when respondents started using their ACUs from April, May and June, only a few of the respondents indicated that they stopped using the air conditioning throughout these months. The respondents who stopped using air conditioning throughout peak months represent only 1.5% of the total respondents.

Depending on the weather conditions, cooling and heating are significantly needed in domestic buildings. Whereas consumption of energy-intensive appliances, occupancy routines, living standards, comfortable expectations, energy-use behaviour, appliance kinds and usage frequency ranges, and cultural customs altogether have an impact on energy intensity [30].

To understand the energy consumption in the residential sector, it's important to identify the different characteristics, including demand management, occupant behaviour and building enhancement on energy performance. Also, the load profile format can stabilise the energy supply's grid reliability and efficiency.

Table 5 Number of buildings in a particular region

Part of Country Living	East	Middle	South	West	Total
One floor house	20	48	69	157	294
Double floor house	22	13	32	83	150
One bedroom flat	1	2	2	3	8
Two-bedroom flat	8	4	13	20	45
Three-bedroom flat	15	7	7	45	74
Four-bedroom flat	6	5	6	26	43
Five-bedroom flat	2	1	2	3	8
Villa (big house)	20	11	9	62	102
Total	94	91	140	399	724

4.12 Predicated zone of the building occupied per households

Based on the occupant's behaviours (OB), the typical building prediction of each zone of buildings through a given estimation of people's actions inside the building. Most Libyan inhabitants rely on air-conditioning in their buildings, not only owing to the particularly hot climate conditions but also because of the poor natural ventilation of the buildings.

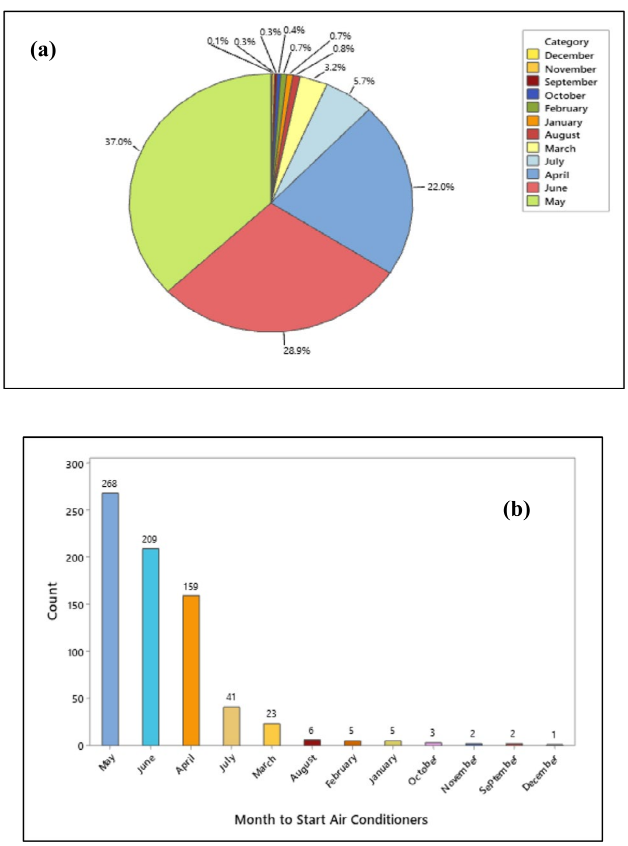


Fig. 13 Annual use of air conditions **a** Months for ending the use of ACUs, as a percentage, **b** Months for ending the use of ACUs

Regarding the study investigating peak cooling for individual buildings and subsequently aggregating for several buildings, several adaptations were modelled to decrease the energy used for cooling. Hence, building energy efficiency enhancements can be categorised into active strategies, including heating system enhancements, ventilation and air conditioning systems and electrical lighting. Also, the passive energy efficient strategies, such as enhancements to building envelope elements [31]. The study deployed a clustering method to define occupancy profiles based on Wi-Fi connection to examine the energy demand and occupancy profiles of four building use types [32].

These models consist of a daily profile of different home zones, which includes, livingroom, kitchen, entrance, rooms, bathrooms and way, as illustrated in Fig. 14a-f. Each zone's daily profile depended on the behaviour, daily occupancy routine, and equipment used in the buildings. So, to manage the cooling, a half-hourly resolution was used to generate meaningful load profiles.

The daily profile for each zone is fully occupied when the modulating value is one and not occupied when the modulating value is zero. Home occupancy pattern behaviours are varied daily. For example, the daily profile for the livingroom was assumed to be occupied from 2 to 4 pm and then 8 to 10 pm. The daily profile for the room was assumed that it is occupied from 12 to 7 am then 2 pm to 4 pm for a nap then from 10 pm to wake up at 7 am.

From the predicated model and survey response, many occupants are extremely unmanaged air condition units used to obtain good results and conserve energy. Also, the occupants’ behaviours are specified via the long duration of ACUs usage of approximately 12 h on average daily.

The occupants' behaviours are based on their culture, where air conditioning is often used in the guests’ rooms. When they visit, they often stay for a protracted period, leading to overusing electricity. Hence, special consideration should be given to the design of the guest room to enhance its energy-saving capacity, especially when they are built separately from the house.

The designed rooms have balconies or windows that are northwest/ north facing. It encourages its occupants to use natural ventilation. Moreover, in the south, the architect ought to design this kind of room with plants if they are built separately from the key building to decrease solar improvement and raise natural cooling.

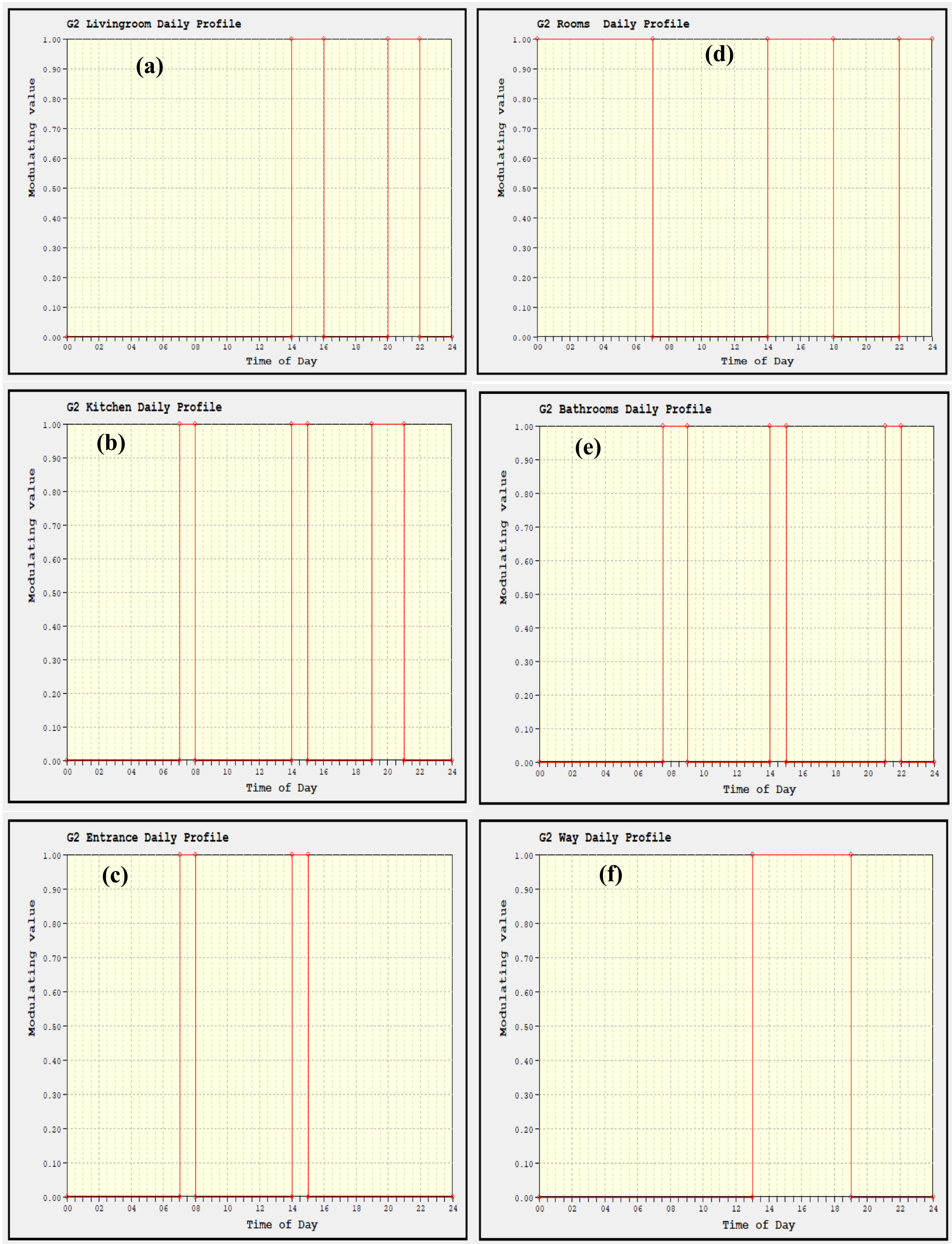


Fig. 14 Internal gain profiles of an electrical load operation profile and cooling operation profile for each zone, **a** livingroom daily profile, **b** kitchen daily profile, **c** entrance daily profile, **d** rooms daily profile, **e** bathrooms daily profile, **f** way daily profile

5 Conclusions

This work analysed residential electricity consumption in the case study of Libya; whereas energy consumption patterns are based on modelling and data of a survey of building types and their behaviour on dwellings' and their occupants' characteristics. Moreover, this work used a survey to obtain an overall indication of electricity demand from cooling in Libyan domestic residences. The questionnaire was designed to predicate the estimated energy consumption and air-conditioning used. The report was with 724 respondents, encompassing key questions including the number of occupants, the size of properties, building type and the number of air conditioning units used.

According to the investigation, the correlation between the household's behaviour and how energy can be decreased in homes within the environment, such as the total and peak demand of generation electricity from the Libyan domestic sector, can be decreased. The study provided information about the locations and times during the summer months when air conditioning was being utilised when it was turned off, when the utilisation of air conditioning started, and when it stopped. Therefore, the concluded investigation showed a significant excessive waste of energy in the dwelling when using ACUs. Moreover, the analysis realised consumption patterns of Libyan households are extraordinary in electricity; however, 40.6% of the respondents live in a one-floor house, which needs further consideration. Thus, to manage these challenges of electricity demand from the architectural perspective, it is necessary to implement innovative/adaptation technologies to lower the amount of electricity consumed in the residential sector and boost the efficiency of the electricity network. Further work needs to be carried out, including further adaptation in Libyan architectural buildings, in order to find an appropriate solution that facilitates high peak demand and decreased demand for energy.

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Authors and Affiliations

Abdusalam Yehmed Alafya[1] · Ali O. M. Maka[2]

✉ Ali O. M. Maka
maca_4212@yahoo.co.uk

Abdusalam Yehmed Alafya
yhmad2000@yahoo.com

[1] School of Computing Engineering and Built Environment, Edinburgh Napier University, Edinburgh, Scotland

[2] The Libyan Centre for Research and Development of Saharian Communities, Murzuq, Libya