ISSN 1848-0071
66.045(612)+692.9=111
Recieved: 2013-11-27
Accepted: 2015-12-15
Professional paper

THE PROPOSAL OF AN AIR-CONDITIONING SYSTEM FOR A HOUSE LOCATED IN LIBYA

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The presented paper deals with the issue of design of air-conditioning devices in a house located in Libya. Due to high temperatures during the day and much lower temperatures at night, it is not possible to ensure thermal comfort for inhabitants in Libya without having and using an air-conditioning device. This is why there is an analysis of weather and temperature conditions during each season in this country carried out in order to design the device properly. Consequently, calculations of thermal gains are carried out and alternative systems are proposed based on these gains.
Key words: air-conditioning, heat gains, thermal comfort, weather conditions in Libya.

Prijedlog klimatizacijskog sustava za kuće smještene u Libiji. Ovaj rad bavi se pitanjem dizajna klima-uređaja za kuće smještene u Libiji. Zbog visokih temperatura tijekom dana i mnogo nižih temperatura noću, nije moguće osigurati toplinsku udobnost za stanovnike Libije bez i pomoću klima-uređaja. Iz tog razloga provedena je analiza vremenskih i temperaturnih uvjeta tijekom svake sezone u toj zemlji kako bi se uređaj ispravno dizajnirao. Prema tome proveden je proračun toplinskih prednosti i predloženi su alternativni sustavi na temelju tih prednosti.
Ključne riječi: klima-uređaj, toplinska prednost, toplinska udobnost, vremenski uvjeti u Libiji.

INTRODUCTION

Humans can work and live best at a certain range of temperatures. Human body can tolerate only a narrow band of change in temperature. Therefore, it is very important to ensure and keep the people's thermal comfort at work and at home. Lots of homes and most offices would not serve for comfortable usage without year-round control of the indoor environment. Historically, air conditioning has implied cooling or otherwise improving the indoor environment during the warm months of the year. In modern times the term refers to the control of temperature, moisture content, cleanliness, air quality, and etc. The aim of the paper is to point out how important it is to determine the proper design conditions for design of the correct air-conditioning devices; mostly in a country with a need for year-round cold supply in which temperatures reach 47 °C in the summer.

WEATHER CONDITIONS IN LIBYA

Libya is located on the coast of North Africa and is the fourth largest country on the continent. It borders with Egypt in the east, Sudan in the south-east, Chad and Niger in the south, Algeria in the west and Tunisia in the north-west and the Mediterranean Sea in the north [1].

Winter in Libya starts on 6th December and finishes on 15th February. Spring starts on 16th February and finishes on 20th May. Summer is from 21st May to 4th November and is divided into four parts: transitional interval (21st May to 5th June), dry summer (6th June and 19th July), humid summer (20th July to 31st August), transitional interval (1st September to 4th November). Autumn is from 5th November to 5th December [2].

The Mediterranean Sea and the Sahara Desert influence Libya's climate. The Ghibli (a hot, dry desert wind that lasts one to four days in both, spring and autumn) causes temperatures to fluctuate by as much as 17° to 22°C in both, summer (June to September) and winter (October to May). Summer temperatures along the north-western coast are from 40°C to 46°C, and temperatures further to the south reach even higher values. In the north-eastern region, summer temperatures range from 27°C to 32°C. In January, average temperatures are approximately 13°C in the northern regions [3].

There are not nearly any rain falls and temperatures quickly climb up to 50°C in the summer in Southern Libya. Daytime winter temperatures range between 15°C and 20°C, they fall below 0°C at night.

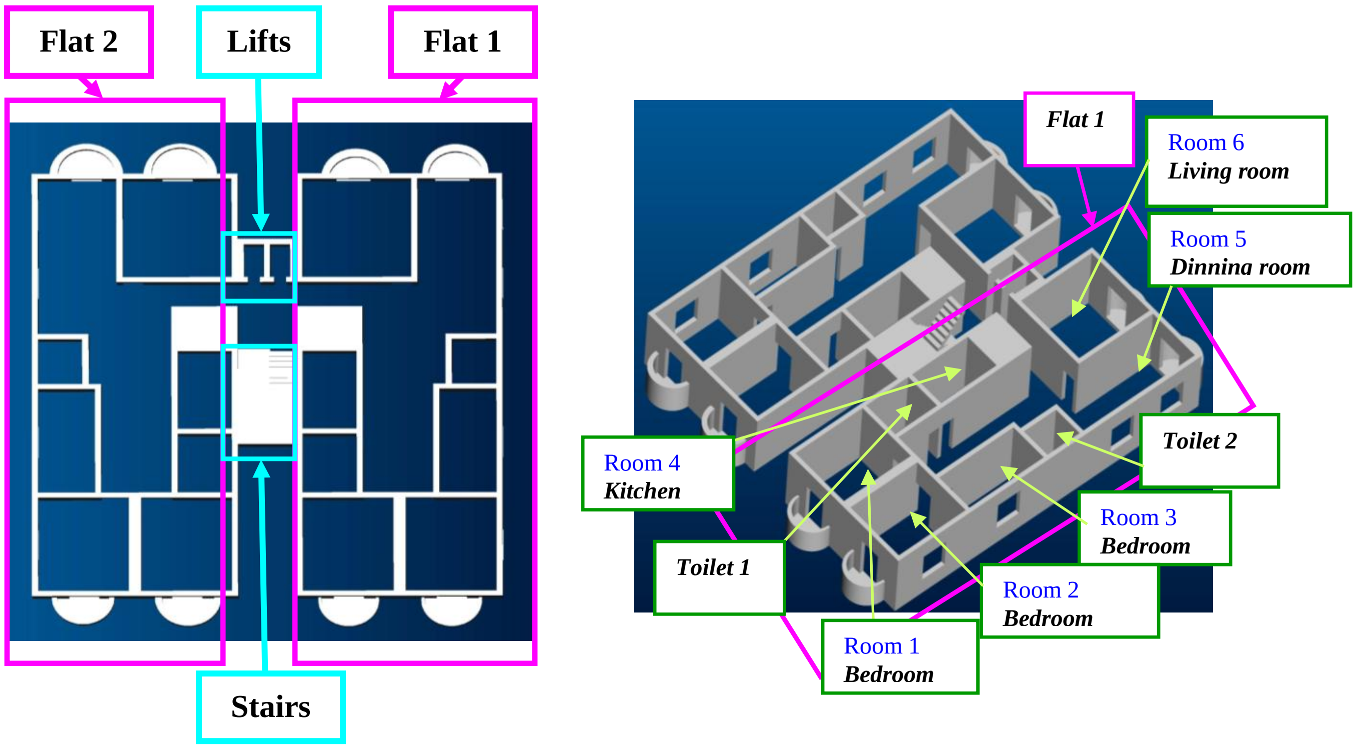
The amount of rainfall varies depending on regions. The north-eastern region receives 40 to 60 centimetres of rain per a year, while other regions receive less than 20 centimetres. The Sahara Desert receives less than 5 centimetres of rain annually. A short winter period brings most of the rain, which usually causes floods.

DESCRIPTION OF THE SELECTED HOUSE AND GENERAL NECESSARY DATA

The selected building, for which the calculation will be done, consists of four floors. There are two flats of the same size (see Fig. 1 a)), and equipment on each floor. The calculation was performed in one selected flat of the selected building (see Fig. 1 b), pink frame) due to the fact that all flats are of the same dimensions.

The residential building is located in a place with an elevation of 10 meters above sea level. The calculations were performed on 21st July at 3 pm. The maximum daily temperature of outdoor air is 53°C, temperature at 3 pm is 43°C and the desired internal temperature in each room is 23.8°C.

The example calculations were performed for one room of flat 1 - Bedroom 1 (see Fig. 2; dimensions are given in millimetres) and the rest of heat gains are summarized and shown in tab. 1.



a) b)

Figure 1. The top view of one floor of the selected residential building (a) and 3D model of one selected flat of the selected building (b)
Slika 1. Na vrhu pogled jednog kata odabrane stambene zgrade (a) i 3D model jednog odabranog stana odabranog objekta (b)

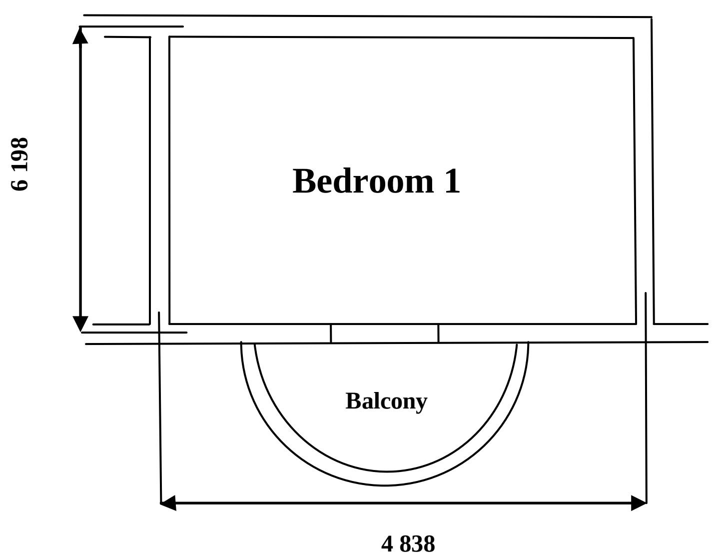


Figure 2. The sketch of bedroom 1 of flat 1
Slika 2. Skica spavaće sobe 1 stan 1

The construction material of the room's ceiling consists of heavy weight concrete - 7 cm thick, slag and stone - 3 cm thick, insulation - 10 cm thick, plaster - 2 cm thick. The construction material of the room's wall consists of concrete block - 14 cm thick, face brick - 114 cm thick, insulation - 3 cm thick, plaster - 2 cm thick.

The area of the room is A = 29.985 m^2/322.752 ft^2. On average, there are 2 people in this room. The wattage of the electric lightings in the room is 800 W. There are not any energy saving bulbs. The total resistance of the ceiling is 14.03 hr.$ft.^2$ °F Btu^{-1}/ 1.762 $m^2.K^{-1}.W^{-1}$.

EXAMPLE CALCULATIONS OF HEAT GAINS THROUGH THE CEILING IN BEDROOM 1

Heat gain through the ceiling was calculated as follows [6]:

$$Q = U \cdot A \cdot (CLTD) \quad (1)$$

Where Q is heat gain through the room's ceiling (W), U is overall heat transfer coefficient ($Btu.hr^{-1}.ft^{-2}.°F^{-1}$), A is ceiling area (m^2), $CLTD$ is cooling load temperature difference (°C).

Overall heat transfer coefficient U is as follows:

$$U = \frac{1}{R} \quad (2)$$

Where R is thermal resistance ($m^2.K.W^{-1}$).

Cooling load temperature difference is determined by the following equation:

$$CLTD = CLTD_{tab} + (25.56 - T_i) + (T_o - 29.44) \quad (3)$$

Where $CLTD_{tab}$ refers to the cooling load temperature difference - tabular value of CLTD (°C), T_i is actual inside design dry-bulb temperature (°C), T_o is outside design dry-bulb temperature (°C).

$CLTD_{tab}$ is corrected for local conditions: the outside design temperature T_o= 127.5 °F/ 53.06°C and the inside design temperature T_i= 75°F/23.89°C.

$$CLTD = 18.89 + (25.56 - 23.89) + (53.06 - 29.44) = 44.18 \text{ °C} \quad (4)$$

Overall heat transfer coefficient is obtained from Eq. 2:

$$U = \frac{1}{1.762} = 0.5674 \text{ W.m}^{-2}.\text{K}^{-1} \quad (5)$$

Then

$$Q = 0.5674 \cdot 29.985 \cdot 44.18 = 751.66 \text{ W} \quad (6)$$

The sum of heat gains (heat gains through external, internal walls, windows, ceiling, floor, surrounding rooms; heat gains from radiation, convection; heat gains from people, lighting, appliances, etc.) in particular rooms can be found in tab.1.

Table 1. The sum of the total heat gains in all rooms
Tablica 1. Zbroj ukupnih toplinskih prednosti u svim sobama

Total heat gains	(Btu.hr^{-1})	(W)
Room 1 - Bed room	15 652	4 587.36
Room 2 - Bed room	11 574.74	3 122.39
Room 3 - Bed room	10 282.01	3 013.53
Room 4 - Kitchen	5 610.28	2 058.45
Room 5 - Dining room	24 250.79	7 107.05
Room 6 - Living room	11 218.37	3 287.9
Toilet 1	2 859.06	837.92
Toilet 2	4 253.17	1 219.52
Infiltration	18 322.6	5 370
Sum of total cooling load	***104 023.02***	***30 604.12***

The cooling load need for each flat in this building is as follows:

$$\dot{Q} = \mathbf{31\ kW} \quad (1)$$

The cooling load need for 8 flats of the building is approximately 248 kW. The performed design of an air-conditioning device for each room was based on the heat gains shown in tab. 1.

THE DESIGN OF AIR-CONDITIONING SYSTEM

After having considered the climate conditions in the area which the house is located in, selection of the suitable air-conditioning units took place. Based on the calculated heat gains for each room of flat 1, two alternative solutions of air-conditioning device were designed. The first alternative is the DC INVERTER DAKOTA WDI DCI system and the other is the fix-speed PRIME system.

Description of the first alternative – DC INVERTER DAKOTA

The DAKOTA WDI wall-mounted split unit range is available with the ecologically friendly fluid R410A. It is possible to save up to 30 % of costs in comparison with conventional ON/OFF system by regulation of revolutions. In addition, these equipments enable heating up to - 15 °C of the outside temperature that allows user to use heat pump at low winter temperatures [5].

The prices of the selected indoor and outdoor units for the first alternative are shown in tab. 2.

Table 2. The prices of particular indoor and outdoor units according to the rooms for the first alternative, DAKOTA WDI DCI, for one flat [5]
Tablica 2. Cijene pojedinih unutarnjih i vanjskih jedinica po sobama za prvu alternativu, DAKOTA WDI DCI, za jedan stan [5]

Description	Prices for the indoor units (€)	Prices for the outdoor units (€)
Room 1 - Bed room	233	959
Room 2 - Bed room	233	959
Room 3 - Bed room	199	641
Room 4 - Kitchen	177	622
Room 5 - Dining room	233 177	959 622
Room 6 - Living room	199	641
Toilet 1	173	601
Toilet 2	174	601
In total	***1 798***	***5 983***

The prices excluding VAT and excluding Cu pipes installation costs

The price for all indoor units for one flat for the 1st alternative is *1 798 €* and for the outdoor units for one flat is 5 983 € (see tab. 2). The price for all indoor and outdoor units for one flat is 7 781 € altogether. The price for all indoor and outdoor units for eight flats (4 floors consisting of 2 flats on each floor) for the 1st alternative is 62 248 € in total.

Description of the second alternative – fix-speed PRIME system

This wall mounted range is particularly designed for residential heating and air conditioning needs. This solution is the most beneficial from the point of view of economy of the system. The required temperature in the air-conditioned area is reached more slowly and the noisiness is higher. Moreover, the compressor ON/OFF regulation causes higher energy consumption and shorter life cycle of the device. [5].

The prices for the selected indoor and outdoor units for the second alternative are in tab. 3.

The price for all indoor units for one flat for the second alternative is *1 881 €* and for the outdoor units for one flat is 4 807 € (see tab. 3). The price for all indoor and outdoor units for one flat is 6 688 € in total. The price for all indoor and outdoor units for eight flats (4 floors consisting of 2 flats on each floor) for the second alternative is 53 504 € in total.

The first alternative, DAKOTA WDI wall-mounted split unit, was selected as the most suitable one out of two alternatives despite being more expensive than the second alternative. It was due to the fact that the required temperature in the air-conditioned rooms is reached faster due to the possibility of increasing compressor revolutions; fluctuation of temperature is lower and the device is more silent in comparison with the other alternative. The disadvantage of the solution is higher price of the system.

Table 3. The prices of particular indoor and outdoor units according to the rooms for the second alternative, RIME, for one flat [5]
Tablica 3. Cijene pojedinih unutarnjih i vanjskih jedinica po sobama za drugu alternativu, RIME, za jedan stan [5]

Description	Prices for the indoor units (€)	Prices for the outdoor units (€)
Room 1 - Bed room	253	546
Room 2 - Bed room	253	546
Room 3 - Bed room	165	1 021
Toilet 2	145	
Room 5 - Dining room	605	1 233
Room 6 - Living room	165	440
Toilet 1	145	1 021
Room 4 - Kitchen	150	
In total	***1 881***	***4 807***

The prices excluding VAT and excluding CU pipes installation costs

CONCLUSION

The presented paper focused on the climate conditions in Libya, their influence on the thermal comfort of inhabitants and performance of air-conditioning systems, the calculation of heat gains in such a hot country where the daily temperature can reach 50 °C. Next, it dealt with the design conditions of two alternatives of air-conditioning system, pros and cons and prices. Since the inhabitants of Libya experience huge temperature differences ranging from 0 °C at night to up to 50 °C during the day in the summer and cold winds and desert storms in the winter, it would be impossible to live in such harsh climate conditions without a functional air-conditioning system working 24/7. Even if the architecture in the desert countries developed some building patterns which can decrease effects of the Mediterranean and Saharan climate and ensure a supply of fresh air and breeze during the tropical heats in the past, they still could not fully relieve the heat load to which the inhabitants have been exposed. Furthermore, the new urban areas do not take advantage of these techniques due to higher comfort and standard of living of the residents. Some of the techniques used to decrease heat load to the maximum include designing a town as a whole with houses attached one to another in order to avoid the intense solar radiation. The streets were covered with shelters and the house's entrance was designed to overlook the street. In addition, the rooms were painted white and equipped with mirrors or shining subjects which reflected the sunshine. However, nowadays, an air-condition device, which can provide so eagerly awaited cool-down during the day and heat at night when temperatures fall down drastically, became an essential part of the everyday life in the desert countries. Moreover, since Libya has large oil reserves, electricity generated there is much cheaper and more affordable than in the European countries. This is to say that the electricity prices do not limit the locals to use air-conditioning units all day long. This way tenants do not have to use another energy source to generate heat such as fire wood, natural gas or coal.

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