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Solar Cooling Alternatives for Residential Houses

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Abstract: The energy consumption rate of non-OECD (non-Organisation for Economic Co-operation and Development) countries rises about 2.3 percent per year as compared to the OECD countries which is 0.6 percent. If developing countries use energy efficient technology and integrate renewable energy systems in the new building their carbon dioxide emission rate reduces by 25 to 44 percent. However, even now, renewable energy integrated buildings are hardly considered while constructing them. This paper focuses on the study of solar cooling system options for residential house of Bahir Dar city, in Ethiopia. To meet the demand of housing in the city, different types of apartments and villa houses are under construction. For the analysis case study was made focusing on two types of residential houses, condominium apartment and Impact Real Estate Villa house. Simulation results of IDA ICE software show that the average operative temperatures and cooling loads for condominium apartment and Real-estate Vila are 31.8 ℃ and 30.7 ℃, 5.53 kW and 5.73 kW respectively. Most of the residences are not satisfied at this operating temperature. There are different types of solar cooling systems. Solar sorption cooling systems are commonly used which can also be classified into absorption, adsorption and desiccant cooling systems. Solar adsorption cooling systems are easy to manufacture locally as compared to solar absorption cooling systems. They do not have moving parts. Some of the working medium pairs used in adsorption cooling system are: activated carbon/ammonia, silica gel/ water, zeolite/water. Adsorption chillier with silica gel/water as a working pair was selected since it can operate at regeneration/desorption temperature as low as 45 ℃ coming from flat plate collectors. At 75 ℃ regeneration temperature, the system delivers 9 ℃ chilled water temperature. From cooling load simulation result direct solar irradiation is the highest source of cooling load for both houses. This gives an opportunity for passive solar cooling technology.

Key words: Adsorption, cooling load, condominium, impact real-estate, IDA ICE.

1. Introduction

Access to affordable energy service is fundamental to human activities, development, and economic growth. Development goals in the areas of water, health, agriculture, and biodiversity often cannot be met without energy inputs and the policies adopted in these sectors similarly impact the availability and reliability of energy services. This is the reason behind the large increment in energy consumption in all over the world and consequently the change in climate [1].

The current energy consumption rate of OECD (Organisation for Economic Co-operation and Development) countries is 0.6 percent in contrast with non-OECD countries which is about 2.3 percent per year. This is due to rapid growth and increase in energy consumption in the non-OECD countries, and availability of energy efficient technologies and incentives in OECD countries [2]. Like many developing countries, Ethiopia's energy consumption is increasing due to development and new construction. Biomass contributes to the largest portion of energy consumption, which is traditional and inefficient. Domestic sector covers 89 percent of energy consumption, which is biomass and mostly in the rural area, used for cooking and lighting [3].

Ethiopia is close enough to the equator and gets plenty of solar power whenever the sun is shining. That is why the name "thirteen months of sunshine" is given. Even in the summer season, there is sunlight for a short period of time. Though there is a huge potential for solar energy utilization as a most promising renewable energy resource, solar energy is not harnessed to generate power in a desirable way. Bahir Dar city has a

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solar insolation of a maximum in April and a minimum in July [4]. This paper focuses on the study of solar cooling options considering the two housing systems, low-cost housing system and villas constructed by the government and real estate companies respectively.

2. Energy in Built Environment

Due to increment of living standard and comfort, energy demand in built environment is increasing. About 25-30 percent of entire energy allied carbon dioxide emission of developed countries comes from buildings. Also in developing countries, building carbon dioxide emission increased from 11 percent to 19 percent from year 1973 to 1990. There is a reduction of carbon intensity of energy services as a result of improvements in efficiency and better technology but the increase of energy consumption for more services has plagued these intensity reductions. Carbon dioxide reduction in buildings includes both energy-efficiency and non-energy efficiency technologies. Fuel changes to non-carbon intensive and also renewable energies are included in non-energy-efficiency technology. Energy efficient technology in buildings includes enhancements to the building shell, better management of energy consumption, and improving the efficiency of different end-uses, for example, energy-efficient windows compact florescent and improved efficiency of biomass stoves, etc. In OECD countries there is a potential of 6-16 percent of reduction in carbon dioxide emission while non-OECD and developing countries have a larger potential of 25-44 percent when comparing energy efficient scenarios to business as usual trends. This higher reduction potential is due to construction of new buildings that gives the opportunity to build in a more efficient way, while in developed countries, energy consumption reduction is done usually by retrofitting on existing buildings. Growth and implementation of new technologies that make energy production and consumption more efficient in non-OECD countries would bring a significant reduction in carbon dioxide emission [5].

The majority of the population in Ethiopia use traditional and inefficient biomass (only 5 to 10 percent of efficiency) for cooking, lighting and in cold season for heating. This results in deforestation and indoor air pollution. Most residential houses are not constructed to take into account the people's comfort at the design stage. Thermal comfort is done by using external shading systems that are natural like planting trees or artificial shading systems, such as infiltration of air through doors and windows, adjusting their wearing style etc. [6].

Bahir Dar city is found at altitude of 1,800 m and the heating/cooling load is not as huge as cities in the north such as Stockholm. The hot season's duration is longer than the cold season. Bahir Dar is one of the fast growing cities in the country. To meet the demand of housing in the city, different types of apartments and villa houses are under construction. However, renewable energy integrated buildings are hardly considered in the construction of theses housings. This can lead to an energy intensive housing system in the near future. Solar technologies can be installed even after the construction of buildings. In the design of solar built environment, several scenarios have to be considered. The resource availability is the first issue to be addressed. A solar energy resource decreases when going from equator to north or south. Ethiopia, which is found near the equator, has a potential to utilize huge available solar energy in buildings. Availability of solar technologies with affordable price is the other main issue to employ solar built buildings. The type of solar technology depends on the required heating/cooling load in a building.

3. Methodology

So as to select an affordable solar cooling technology for Bahir Dar city, it is crucial to study different solar cooling technology, potential of solar irradiation and cooling load demand of the houses. Depending on people income level and type of building, two case studies will be considered. Low income level people are most likely to live in low cost housing (Condominium) while people with high income level live in villas (such as Impact Real Estate), which are mostly found in the suburb of the city. For these reasons of solar cooling, condominium apartments and Impact Real Estate are the two case studies considered in this study. A study of household energy demand and internal heat gain of the two cases mentioned will be done by interviews to gather information on household energy demand and material of construction for both cases by preparing questionnaires for household responsible and for construction managers. Then using IDA ICE software cooling loads for the two house cases will be determined. Depending on the simulated load, appropriate solar cooling technology will be selected.

4. Solar Sorption Refrigeration

The process of attracting and sustaining gases or liquids is described as sorption. In sorption refrigeration the solar thermal energy is directly converted to cooling effect by physical or chemical attraction between a pair of substances. The pair of substances are sorbate and sorbent. Sorbate is a substance having lower boiling temperature and plays the role of the refrigerant. The sorbent has the ability to attract and hold other gases or liquids [7].

Sorption refrigeration system can be classified as closed and open sorption system. Closed sorption system includes absorption and adsorption refrigeration. Desiccant refrigeration is an open sorption system [8]. Absorption is a type of sorption process in which the sorbent absorbs a refrigerant molecule internally and changes its property (physical or chemical) in the process. Adsorption involves a solid sorbent and does not involve phase change during the process; rather the sorbent only increases by weight due to the adsorbed sorbate. The major difference between absorption and adsorption is the nature of sorbent and the duration of the process which is longer for adsorption [9]. Desiccants are sorbents having a special attraction to water. Here the sorbent or desiccant, absorbs moisture from humid air without changing the physical characteristic of the desiccant [8].

4.1 Absorption

Absorption is the most common types of solar refrigeration system. It is a reversible process. For the same capacity it has smaller physical dimensions than adsorption due to the high heat transfer coefficient and fluid property of absorbent. The phenomena in absorption refrigeration include fluid phases having strong affinity [7, 10].

As shown in Fig. 1 the main components of absorption chillers are generator, absorber, condenser, evaporator, pump and expansion valves. The generator is a component in which desorption (regeneration) takes place using heat and the absorber is a component where sorption takes places. Cooling is formed in the evaporator where the refrigerant is vaporised by removing a cooling load of Q_e. The vaporised refrigerant goes to absorber and is absorbed by the sorbent. Here the dilute solution of sorbent sorbate is formed and pumped to generator. In order to increase the efficiency of the process, cooling is done. The heat Q_g produced by the solar collector regenerates the sorbent in generator that absorbs the refrigerant (sorbate) in the absorber. The concentrated vaporised refrigerant goes to condenser where heat (Q_c) is rejected, whereas the sorbent goes to absorber to absorb the coming refrigerant from the evaporator by rejecting a sorption heat Q_a to the ambient. The condensed refrigerant goes to evaporator for another cycle [9].

A fundamental requirement of refrigerant/sorbent mixture is the margins of miscibility that must be in the range of operation temperature of the cycle. In addition they must be non-toxic, chemically stable and non-explosive. There are many types of working fluids, but water/NH_3 and LiBr/water are most commonly used. In the first case NH_3 is the refrigerant and in the second one water vapour is the refrigerant. The water/NH_3 system needs a rectifying column to assure no water vapour enters in the evaporator, which results freezing

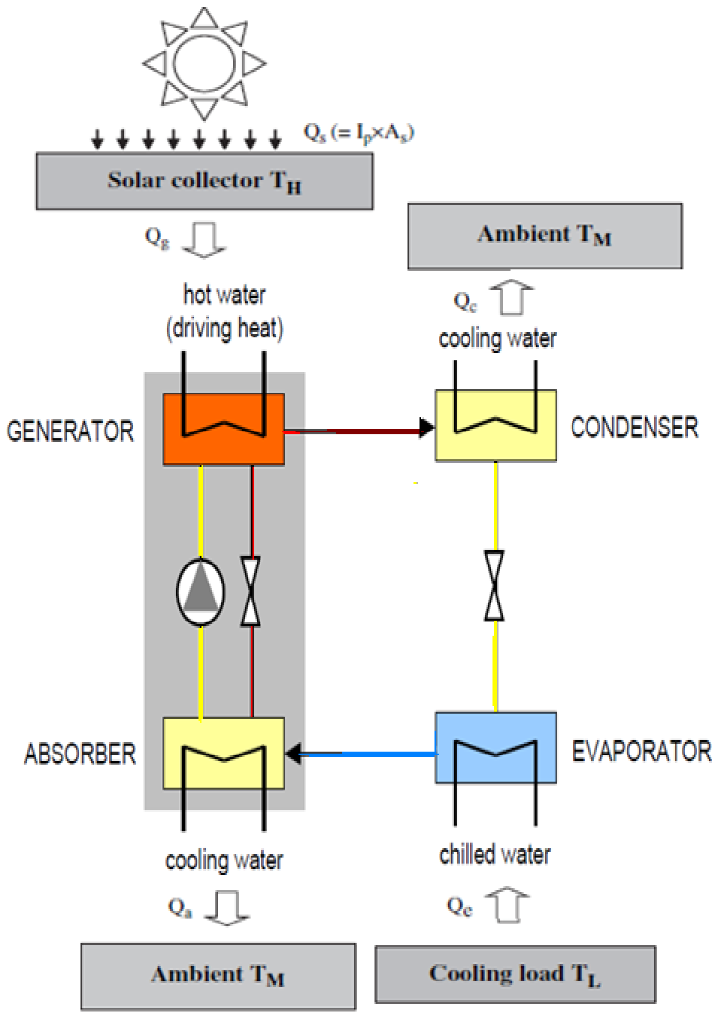

Fig. 1 Schematic diagram of closed solar sorption refrigeration [7].

in the evaporator. In addition the system needs a high generator's temperature. Generally NH_3/water system is usually used for refrigeration in industrial applications, while LiBr/water systems are common in air conditioning applications [9, 11].

A single effect water/NH_3 solution with a heat source regeneration temperature of 80 to 120 ℃ can give a COP of 0.3 to 0.7. A LiBr/water absorption chiller usually works with a heat source temperature of above 88 ℃ and results a COP of 0.6. Even though these systems can operate with flat plate collectors usually to obtain a higher COP they are equipped with an evacuated type collector especially for LiBr/water working fluid. For a double effect LiBr/water absorption chillers a regeneration temperature of 150 ℃ is required which is obtained by concentrated type collector [11].

Most commercial available absorption chillers have a capacity of 100 kW and a small capacity less than 50 kW is very rare [12]. But recently small capacity even less than 10 kW are becoming available in market. SolarNext a German company produces a 10 kW single effect NH_3/water absorption chillier and it requires a supply hot water temperature of 68 to 75 ℃. The produced chilled water temperature and COP are 19 to 6 ℃ and 0.64 respectively. Another small-scale market available absorption chillier is developed by Rotartica Company in Spain. It is a single effect LiBr/water having a cooling capacity of 4.5 kW. For a regeneration hot water supply of 90 ℃ its COP will be 0.7. By varying the supply temperature different COP and chilled water can be obtained [11].

4.2 Adsorption Chillers

Adsorption process results from an interaction between a solid (adsorbent) and fluid (refrigerants). Depending on the type of adsorbent and refrigerant reaction, the reaction can be categorised as physical and chemical adsorption. In physical adsorption the adsorbents are highly porous and have high surface to volume ratio that can selectively catch and hold refrigerants through Van der Waals force [9]. Common working physical adsorbent refrigerant pairs are activated carbon-methanol or ammonia and silica gel-water. Strong chemical bond between the refrigerant and the adsorbent is characteristic of chemical adsorption. This strong bond makes the process complex as it needs more energy in order to regenerate and reverse the process than the physical adsorption process. The most common chemical adsorbent used in solar cooling system is calcium chloride ($CaCl_2$) with ammonia and water as a refrigerant [7]. In solar powered adsorption activated carbon, silica gel and zeolite are common types of adsorbents while water, methanol, ethanol and ammonia are common refrigerants used [9]. Silica gel-water is the best combination adsorption refrigeration due to its low regenerating temperature. It can operate with a supply hot water temperature of 45 to 90 ℃. This temperature can be achieved by flat plate solar collector. In addition it will enable the chillier to work more than 8 h in a day. At lower regeneration temperature a COP of 0.3 can be obtained [11]. Zeolite-water pair needs a regenerating temperature of above 200 ℃ and activated carbon-ammonia pair needs around 150 ℃. And these temperatures cannot be obtained by flat plate or evacuated type collector [13].

Components of adsorption chillers are similar with absorption chillers. The adsorption process can take place with a single adsorbent bed called fixed bed or multiple adsorbent beds. If fixed bed is used the process will operate without any moving parts which results in silence and high reliability. However, the process will be intermittent, as a result COP of the system will decrease; therefore, multiple adsorbent beds are required for continuous process to increase COP of the system [14]. For example in double adsorbent bed (Fig. 2), the refrigerant in the evaporator creates a cooling effect by vaporisation. Then it goes to bed 2 and is adsorbed by the sorbent bed while the refrigerant in bed 1 is regenerated by using hot water. In this case bed one acts as an adsorbent bed while bed 2 is a regenerator. For the second cycle bed 2 will act as a generator and bed 1 as an adsorber, the adsorbent bed is changed between regeneration stage and adsorption stage so as to form a pseudo cyclic system [13].

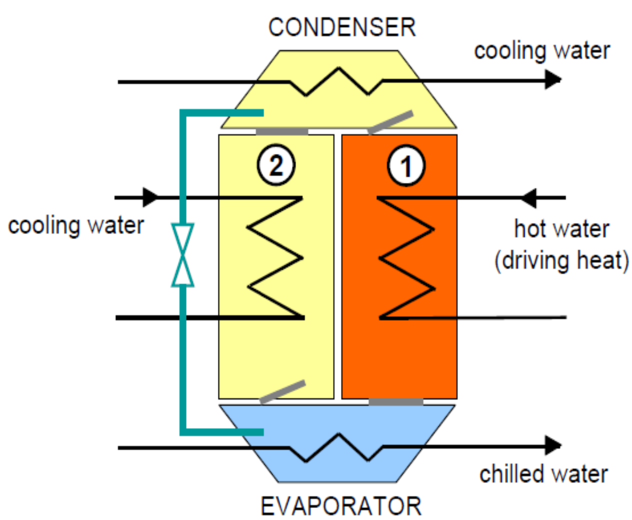

Fig. 2 Working principle of adsorption chillers [13].

Unlike absorption process crystallization and corrosion are not a problem in adsorption process. It is much flexible in regeneration temperature and can be best applicable for part load process [14]. The principal limitations of the adsorption system are weak heat and mass transfer character of the adsorbent beds. The adsorbents such as zeolites, activated carbon and silica gel have low thermal and poor porosity characteristics, as a result its components (collector/generator/absorber) are bulky and expensive. And thus, its excessive heating capacity leads to rather low thermal COP [9]. Optimum adsorbent bed structure lies between a high porosity required for fast vapour diffusion and the high density required for good thermal conductivity. To improve the mass and heat transfer of the adsorbent bed so as to decrease the size and cost of the system, addition of packing density of adsorbent, using selective coating material, using heat transfer fins, employment of consolidated adsorbent and selecting a suitable working environment are the main technologies [14].

Most market available adsorption systems working fluids are water/silica gel with capacity that ranges between 50 kW and 500 kW [13]. For residential application with small cooling capacity adsorption chillers are very limited in the market. Sortech, a German company developed a water/silica gel adsorption chillier with a capacity less than 10 kW. At a regeneration temperature of 75 to 67 ℃, it produces 5.5 kW capacities with 18 to 15 ℃ chilled water production [11].

4.3 Solar Desiccant Cooling

Open sorption system is usually called desiccant cooling where the desiccant or sorbent is used to dehumidify air. The conventional air conditioning systems usually do not control the humidity but only the temperature of conditioned space. If they do, they control it indirectly through temperature. But, desiccant cooling systems directly achieve the dehumidifying process through the use of desiccant materials [15] and this makes a desiccant cooling system a complete HVAC (heating ventilating and air conditioning) system. Desiccant materials have the ability to absorb water. Silica gel, activated alumina, zeolite, LiCl and LiBr are examples of desiccant or absorbing sorbents [7].

Basically there are two types of desiccant systems: liquid and solid depending on the phase of sorbent used. In liquid desiccant cooling technology both the liquid and the air flow between a dehumidifier and a regenerator. The working fluid for liquid desiccant is LiCl/water which works at atmospheric pressure, that will reduce the cost of sealing when compared to absorption chillers. It can be used with a low temperature of 40 ℃. However, this technology has a problem of corrosion which is formed by inorganic salt and the container. To solve this problem a polymer type of equipment is used. Due to the liquid working fluids its systems are big and also not available in the market; however research and developments are ongoing [11].

A typical solid desiccant cooling system is shown in Fig. 3. Unlike the liquid, it is more compact. The return air from the conditioned space passes through an evaporative cooler and becomes cold and humidified (5→6). Then it passes through a sensible heat exchanger and becomes warmer (6→7).

This warm and humid air passes through the solar heating coils and becomes hot and humid air (7→8), which heats and regenerates the desiccant wheel while passing through it and exhausts to the ambient (8→9). Fresh air passes through the regenerated desiccant wheel where water in the air is absorbed by and becomes dry and hot (1→2). This dehumidified hot air enters into the sensible heat exchanger and cools down (2→3) by preheating the cold air (6→7). After this, it can be directly supplied to the conditioned space or cools down by the evaporative cooler if necessary (3→4). Evaporative cooler is used to adjust the humidity and temperature if necessary. The sensible heat in the air will evaporate the water in the evaporative cooler and results in a lower temperature and higher humidity content of supply air to the conditioned room [7].

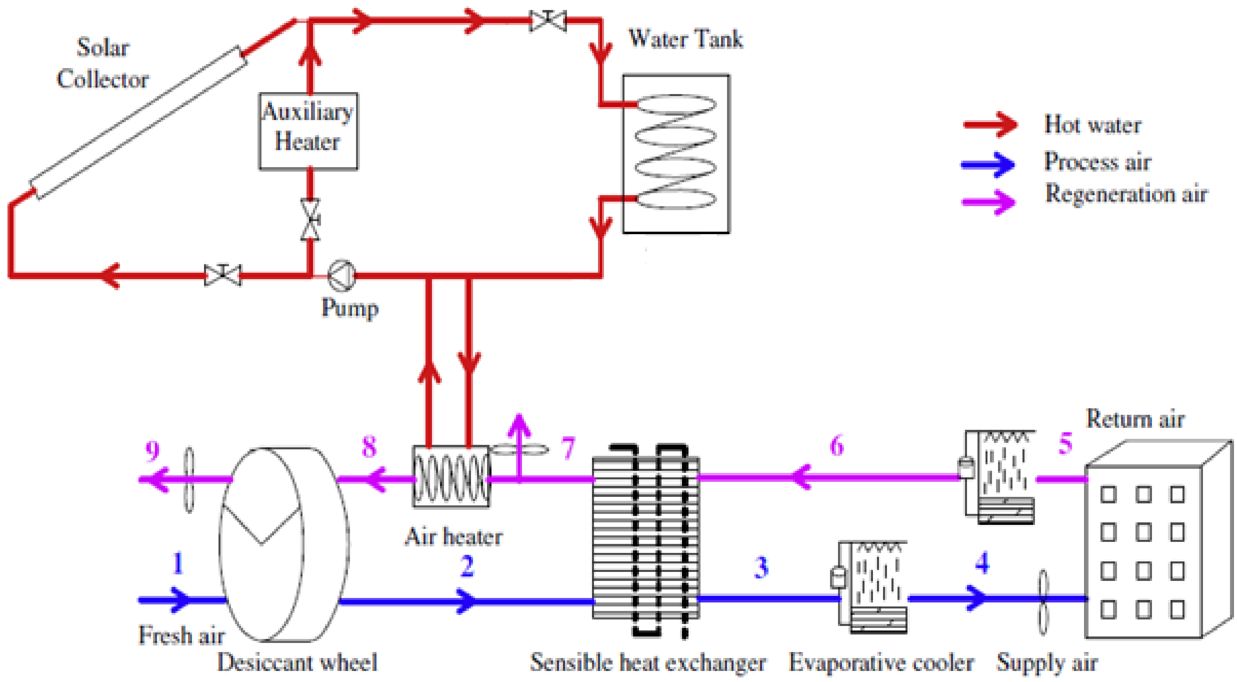

Fig. 3 Schematic diagram of solar solid desiccant cooling [16].

This type of desiccant system is applicable for temperate zones where the dehumidification process is not as high as compared to Mediterranean countries [12].

LiCl and silica gel are widely used in solid desiccant wheel with regeneration temperature of 60 to 120 ℃ and 80 to 150 ℃ respectively. Compared to the other types of desiccant LiCl has a high moisture removal capacity. Researches show that using a composite desiccant such as silica gel haloids it is possible to increase a moisture removal of 20 to 30 percent compared to silica gel alone [11].

Desiccant cooling is a complete HVAC system and performs more efficiently in humid climate than all sorption systems. It is easy for maintenance and reliable but when compared to other sorption systems it is big in size and complex for residential installation. It is very expensive and problems related to installation of the complex system components while connecting to the solar heating system, results in problem of unsuccessful integration with buildings [15].

Commercial availability of this technology is very limited especially in small size. In China 11 kW cooling power desiccant wheel is installed for demonstration. Experiment shows that when the outdoor condition is 35 ℃ and 23.2 g/kg of relative humidity, it supplies air at temperature of 25 ℃ and relative humidity of 17.7 g/kg [11].

5. Estimation of Solar Radiation in Bahir Dar City

Bahir Dar city is found at latitude and longitude of 11.15 °E and 37.77 °N, which is in north western part of Ethiopia at 578 km from Addis Ababa the capital city. The city is placed on the northern shore of Lake Tana (the largest lake in Ethiopia and the source of the Blue Nile River (Tis Abay)). It is the capital city of the Amhara region.

Majority of the year season is summer. June, July and August months are winter seasons having high rainfall and relative humidity (up to 81 percent) in relative to other months as shown in Fig. 4. As a result the ambient temperature drops in these months. The rest of the year is summer season (relatively hot and dry), in which there is low relative humidity (minimum of 46 percent). The highest temperature recorded is in March, April and May.

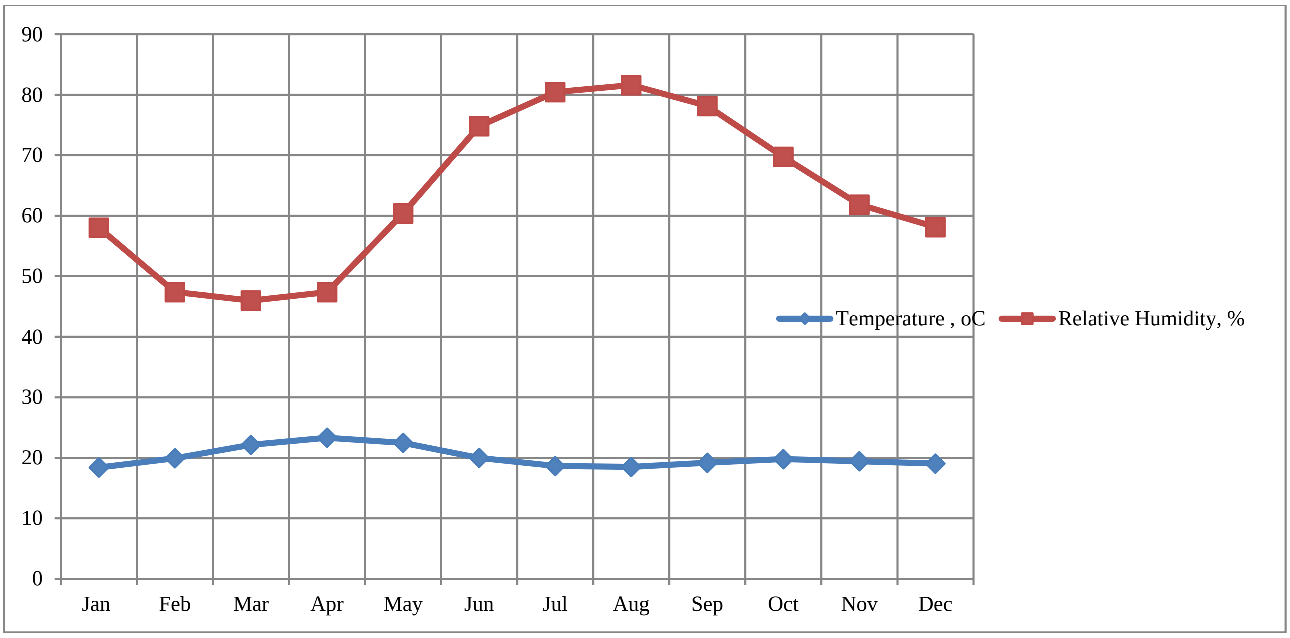

Fig. 4 Monthly average temperature and relative humidity of Bahir Dar city.

In order to select solar cooling system for the city, the amount of solar irradiation must be known. NMSA (National Metrological Agency Service) is responsible for supplying metrological data of weather in the country. But regularly recorded data of solar irradiation are not available for all regions, only for Addis Ababa city. For the city available metrological data found are sunshine hour, temperatures (monthly minimum and maximum), relative humidity and wind speed. Therefore, global solar irradiation is estimated using an empirical formula called Linear (1) and Quadratic Angestrom (2) method. These empirical formulas correlate sunshine hour with global solar radiation. Global solar radiation that is the total solar radiation is measured on a horizontal surface and it can also be measured using pyranometer instrument [17].

$$H/_{Ho} = a + b\left(\frac{n}{Nd}\right) \quad (1)$$

$$H/_{Ho} = ao + a1\left(\frac{n}{Nd}\right) + a2\left(\frac{n}{Nd}\right)^2 \quad (2)$$

where, H = monthly average of the daily global radiation on a horizontal surface, W/m^2.

H_o = average value of daily extraterrestrial solar radiation on a horizontal surface for each month, W/m^2.

n = monthly average of daily bright sunshine hours.

N_d = average of the maximum possible daily hours of sunshine.

a, b, a_0, a_1, a_2 are dimensionless empirical coefficients

The coefficients a, b, a_0, a_1, and a_2 are 0.385, 0.348, 0.0317, 1.54 and -0.936 for Bahir Dar city respectively [17]. Average calculated values using Eqs. (1) and (2) and the given parameters are shown in Table 1.

Solar radiation results from linear regression formula align with solar radiation from NASA in Fig. 5. The result from quadratic regression formula deviates by increasing in March, April and June months and decreasing in July and August months. Therefore, linear regression can be taken as a best solar radiation estimation method for Bahir Dar city. The city has minimum irradiation in July and August and a maximum in March, April and May (Fig. 5). It has an average monthly daily solar irradiation of 250 W/m^2. Compared with an average value of Ethiopia which is 231.48 W/m^2 it gets a higher solar irradiation [18].

Table 1 Average solar irradiation calculated results.

	H_{Linear} (W/m^2)	$H_{Quadratic}$ (W/m^2)	H_{NASA} (W/m^2)
Average	252.25	250.12	249.81

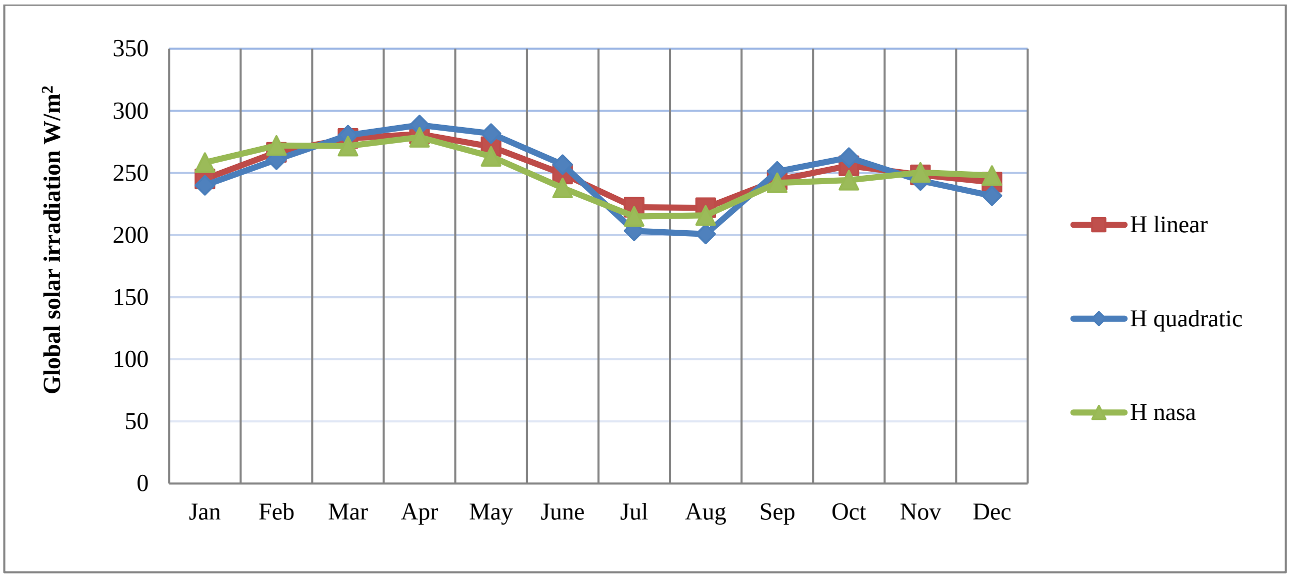

Fig. 5 Comparison of solar irradiation results.

6. IDA ICE Software and Building Description

Cooling load is the amount of heat that must be removed from a building in order to meet the design conditions of temperature and humidity for comfortable zone [19]. Cooling load estimation of the buildings is simulated using IDA ICE software. It can model a building with one or more rooms with existing heating and ventilation systems [20]. A room to be conditioned is called zone. A zone can be one or more rooms together that have uniform heat gain [19]. One house in both cases is taken as one zone and after simulation of the cooling load of one zone then, it is multiplied by the total number of houses in the building.

Inputs for load simulation are climate data, type of material of construction, AutoCAD drawing of floor plan, orientation, and internal heat gain that include occupant and different appliance. Internal heat gain for the two house cases generated from interview is shown in Table 2. Climate data for the software input are generated from METEONORM software by using the latitude, longitude, elevation and time zone as input parameter [21].

Heat transfer or energy exchange between the indoor and outdoor environment is dependent on the type and property of building envelope. Table 3 shows *U*_values for different building envelope that is dependent on thickness and material type. Materials of construction for condominium apartment and impact real-estate are more of similar except finishing parts such as wall paints and tile finishing floor that are common for impact real-estate.

6.1 Condominium Building Description

The selected model condominium house (Fig. 6) is located in Abay Mado site. In this site, there are three buildings, each with ground plus four. In one floor there are five numbers of zones (houses) with a total of twenty five zones in one building. The selected house has one bed room, living room, kitchen and bath room. It is oriented towards south and has a floor area of 27 m^2 and a height of 2.6 m. It has a total of four windows and one entrance door. The average number of occupant is four.

6.2 Impact Real Estate Building Description

Impact Real Estate is a private limited company which builds luxury homes. The selected modal zone has 500 m^2 surface areas with a floor plan area of 162 m^2 and 2.6 m height.

Table 2 Internal heat gain of Impact Real-Estate and Condominium.

	Impact Real-Estate	Condominium
	Heat gain (W)	Heat gain (W)
Occupant	808.12	461.78
Lighting		
Bulb	168	48
Equipment		
Television set	21.67	21.67
Radio/tape	4.67	1.49
Refrigeration	40	40
Stove	68.75	-
Micro-oven	125	-
Laundry machine	562.5	-
Desktop computer	14.37	-
Total internal heat gain	1,813.08	572.94

Table 3 Characteristics of building envelop [22].

	Thickness (mm)	*U*_value
External wall	312.5	0.6629
Internal wall	146	0.6187
Window	1 pane glazing	5.8
Floor	125	1.025
Roof	708	0.172

Fig. 6 3-D diagram of one zone of condominium building from IDA ICE software.

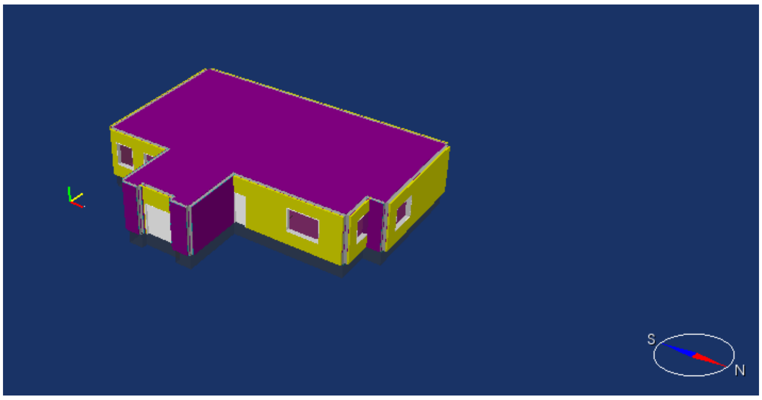

Fig. 7 3-D diagram of Impact Real Estate from IDA ICE.

The 3-D diagram of Impact Real Estate from IDA ICE is shown in Fig. 7. It has three bed rooms, two bath rooms, one guest bath room, one modern kitchen, and one salon and ten windows. There are a total of 25 such zones and are oriented to east wards. The number of occupant is assumed to be seven.

7. Results of IDA ICE

The simulation result includes heat removed (cooling load) in watt, dry bulb and operating temperature in degree centigrade, and PPD (percentage of dissatisfaction) for the single and total zone (Table 4). Cooling design results are simulated at the time of maximum cooling load, which is the maximum heat that must be removed from the conditioned room in order to satisfy the occupants. It is the capacity of cooling equipment device. Heat gain is the rate at which energy is generated within or transfer to a space. But only when the indoor air receives the energy by convection does this energy become cooling load. The radiant energy gain from different sources does not directly heat the indoor air but first it is absorbed by interior envelops and masses.

From simulation results, cooling equipment capacity should have a maximum of 5.53 kW for condominium (for 25 zones) and 5.73 kW (for 2 zones) for Impact Real Estate (Table 4). Cooling load of Impact Real Estate is higher than condominium, mainly due to its high internal heat gain (Table 2) and larger surface area of windows. However, the design main temperatures (Table 5) of condominium are higher than Impact Real-Estate, which result in high PPD value for condominium (98.69 percent) than Impact Real Estate (93.96 percent). This is mainly because heat gain per unit area of condominium is higher than Impact Real Estate, even though there are relatively high internal heat gain sources in Impact Real Estate. For the same heat gain if large and small buildings are compared, keeping the other factors similar, heat gain per unit area of small building will be higher than the larger building. This results in a higher operative temperature for the smaller building.

7.1 Main Temperatures

Main temperatures in IDA ICE software are indoor operative and mean air temperature. The average value for both houses can be seen in Table 5 and monthly values can be seen in Fig. 8. Condominium gets its minimum main temperature in June, July and August and maximum in March and April. Impact Real Estate attains its minimum main temperature in January and August, and maximum in March, April and May. Average main temperature of condominium (28.7 ℃) is higher than Impact Real Estate (27 ℃). This is mainly because heat gain per unit area of condominium is higher than Impact Real Estate.

When the average main temperature results are compared to the comfort condition [23], almost in all months both houses are not in a comfortable condition so that cooling system is required. Only in November, December, January months the operative temperatures of Impact Real Estate houses are 26, 25.2 and 24.8 ℃

Table 4 Cooling design results of IDA ICE.

	Zone multiplier	Cooling load (W)	Mean air temperature (℃)	Operating temperature (℃)	PPD (%)
Condominium	1	221	32.1	31.82	98.69
	25	5,525			
Impact Real Estate	1	2,863	31.21	30.7	93.96
	2	5,726			

Table 5 Average mean air and operative temperature of Condominium and Impact Real-Estate.

Condominium		Impact Real Estate	
Mean air temperature (℃)	Operative temperature (℃)	Mean air temperature (℃)	Operative temperature (℃)
28.7	28.5	27.2	27

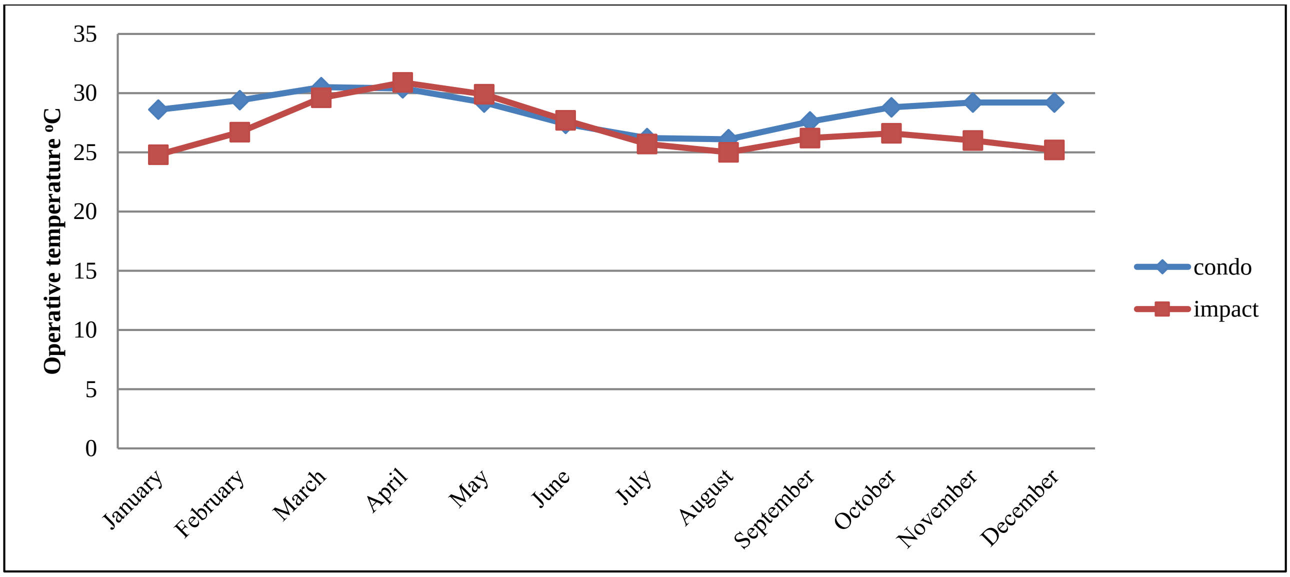

Fig. 8 Operative temperature of condominium and Impact Real-Estate.

respectively and it shows that occupants are in a comfortable zone and no cooling or heating system is required.

7.2 Total Heat Balance

Average values of heat balance can be seen in Table 6 and Fig. 9. It shows that heat gain through envelop, window and thermal bridges reduces building heat gain and becomes heat loss whereas direct solar, equipment, occupant and lighting add cooling load. The average total heat gain of condominium is 174 W while for Impact Real Estate it is 266.6 W per zone. These result in a total heat gain for the whole building approximately equal to 4,350 W (25 zones) and 533 W (2 zones) respectively. For both houses direct solar irradiation is the maximum heat gain with an average value of 434 W for condominium and 1,471 W for Impact Real Estate. Heat loss through walls and floors shares the maximum heat loss from both houses.

Condominium attains minimum heat gain in July and August (121 W and 117 W respectively) while Impact Real Estate minimum heat gain is in January and August (193 W and 195 W respectively) (Table 7). Both houses attain maximum heat gain in April which is 397.7 W for Impact Real Estate and 216.7 W for condominium. This is because the maximum heat gain source which is solar irradiation increases in this month which is the local summer season.

Table 6 Total heat balance of condominium and Impact Real Estate.

	Condominium	Impact Real Estate
Thermal bridges (W)	-37	-137.2
Walls and floors (W)	-445.6	-1,897.3
Direct solar (W)	433.8	1,471.5
Equipment (W)	76.8	837
Windows openings (W)	-191	-689.3
Lighting (W)	46.3	162.1
Occupants (W)	292.2	538.2
Air flows (W)	-1.5	-18.4
Total heat balance (W)	174	266.6

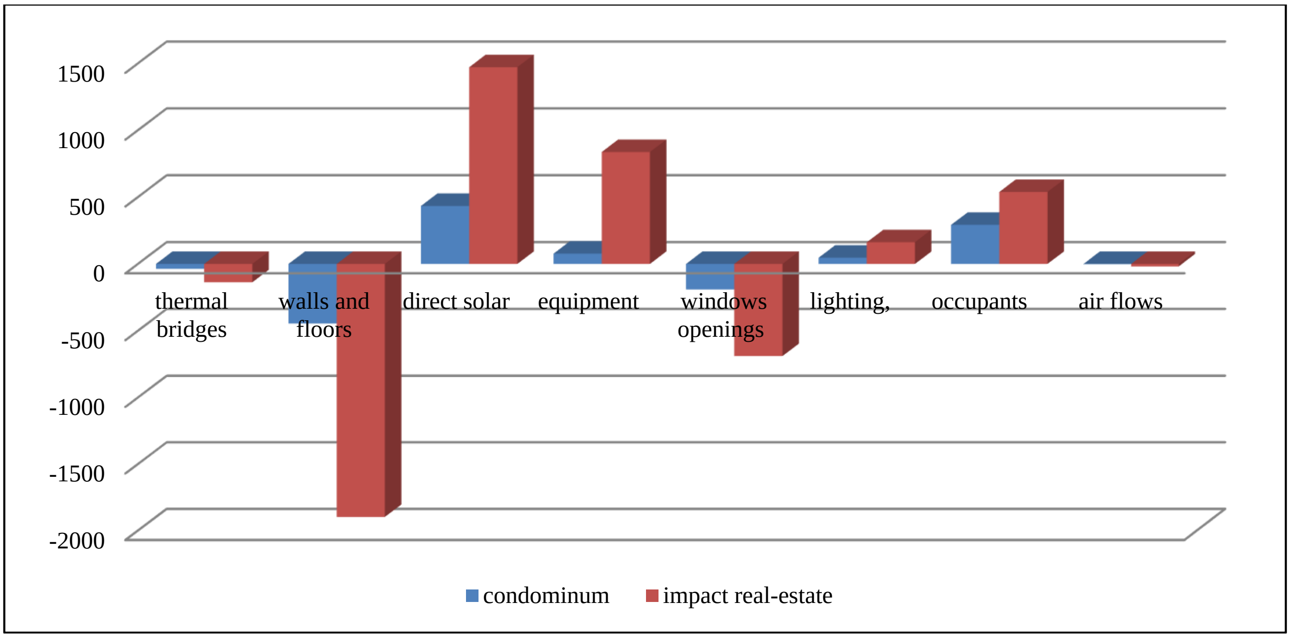

Fig. 9 Total heat balance of Condominium and Impact Real Estate in Watt.

Table 7 Monthly average total heat balance in Watt.

Month	Impact Real Estate	Condominium
January	192.9	176.7
February	244.6	192.2
March	336.9	213.3
April	397.7	216.7
May	389.4	187
June	282.6	145.2
July	218.5	121.5
August	194.8	116.8
September	241	154.4
October	267.4	185.5
November	225.1	187.8
December	209.3	191.9
Mean	266.6	174

8. Conclusion

Bahir Dar is located in tropical zone, and it gets quite enough solar irradiation, about 250 W/m^2. It has minimum irradiation in July and August (local winter seasons) and a maximum in March, April and May (local summer seasons).

Houses of Impact Real Estate Villa are bigger in size than the condominium houses. As a result, the total heat gain per zone of the Impact Real Estate villa house was around 267 W whereas this value for condominium house was 174 W. For both houses direct solar irradiation shares the highest source of heat gain while building envelope shares the highest heat loss. At an operating temperature of 30.7 ℃ and 31.8 ℃, IDA ICE simulation gave design cooling loads of 5.53 kW and 5.73 kW for 25 zones of condominium and for 2 zones of Impact Real Estate Villa respectively.

A single effect water/NH_3 vapour absorption chiller with a regeneration temperature of 80 to 120 ℃ has a COP value in the range of 0.3 to 0.7. A LiBr/water absorption chiller usually works with a heat source temperature beyond 88 ℃ and has COP value of about 0.6. These systems operate using evacuated tube solar collector to have better performance. Though its COP is low, about 0.3, silica gel/water adsorption chiller can operate at regeneration temperature as low as 45 ℃. This temperature can easily be achieved using a simple flat plate solar collector and also it will enable the chillier to work more than 8 h in a day. Zeolite/water pair needs a regenerating temperature of above 200 ℃ and activated carbon/ammonia pair needs around 150 ℃. These temperatures cannot be achieved from flat plate or evacuated type collectors. Thus, silica gel/water adsorption chiller having a capacity of 7 kW is proposed for both houses.

9. Recommendation and Future Work

Solar irradiation through windows and openings is the highest heat gain in both cases. Hence, it is recommended if roof overhang or other direct sunlight blocking system is integrated in the building.

The ambient temperature is less than the indoor operative temperature so that passive technology such as solar chimney that ventilates the room can be considered and further investigation should be taken.

Future work can be done on design of solar cooling system that considers simulation of the whole solar cooling system with the building.

In addition to solar potential resource Ethiopia also has a biomass potential so further investigation is recommended on this resource.

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