

Energy-Efficient Cooling Systems for Buildings: an Analysis of Solutions Using the Example of the Equatorial Climate

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Abstract: The article is devoted to selecting the most efficient cooling system for public buildings in an equatorial climate, using Colombia as an example. Both traditional energy sources and renewable sources are considered. Special attention is paid to solar energy use. Equatorial countries have abundant solar resources (4.5 – 6 kWh / m² per day), but most electricity is still generated by thermal power stations, which has a negative impact on the environment. The main goal of the study is to find methods to reduce energy use and operating costs for refrigeration systems in air conditioning systems. After economic analysis, an integrated system including an absorption chiller and solar thermal installation was found to have a 40 percent increase in capital expenditure compared to traditional chillers. However, absorption chillers have a significant 78 percent reduction in energy use compared to their traditional counterparts. This is a significant improvement, confirming the effectiveness of this system in minimizing energy costs.

1 INTRODUCTION

The interest in the research topic arises from the global energy conservation policy, the trend of increasing urbanization worldwide, and the need to maintain comfortable microclimate in buildings (Sarbu, 2021). The main issue is developing energy-efficient refrigeration systems that can provide optimal conditions in different temperature and humidity conditions (Zhang, Li, Wang, 2024).

The objective of our work is to select a building cooling system based on either traditional or renewable energy, especially solar energy (Kyere, Tien-Chien, Tartibu, 2023). The object of study is the BURO25 building in Medellin, Colombia in 2019, a five-story structure with an area of 3,100 m². It has a glass facade and is made of brick and concrete. The building provides office space, which also houses a call centre for 750 employees.

The Colombian Institute of Hydrology, Meteorology, and Environmental Research (IDEAM) predicts that average temperatures in Colombia will rise by 1-2°C by 2050, so we need to reduce energy

use in air conditioning. This means switching from fossil fuels to solar energy is important. Most electricity in Colombia comes from thermal power plants using oil, coal and gas, but there is also solar potential. The average daily solar radiation in the country is 4.5 kWh/m², with some areas reaching up to 6 kWh/m².

We will analyse climate data, examine existing systems, evaluate their energy efficiency, determine criteria for choosing the best system, and formulate recommendations for optimizing energy consumption.

The practical importance of this work lies in the reduction of energy consumption by refrigeration systems and the corresponding savings in operational costs.

The anticipated results of this study will enable the formulation of conclusions regarding the effectiveness of various refrigeration systems and propose methods for their improvement.

This research is potentially significant for the advancement of modern refrigeration technologies under conditions of extreme climatic stress,

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particularly crucial for developing countries in tropical zones.

2 DESCRIPTION OF THE OBJECT OF RESEARCH AND THE METHODS OF THE WORK PERFORMANCE

To determine the calculated outdoor climate parameters, archived data from the Medellín/Olaya Herrera meteorological station for 2024 were used (Institute of Hydrology, Metrology, and Environmental Research of Colombia, 2025). The obtained data are presented in Figure 1.

In Medellín, the highest temperatures were observed from January to March, so January was chosen as the calculation month.

To more accurately calculate the outdoor air parameters, hourly data on temperature, relative humidity, and wind speed for each day of January were obtained from the website (Power Data Methodology, 2025). Specific enthalpy and moisture content were determined using an I-d diagram taking into account temperature and relative humidity. Climate data were selected based on the methodology outlined in SP 131.13330.2025.

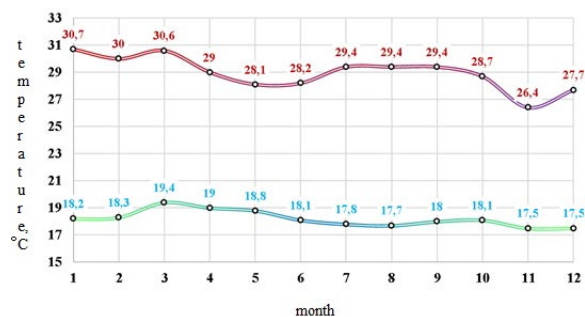


Figure 1: Temperature change throughout the year. Average daily maximum temperature (red line) and average daily minimum temperature (green-blue line).

According to the results obtained for the selection of air conditioning systems, the estimated outdoor air temperature is 22.82 °C, relative humidity is 61.89 %, wind speed is 1.04 m/s, specific enthalpy is 48.16 kJ/kg, and moisture content is 10.3 g/kg.

As a rule, the calculated indoor air parameters in Colombia comply with the requirements of paragraph 5 of the ASHRAE standard (American Society of Heating, Cooling and Air Conditioning Engineers) (ANSI/ASHRAE Standard 55-2023) (Figure 2).

The indoor air temperature is assumed to be – 21.5 °C, which is also within the permissible range according to GOST 30494 – 2011.

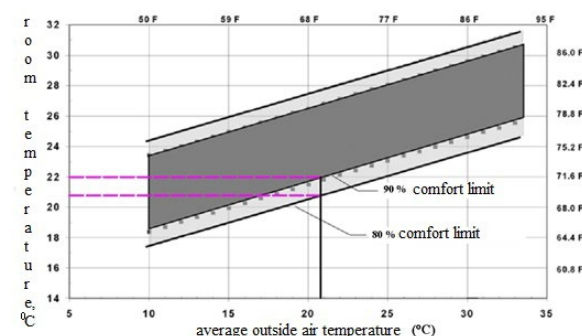


Figure 2: Operating temperature ranges.

Further, all possible types of heat input were calculated for the building under study: from people – 59 kW, from lighting - 20 kW, from equipment – 61.5 kW, from solar radiation through enclosing and translucent structures - 70.5 kW. Accordingly, with known heat surpluses in the building and air parameters, the total cold demand will be 191.5 kW.

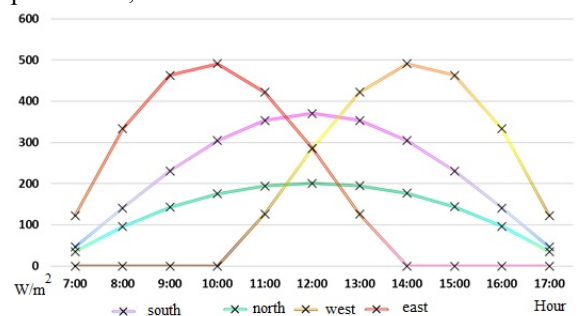


Figure 3: Solar radiation by the hour, arriving at a vertical surface of different orientations, W/m² (Nazarov, Saliev, Makhmudov, Abdullaev, 2015).

The refrigeration systems considered in the study provide two implementation options (Bollin, Striebel, Becker, Ritzenhoff, 2023). The first option involves using a vapor-compression refrigeration system (classical scheme) (Kirkpatrick, 2023). The second option is based on using an absorption refrigerant system operating with solar collectors (ABC scheme) (Hadj Ammar, Benhaoua, Bouras, 2017). Both options support the operation of a central air handling unit with an air cooler and cassette fan coil units (local air handling units) in the rooms.

One of the main processes in a continuously operating refrigeration machine consuming mechanical or thermal energy is the compression of the working fluid. Machines in which this process is

accomplished by compressors are called compressor-type machines; when using thermochemical compressors operating on the principle of chemical absorption, they are called absorption compressors (Saparov, Bekmyradov, 2023).

One promising approach to reducing the load on buildings' electrical power from air conditioning systems is the use of Absorption Chiller (ABC). In these machines, cooling is achieved by consuming thermal energy rather than electrical energy (as in vapor-compressor refrigeration machines). In this case, thermal energy can be efficiently generated using a solar thermal system. Using a solar thermal system is highly cost-effective, as it significantly reduces thermal energy production costs (Alemu, 2025).

Currently, lithium bromide absorption refrigeration units are the most widely used. These units are designed to cool water to 4°C. Low-pressure steam at 125°C or hot water at 90 to 120°C can be used as the heating medium. Lithium bromide refrigeration units should be located outdoors or in separate rooms of buildings according to SP 60.13330.20220.

A solar thermal installation or solar thermal system (STS) converts radiant energy into thermal energy and stores it as hot water before it is consumed by the refrigeration unit. The storage system smooths out temperature fluctuations that solar energy cannot provide continuously throughout the day.

The basic diagram of a STS can be divided into the following main groups of elements: a conversion system that transforms solar radiation into thermal energy, increasing the temperature of the working fluid; a heat exchange system between the working fluid circulating in the primary circuit and the working fluid of the secondary circuit; a storage system that stores thermal energy until it is required; and an auxiliary system that has energy available to reserve the expected power consumption.

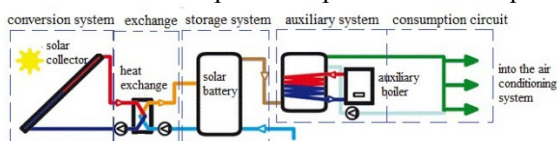


Figure 4: Schematic diagram of a system with a solar installation

A solar thermal system consists of a solar collector, a storage bank, a pump station, and a controller.

A solar collector is a device designed to convert solar energy into thermal energy to heat a coolant. Its main component is an adsorber, coated with a special black compound for maximum solar absorption. This

adsorber is a copper plate connected to a water circulation pipe within the system. When the copper plate is heated by the sun, the water in the pipe is heated.

Depending on their operating principle and design, there are three types of solar collectors: flat plate (efficiency from 50 % to 80 %), evacuated tube (efficiency from 67 % to 80 %), and tubular (efficiency from 65 % to 80 %) (Elistratov, 2016).

The designed building includes a refrigeration unit with a total system cooling capacity of 211 kW. The YHAU C-60 EXET (L) chiller was selected based on the manufacturer's electronic product catalog (YORK).

For the classic refrigeration system, a water-cooled chiller with scroll compressors and a nominal cooling capacity of 216 kW was selected. Based on the manufacturer's product catalog (Carrier), the 30RW-210 chiller was selected.

For the system with a condensing unit (CHU), a single-stage absorption chiller was selected, as two-stage systems are not suitable for solar collectors due to the high water temperatures they require.

Calculations for selecting a solar thermal system were performed in accordance with the Ministry of Energy's Guide for the Design and Installation of Large Hot Water Systems (Ministry of Energy, 2010).

The operating temperature of an absorption chiller varies depending on the manufacturer and application. It can reach 90°C, which is higher than the coolant temperature in a solar collector. Therefore, only evacuated tube collectors are suitable for such systems. The model of vacuum tube solar collectors THERMOMAX DF400 from LKN SISTEMES was considered, with the following technical characteristics in Table 1.

Table 1: Technical characteristics of evacuated tube solar collectors.

30-tube solar collector	
Absorption area, m ²	3,021
Dimensions, mm	1951 x 2125 x 93
Heat carrier capacity, l	5,6
Recommended slope	0 - 90
Collector optical efficiency, %	77
Nominal flow rate, l/h	240

The following technique will help to calculate the efficiency of a solar vacuum collector in the first approximation (Ministry of Energy, 2010):

1. Calculate the daily heat consumption.

Our ABHM chiller requires 11,600 liters per day at 95°C, according to the technical specifications.

Therefore, heating 13,000 liters of water from 30°C to 95°C would require 983 kW.

2. Calculate the power of the solar vacuum tube (Raam Dheep, 2025.).

The solar radiation on a surface inclined at 45° to the horizon and facing south, based on data for January, per square meter is 4.5 kW/day. With a collector efficiency of 0.77 (Table 1) and the absorption area data specified for the entire THERMOMAX DF400 vacuum collector (consisting of 30 tubes), the absorption area of one glass tube can be determined as $3.021/30 = 0.1 \text{ m}^2$. The power of one tube is then: $3.47 \cdot 0.1 = 0.35 \text{ kW} \cdot \text{h}$.

3. Calculating the required number of tubes (Stieglitz, Platzer, 2024).

Determine the number of tubes to be installed. The energy transmitted by one vacuum tube is 0.35 kW, so a total of $983/0.35 = 2816$ tubes is required. It is recommended to use 94 30-tube collectors.

For a volume of 13,000 liters, two 5,000-liter storage tanks and one 3,000-liter storage tank were selected. A pumping station with four pumps was also installed to ensure tank filling and coolant circulation. The unit is a complete system, including a pump, electric motor, diaphragm pressure tank, pressure and flow sensor, control system, and check valve.

Any water-cooled refrigeration unit must remove the heat released during refrigerant condensation. Similarly, absorption and vapor-compression units require heat removal using an open-circuit cooling tower.

For the first option, a water-cooled chiller with scroll compressors consumes 38 m³/h of water. Therefore, it was decided to use a cooling tower with a water flow rate in the range of 30–40 m³/h.

For the second option, a single-stage absorption chiller requires 52.8 m³/h of water. In this regard, it was decided to use a cooling tower with a water flow rate in the range of 50 – 60 m³/h.

3 RESULTS OF CALCULATIONS AND THEIR DISCUSSION

Within the framework of this study, detailed economic analysis will be carried out on two alternative solutions in accordance with (Samarin, 2015)

The first cooling option involves the use of a water-cooled chiller with a nominal cooling capacity of 216 kW.

The second option involves the use of a single-stage absorption chiller with a nominal cooling

capacity of 211 kW. In addition to the chiller, a solar thermal system is planned to serve as a source of thermal energy. The system will consist of 94 collectors. Four pumping units are installed to ensure uninterrupted filling of the storage tank.

Table 2 shows the general set of components for the cooling system (Kirkpatrick, A.T., 2023).

Table 2. Summary table of equipment costs.

Option 1		Option 2	
Chiller	\$ 25 000 (1 991 500 ₪)	Chiller	\$ 15 000 (1 194 900 ₪)
Cooling Tower 30 - 40	\$ 3 200 (254 912 ₪)	Cooling Tower 50 - 60	\$ 5 200 (414 232 ₪)
-	-	Solar Collectors	\$ 101 000 (8 045 660 ₪)
-	-	Accumulator Tank	\$ 11 200 (892 192 ₪)
-	-	Pump Station	\$ 1 300 (103 558 ₪)
Cassette Fan Coils	\$ 62 000 (4 938 920 ₪)	Cassette Fan Coils	\$ 62 000 (4 938 920 ₪)
Supply air handling unit	\$ 36 700 (2 923 522 ₪)	Supply air handling unit	\$ 36 700 (2 923 522 ₪)
Total cost	\$ 126 809 (10 108 854 ₪)	Total cost	\$ 233 079 (18 567 073 ₪)

The technical and economic calculations provide for an assessment of the economic feasibility of a solar thermal system, with a determination of its payback period. Additional capital expenditures for additional equipment are taken into account in this assessment.

1. We determine the capital costs (C) for the purchase and installation of equipment for the designed systems.

This also includes additional coefficients for automation costs:

- Installation increase coefficient – 65% of the equipment cost;
- Automation increase coefficient – 35% of the equipment cost.

2. The system's electricity consumption costs are determined based on an operating time of 8 hours per day, 240 days per year, including weekends.

Labor costs for the operation department and standard depreciation deductions are also taken into account. The total annual operating costs (O) were \$77,422/year (RUB 6,167,497/year) for Option 1 of

the refrigeration system and \$68,978/year (RUB 5,494,863/year) for Option 2, respectively.

Assuming that additional investor funds are used to purchase additional equipment and that operating costs are the same for each year, the total (over a period of years) discounted costs (TDC), discounted to the end of the calculation period, for each option are determined using the following formula:

$$TDC = C \cdot \left(1 + \frac{P}{100}\right)^T + O \cdot \left[\left(1 + \frac{P}{100}\right)^T - 1\right] \cdot \left(\frac{100}{P}\right)$$

As of 2024, the discount rate (p) in Colombia is 11.5%.

To assess the effectiveness of additional capital investments and determine their payback period, it is necessary to plot graphs of the time-dependent solar power consumption for the two options and find their intersection point (the orange line on the graph represents the solar power consumption without solar collectors, and the blue line represents the solar power consumption with solar collectors).

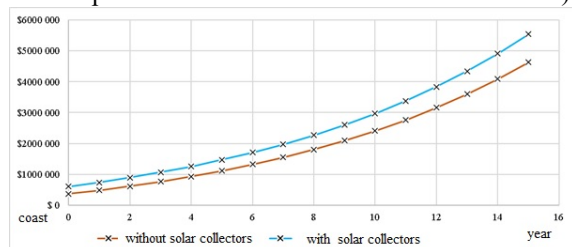


Figure 5: Graphs of the dependence of total discounted costs on time

As a result of the comparative analysis of two options based on monetary factors, it was found that the first option for organizing refrigeration has lower capital and operating costs than the second option, which involves higher financial costs.

4 CONCLUSIONS

To integrate renewable energy sources into the cooling systems of administrative buildings in order to minimize energy consumption traditionally generated by burning hydrocarbons, it is proposed to introduce innovative solutions with renewable energy sources.

Due to their proximity to the equator, countries such as Colombia are classified as isothermal, which means they require year-round operation of indoor air conditioning systems. This continuous usage leads to an increase in overall energy consumption.

According to calculations, air exchange must be provided at the minimum necessary level to maintain

sanitary and hygienic conditions and prevent the accumulation of carbon dioxide and dust. To effectively remove excess heat and maintain optimal temperatures, equipment with a minimum cooling capacity of 191 kW is required.

A technical and economic analysis of two alternative cooling system solutions was conducted. The first option involves the use of a chiller equipped with a scroll compressor, which consumes 84.9 kilowatts of electricity. The second option is based on the use of an absorption chiller (ABC) operating on thermal energy from solar collectors. This solution significantly reduces energy consumption, as the absorption chiller consumes only 2 kW.

An economic analysis revealed that an integrated system including an absorption chiller and a solar thermal system demonstrates a 40 % increase in capital costs compared to a traditional chiller. However, the absorption chiller demonstrates a significant reduction in energy consumption by 78 % compared to its traditional counterpart. This significantly higher figure confirms the system's effectiveness in minimizing energy costs.

Despite the significant potential for using absorption refrigeration systems integrated with solar thermal systems as cold sources, these technologies face a number of significant technical and economic challenges. A key aspect is the instability and intermittency of energy generation, due to its dependence on the time of day and weather conditions. Cloud cover has a significant negative impact on the efficiency of solar collectors, reducing their performance compared to traditional energy sources. This, in turn, requires increased equipment and investment to ensure the required level of energy supply through backup energy sources.

Colombia currently lacks clearly defined legislation regulating the use of renewable energy sources. Government support for the development of this sector also remains insufficient, reducing the investment attractiveness of renewable energy projects. These challenges are also common in most countries, including the Russian Federation. These factors create significant barriers to the implementation and scaling of absorption refrigeration systems with solar thermal systems, despite their obvious energy efficiency advantages.

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