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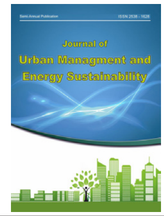

CASE STUDY RESEARCH PAPER

# Explaining and evaluating smart architectural materials application in optimizing energy consumption

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ABSTRACT

The expansion of urbanization has changed the type of ground cover and impervious materials in architecture such as asphalt and construction materials have replaced natural soil, and these impervious materials and surfaces are important factors affecting thermal comfort and the environment. The use of urban materials with a high albedo, in addition to reducing the effects of heat islands, can have positive and negative environmental effects. Smart materials are a new term for materials and products that can understand and process environmental events and react accordingly. The current research is descriptive-analytical type, which is considered as an applied purpose, and considering the extraction of the optimization model. The research tool is the library and the analysis stage in the form of case sampling and also the use of simulation and analysis software like Open Studio. 9.5 in the sample materials is recognized. As a result, the main issue in cold climates is providing thermal comfort in the indoor space in winter, and for this purpose, various equipment and insulation works are used in buildings. The results show that in the general state of gas energy consumption, which is the dominant energy for providing internal heating of the building, if smart concrete of thermochromic type is used in the outer walls of the building, approximately 19-22% of the energy consumption required for It has reduced the generation of heating. Therefore, this amount of energy saving in a building can create significant efficiency in the urban context and on larger scales.

Running Title: Smart architectural materials application in optimizing energy consumption

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## 1. INTRODUCTION

According to the statistics of various institutions, the amount of urbanization with its increasing growth will cause this amount of consumption to increase by 2050 and reach 80% of the total energy consumption (Huang and Hwang, 2010). Human beings require a healthy shelter to sustain their lives. (Rahbari and et al., 2023). The program for changing energy sources is based on five axes, according to which the largest amount of urban energy consumption takes place in buildings (Canniffe, 2011). The environment is made from both physical and social aspects. Humans create the places around them and a place independent of humans has no meaning (Sheikhbaglou, 2023) In this regard, the forgotten solutions in the design of a sustainable residential environment should be identified by updating them according to the available technologies, they should be used in the design of sustainable buildings. (Hajali Zadeh, 2023) The expansion of urbanization has changed the type of land cover and impervious materials such as asphalt and construction materials have replaced natural soil, and these impervious materials and surfaces are important factors affecting thermal comfort and the environment. (Stewart, 2022) Urban materials are selected by architects, designers, and urban planners based on various needs, such as safety, longevity, cost, and environmental considerations (Arens et al., 2010). Most of the materials used in cities show different changes in albedo with time, for example, the albedo of concrete and colored stones decreases with time, but asphalt becomes lighter and its albedo increases over time (Huang et al., 2015). The results of studies conducted in Athens show that by using materials with high albedo on a large scale, the air temperature can be reduced by 20 degrees (Kaza, 2021, Taha et al 2021, Taleghani, 2014). The use of urban materials with a high albedo, in addition to reducing the effects of heat islands, can have positive and negative environmental effects. (Stewart and Oke, 2012 Tan, 2016) So that if materials with high albedo are used only to reduce the ambient temperature, the amount of vegetation cover will be less and, in this case, thermal stress and humidity reduction and other cases mentioned in the absence of vegetation cover will occur (Martinelli and Matzarakis. 2015 and Taslim et al., 2015). In today's era, the important role of sustainable architecture with green architecture is important in using new polymer materials that are prepared with smart and nanotechnology with the approach of exploiting renewable resources instead of non-renewable resources in the earth. Sustainable architecture using green and recyclable materials is a logical response to the issues and problems of the industrial age. Building materials play an important role in sustainability. (Sharmin et al., 2015) Architects of the future will be able to design buildings whose geometry changes according to the weight of the people who are inside the building, therefore, to design buildings that interact with the environment in the best way and also provide the possibility of saving as much energy as possible. finding out the characteristics of smart materials and their application is inevitable. (Santamaria, 2021) Smart materials are a new term for materials and products that can understand and process environmental events and react accordingly. In other words, these materials can change and can reversibly change their shape, form, color, and internal energy in response to the physical or chemical effects of the surrounding environment. (Ruiz and Correa, 2015). If we classify the materials into three groups of non-intelligent, semi-intelligent, and intelligent materials, the first group, i.e., non-intelligent materials, do not have the above specific characteristics, semi-intelligent materials are only able to change their shape and form for a time or a period in response to environmental influences. change a little, but in smart materials, these changes will be repeatable and reversible. Smart materials are also known as "flexible" and "adaptable" materials, and this is due to their special feature in adjusting themselves to environmental conditions. (Nations, 2022) Considering the issue of making building materials smart and its importance in optimizing energy consumption, the emphasis of the research is on the type of building materials such as smart concrete, and also its investigation in a case study of cold and mountainous climates, taking into account the explanation of the model Its origin is considered as research innovation. The results obtained from the behavior of smart concrete according to its specific type in the climate of the Murray sample, in addition to the type of simulation in the type of analytical variables can also be considered as a type of innovation, therefore the focus of the current research is based on self-regulating concrete and the results will be interpreted and generalized after extraction. The current research aims to investigate and evaluate the mechanism of using smart materials in the cold and mountainous climate of Tabriz city, to reach a specific framework of findings.

## 2. MATERIALS AND METHODS

The current research is descriptive-analytical type, which is considered as an applied goal, and considering the extraction of the optimization model, it can also be given a developmental role. The research tool is library and documentary and the use of basic sources is given priority, and to carry out the analysis stage in the form of field sampling and also the use of simulation and analysis software in the sample materials is recognized. In the first stage, by reviewing the theoretical literature and the background of the research to achieve the initial conceptual framework and also to explain the proposed model to present the role of building materials in the issue of building energy consumption, finally, a specific research framework can be developed based on the collection of opinions. In the second step, based on the proposed model, a case sample is selected and according to the basic information based on geographic, climatic, etc., its current condition according to the type of materials in 7 positions including the external wall, roof, floor The ground, the external door, the separating wall, the light barrier, and the separating wall are generally subjected to simulation and preliminary analysis. In the following, after applying the characteristics and the impact of smart materials in replacing the current materials, the same analysis is done and the results are analyzed and interpreted.

This research is based on a series of simulations made by the simulation software Energy Plus version 9.5, Open Studio version 1.5, and Radiance version 5.2 to calculate the amount of energy consumption and lighting of buildings. The geometry of the building is modeled by Open Studio version 1.5 software and connected to simulator engines. It should be noted that the energy codes used in the residential part of the urban bed are taken from the Ashri 90.2 standard of 2018. The purpose of these analyses is to find the most important architectural elements affecting the energy performance of buildings and their development in contemporary architecture.

Standard-7730 Thermal environment ergonomics - Analytical determination and interpretation of thermal comfort by calculating the average vote estimate index and the average percentage of dissatisfied people and local thermal comfort criteria deal with the indicators computationally affecting thermal comfort. This standard is developed using the principles of heat balance and experimental data taken from the room under constant weather conditions. The basis of these studies was based on the fact that residents dynamically interact with their environment. Among the human variables used to calculate thermal comfort, we can refer to the rate of clothing and activity of people. Clothing is an effective factor in the heat exchange of the human body with the surrounding environment. Clothing as a non-conductive structure covers a part of the body and reduces the contact of the body surface with the surrounding environment. On the other hand, the person changes the body's metabolic rhythm with the activity he performs. Therefore, according to the thermal efficiency of the body, we see the production of heat. Asheri standard 55 residential sections, the clothing rate for simulating energy in the winter season is equal to 1 and in the summer, season is considered equal to 0.5 kilo, also the activity rate is assumed to be equal to 70 watts per square meter or 1.2 meters. Table 1 shows the different values of clothing and activity rates. (Tab.1)

Table 1: Clothing and activity rates

| Activity rate | | | Clothing rates | |
|---|---|---|---|---|
| Activity rate (.Met) | The song of metabolism (W/sqm) | Type of Activity | The value of (.Clo) failure | Cover type |
| 0.6 | 41 | sleeping | 0 | without clothes |
| 0.7 | 47 | rest | 0.1 | underwear |
| 1 | 58 | Sitting | 0.5 | Men's style summer clothes |
| 1.2 | 70 | standing | 0.7 | Men's style work clothes |
| 2 | 115 | walk | 0.7-0.9 | Covering the inside of the lady's house |
| 2.5 | 150 | house cleaning | 1.5 | heavy man cover |
| 3.2 | 200 | heavy activity | 2.0-2.5 | Very heavy wool cover |

The defined usage in the simulated residential cases is of short order, and to compare the building with contemporary buildings, the presence of people and their type of activity are defined similarly to contemporary structures. In this program, the presence of people in the building is defined from 6 in the evening to 6 in the morning (8 in the morning to 5 in the afternoon is assum in the afternoon is assumed as working time). Figure 1 shows the attendance schedule of people for one year. The per capita considered for the presence of all people is assumed equal to 0.025 people/square meter, this number means that if we have a space of 100 square meters, 4 people will be present in this space. (Fig. 1)

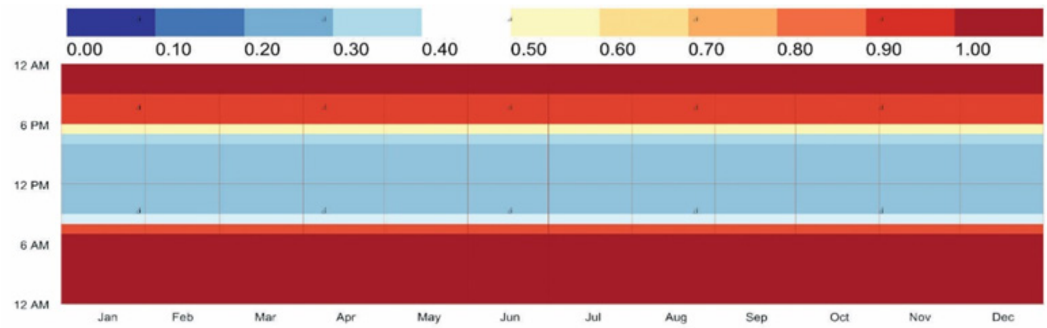


Figure 1: People's attendance schedule

Air temperature, average radiant temperature, relative humidity, and wind speed can be mentioned among the factors influencing the determination of the thermal comfort range. These indicators have been investigated in climate analysis. In general, due to the effect of these factors on each other, as well as the effectiveness of the rate of clothing and activity in thermal comfort, it is not possible to determine specific numbers for each of these factors. Asheri standard 55 determines the limits of each of these factors according to statistical data in providing thermal comfort. According to this standard, a temperature of 23 to 25 degrees centigrade provides thermal comfort for almost all people. To establish thermal comfort, the temperature difference between the head and feet should not exceed 3 degrees centigrade. As the relative humidity decreases, the rate of evaporation increases. The pleasant level of relative humidity is in the range of 30% to 70%, and the relative humidity of 50% is the most ideal possible value. Another factor that is important in thermal comfort is the intensity of the airflow, in general, if the airflow has a speed greater than 0.2 m/s, it can be uncomfortable for the residents. It should be noted that there are differences in the Ashri-55 standard between places where residents can open and close their windows and places equipped with air conditioning systems. Therefore, in the aforementioned standard, different criteria are considered for buildings with natural ventilation and buildings equipped with an airconditioning system.

If thermal comfort conditions are not provided, these conditions can be provided by using active systems. In general, it is necessary to determine the temperature of cooling and heating around the consumption of active systems. According to the standards, the starting temperature for heating equipment is equal to 21.7 °C and for cooling equipment is equal to 24.4 °C. It should be noted that the maximum temperature provided by the system is assumed to be 30 and the minimum temperature is 18 degrees Celsius. Also, the appropriate range for relative humidity is assumed to be between 20 and 80 percent. Because the systems are the same in different simulation options, the performance rate of the systems has been assumed to be equal to 1 (there is no energy loss), so the heat recovery systems have also been considered economical. In general, the assumed facility systems have ideal air conditions. Considering the importance of environmental issues and the amount of carbon dioxide equivalent due to the operation of the building, the amount of 0.231 kg of carbon equivalent per kilowatt hour for heating purposes and 0.612 kg of carbon equivalent per kilowatt hour for cooling and electricity purposes should be considered. According to what was stated earlier, the assumptions of space utilization are summarized in Table 2. These details are further defined following the Ashry 90.2 standard; which is written around low-consumption residential buildings. (Tab. 2)

Table 2: Defaults for space utilization

| User | Attendance Per Capita | Average Activity Rate | Clothing Rates |
|---|---|---|---|
| Residential - independent | 0.025 person/square meter | 1.2 | Winter 1 - Summer 0.5 |
| Lighting consumption rate | Equipment consumption rate | Equipment consumption rate | Equipment consumption rate |
| (when present) | (gas) | (when present) | (absence) |
| Watt / square meter 11.5 | - | watt/square meter 6.65 | 2.00 watts / square meter |
| Hot water consumption rate | Hot water target temperature | ventilation rate | Air penetration rate |
| 0.15 liters/square meter | 60 degrees Celsius | Air change at 0.35 hours | 0.0006 cubic meters of space/square meters of facade |
| System performance rate | Relative humidity range | Cooling point temperature | Heating point temperature |

Climate

The maximum and minimum dry temperature recorded for Tabriz City is -12 and 39 degrees Celsius. The extreme cold of this city has reduced the relative humidity and dryness of the air in this city. In general, 41.16% of the year in Tabriz city is in a condition without heat stress, while 52.48% of the year this city is in a state of cold heat stress. According to this weather information , Tabriz has 2575 cold days and 403 hot days. As it is clear in the graphs, the cold currents in this city start in December and continue until the end of March. According to the annual wind of this city, the prevailing wind of this city is from the west side and the highest recorded wind speed for this city is 26.8 meters per second. Also, due to the low wind speed in this city, there is a need to protect the building against the wind in only 49 hours of the year. The maximum elevation angle of the sun on long summer days in this city is about 74.2 degrees, which is a great angle for the sun to shine. As a result, at this time of the year, the use of a small horizontal canopy can provide the required shade for the southern windows. Due to the high elevation angle of the sun, the sun's rays shine almost vertically on the horizontal surfaces of the building in summer noons; Therefore, horizontal surfaces, such as the roof, , receive a large amount of radiant energy in these conditions and this amount of absorption reaches its maximum value around noon; Therefore, the vertical surfaces, especially the surfaces located on the south face of the building, receive the most amount of useful radiant energy, and therefore, these surfaces have the potential to be used for passive heating of the building. Also, Figure 4 shows the simulated state of Tabriz Sky Dome. It should be mentioned that the highest level of radiation in this city is equal to 2018 kilowatt hours per square meter per year. Figure 2 shows the psychrometric chart of Tabriz City. According to the psychrometric diagram of this city, both heating and cooling are needed to achieve the thermal comfort conditions required by humans in residential buildings. In this city, about 11.8% of the time of the year, the conditions are within the range of thermal comfort. Table No. 1 shows the annual percentage of time and the number of hours that each of the passive and active methods is capable of providing thermal comfort in this climate. The need for heating and cooling energy in a building, regardless of the climate of the location of this building, depends on its architecture and also on its thermal shell materials. The duration mentioned for each of these methods was determined only according to the climate, and the characteristics of the building, including its architecture and materials, did not play a role in determining these amounts. (Fig. 2) (Tab. 3)

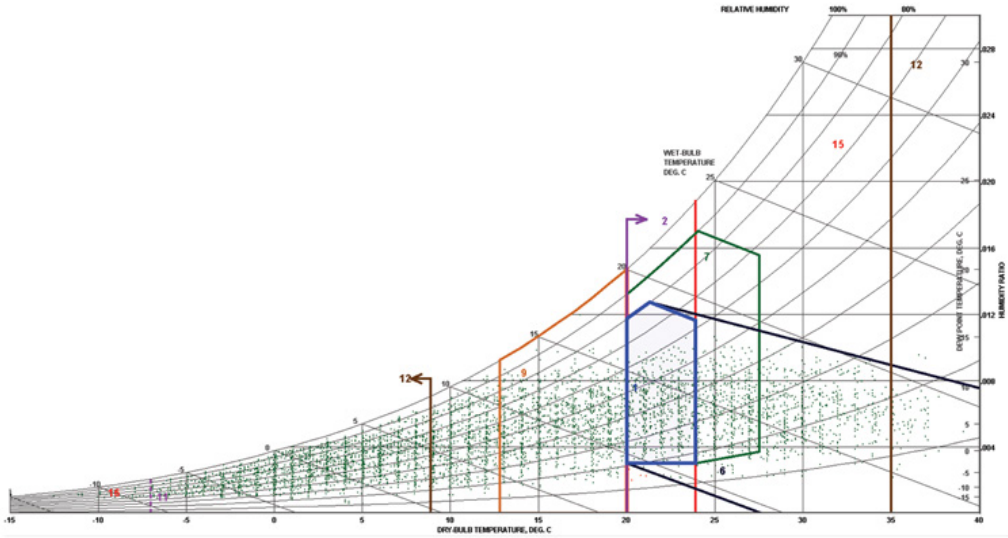


Figure 2: Psychrometric diagram of Tabriz city (analysis software: Climate Consultant version 6)

Table 3: thermal solutions suitable for the climate of Tabriz city (analysis software: Climate Consultant version 6)

| The Watch | Percentage Of Time | Strategy | | The Watch | Percentage Of Time | Strategy | |
|---|---|---|---|---|---|---|---|
| 1722 | 19.7 | Receiving heat from internal sources | 9 | 1035 | 11.8 | Thermal comfort | 1 |
| - | - | Direct passive solar absorption (with low thermal mass) | 10 | 1409 | 16.1 | Shading on windows | 2 |
| 1377 | 15.7 | Direct passive solar absorption (with high thermal mass) | 11 | - | - | High thermal mass | 3 |
| 49 | 0.6 | Wind protection | 12 | - | - | High thermal mass and night ventilation | 4 |
| - | - | Humidification | 13 | - | - | Direct evaporative cooling | 5 |
| - | - | Dehumidification | 14 | 1774 | 20.3 | Two-stage evaporative cooling | 6 |
| 7 | 0.1 | Active cooling and humidification if needed | 15 | 796 | 9.1 | Cooling with natural ventilation | 7 |
| 3542 | 40.4 | Active heating and humidification if needed | 16 | - | - | Cooling with mechanical ventilation | 8 |

For the geometrical definition of the walls of the building, the outermost surface of the walls of the building was selected for thermal zoning in the simulation software (according to the change in the thickness of the walls, the average thickness was applied in the software), then the effective volume for cooling and heating of the space was seen for the significant area of the walls of the building. Also, the physical properties of the materials have been determined in the software according to the 2019 edition of the 19th topic of the National Building Regulations. For example, to define the walls of the house, brick walls with a heat transfer coefficient of 0.88 W/m-K are considered, or around the definition of the openings of the building, they are defined as single-paned glass with a wooden frame, and its heat transfer coefficient is assumed to be 5.70 W/m-K.It should be noted that except for the communication spaces, the rest of the building spaces are ventilated. Despite the constant use of spaces with the direction of the different presence of people in the space, thermal zones are defined in multiple ways. Also, to investigate the effect of the physical variables of the architecture, the seasonal shading of plants in the outer yard has been omitted, but the shadow side on the building has been calculated by the software in the geometry part of the building by defining it as a substrate. The simulation results stated in this part show the amount of energy required to establish thermal comfort conditions along with the assumption of constant equipment consumption loads in all spaces of the building. In these analyses, the investigation of passive solutions based on the user (people present in the building) which has been traditionally used, such as regional heating or moving the living space during the day, has been omitted.

According to the available statistics and information from the 2015 census of Tabriz, a significant majority (nearly 70%) of households in Tabriz live in units with 2 or 3 rooms. About half of the residential units in Tabriz are units with an area of 100 to 200 square meters. Also, the above information shows that citizens are not interested in units with an area of 75 to 80 square meters. Also, in most areas (3, 4, 5, 6, 7, 9, and 10), the number of units with an area of 100 to 150 square meters is more than the number of units with an area of 150 to 200 square meters, but in areas 1, 2, and 8, this trend is reversed. and the number of 150 to 200 square meter units is more than 100 to 150 square meter units. Therefore, the main type of residence selected according to the above-mentioned items is a 3-bedroom apartment unit with an approximate area of 140 meters. Also, according to the available statistics, more than 55% of the residential context of Rushdieh Tabriz includes 2-3 story buildings, most of which are villa buildings. It should be noted that this type of residence with this concentration and density exists only in this part of the city. Therefore, it is chosen as the best option for evaluation. Also, the largest percentage of residential units in this context are units with an area of 101 to 150 square meters. Therefore, a selected sample for an inner-city villa residential unit has been selected from this area, , with an approximate area of 150 square meters and two floors. (Fig. 3)

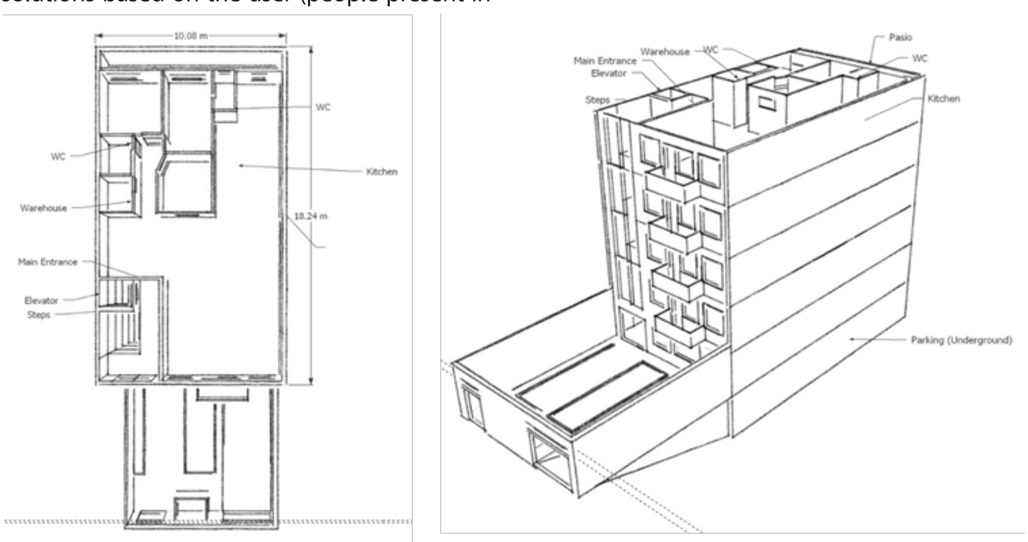


Figure 3: Floor plan and 3D model of the simulated apartment unit

In the study of contemporary residential types, sample apartment units have been selected based on statistical results. The specifications of all the walls are considered similar to the suggestions of topic 19 of the national regulations of the building with insulation. The chosen structure is metal. In the simulation results of the residential apartment, we see the annual need of 55 kWh/sqm in the cooling sector, which is mainly due to the high thermal capacity of the building shell and sunlight. On the other hand, in the heating sector, the annual requirement of 147 kWh/sqm is predicted, this requirement is mainly related to heat loss in the form of convection flow from building walls and unwanted air infiltration into the building. According to the opening surface of the building, artificial lighting consumption for this building is estimated to be equal to 9.5 kWh/sqm annually. Also, home equipment consumption is estimated at 38 kWh/sqm, and hot water consumption at 45 kWh/sqm. In total, the energy consumption of this apartment is estimated to be 295 kWh/sqm in case of operation under contemporary structures. The amount of equivalent carbon consumption in case of default operation is predicted to be 107 kg/sqm annually. The plan of the desired unit has been modeled in the Open Studio software space and the thermal volume, materials, heating and cooling facilities, and other items have been observed based on the standards in the topic of 19 buildings. The type and amount of activity, theconditions of coverage, and other details are also considered according to what has been stated and if not mentioned, as a default standard or as a fixed variable. (Fig. 4)

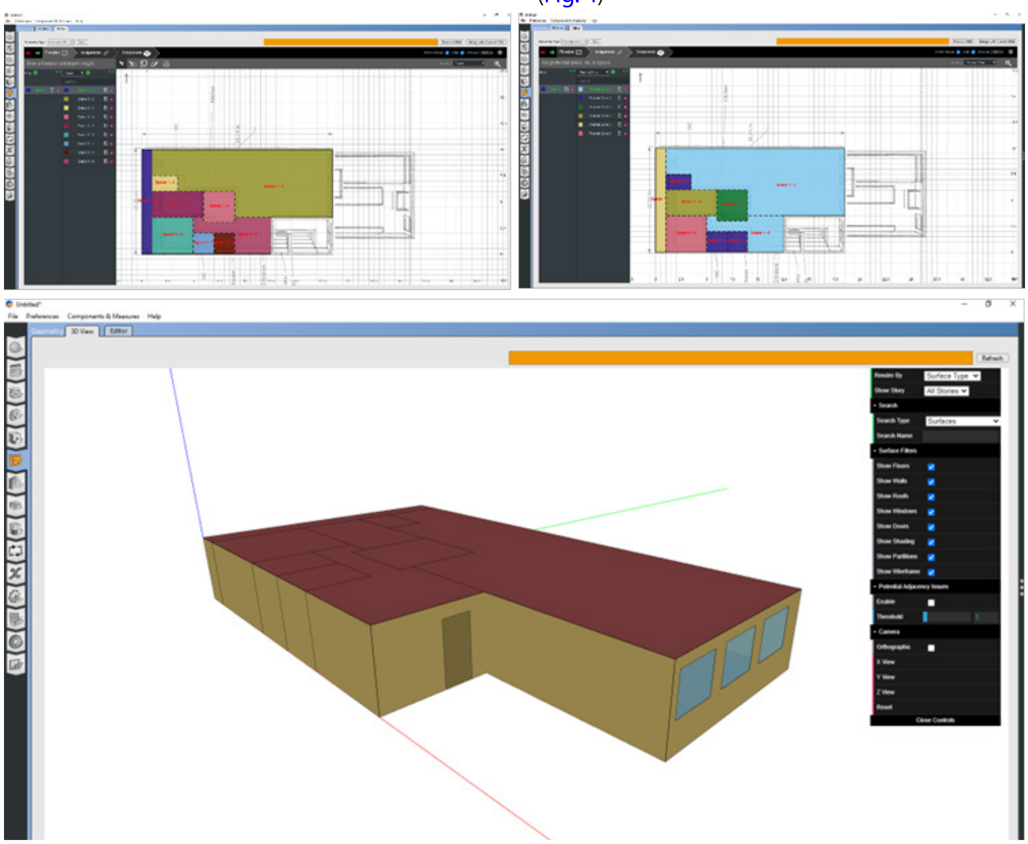

Figure 4: Modeling of the apartment unit in Open Studio 1.5 software space

FINDINGS AND DISCUSSION

After modeling, the amount of annual energy consumption for the desired unit in two modes; is done by using normal concrete and using thermochromic The amount of annual energy consumption in both modes was investigated in five fields of lighting, cart and electrical equipment, cooling and heating, and graphs 5 and 6 show the amount of change in energy consumption per building unit in the case of using two types of concrete. (Fig. 5 and 6)

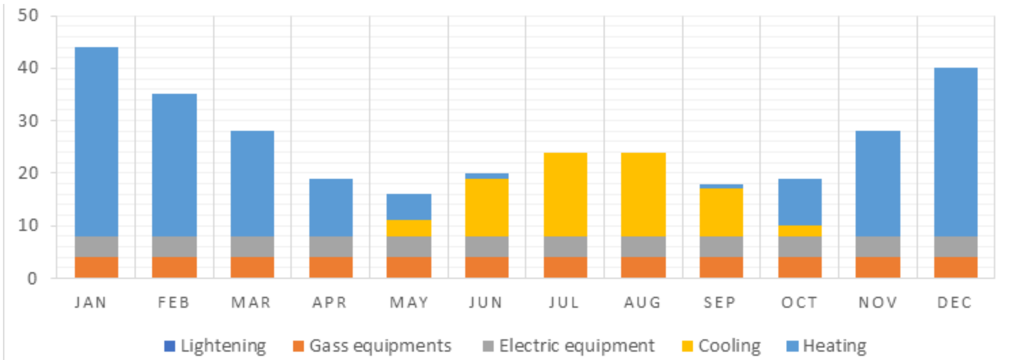


Figure 5: Monthly graph of energy consumption of an apartment unit - Tabriz with ordinary concrete

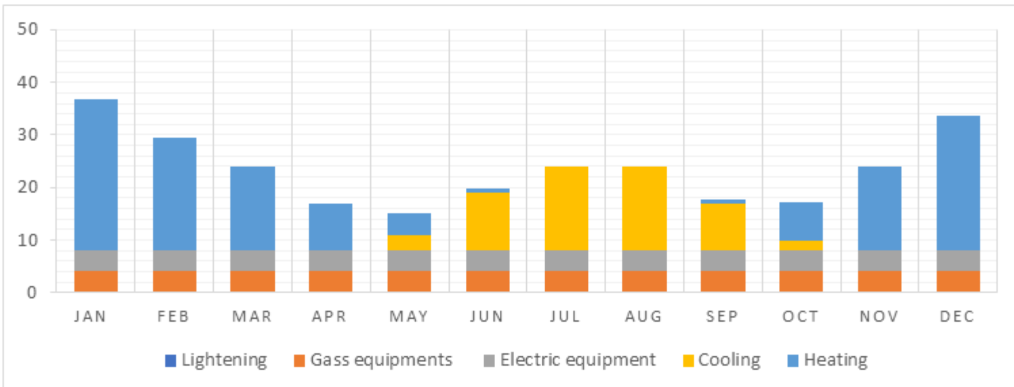


Figure 6: Monthly graph of energy consumption of an apartment unit - Tabriz with thermochromic concrete

For a better and more tangible comparison of these two situations, we can see the amount and how the energy consumption in the building differs in the comparison chart below. It is clear that according to the studied climate and the main energy in question, which is gas energy for heating, the difference was also in this case. By examining these changes, we get to know the effect of using smart materials on the amount of energy consumption in the building. (Fig. 7)

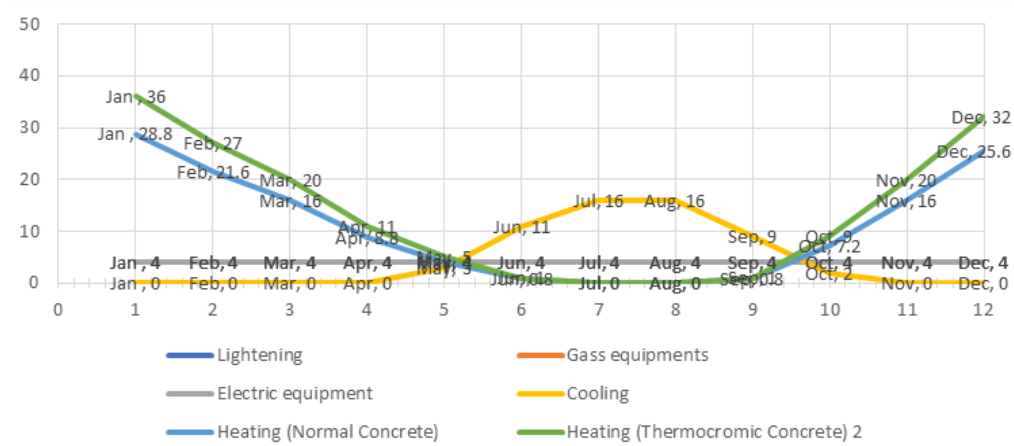


Figure 7: The amount of difference in the need for energy consumption in the building block in two cases of using thermochromic and normal concrete

## RESULT AND CONCLUSION

In general, the main issue in cold climates is providing thermal comfort in the indoor space in winter, and for this purpose, various equipment and insulation works are used in buildings. The use of these items is forced to some extent according to the laws. But regarding the materials used in the main structure of the building, especially in the external walls, old and traditional materials are still used. Regarding the physical system of buildings, the use of thermal mass is unattainable due to the importance of building weight and structural performance, and the use of thermal insulation in buildings is more important to designers. The simulation results of the energy requirement also confirm the more effective use of smart materials. In the national standards of Iran, the minimum thermal resistance considered for building shells is equal to 0.5 m2. K/W; Achieving this amount of resistance for the external wall by using only thermal mass leads to the thickness and weight of unusual walls. Due to the potential of heating and air conditioning equipment to provide thermal comfort conditions, the residents of contemporary houses have a bio-balanced model in their buildings. Today, smart concretes have shown very high efficiency in various cases and fields. As mentioned, normal buildings use normal and not smart materials. The main reasons are price and cost. In this research, an attempt was made to evaluate the impact of the use of smart concrete on the amount of energy consumption required for heating to achieve standard thermal comfort inside the building. The results show that in the general state of gas energy consumption, which is the dominant energy for providing internal heating of the building, if smart concrete of thermochromic type is used in the outer walls of the building, approximately 19-22% of the energy consumption required for It has reduced the generation of heating. Therefore, this amount of energy saving in a building can create significant efficiency in the urban context and on larger scales. According to existing studies, in developing countries, 40% of energy consumption at the city level takes place in buildings, and taking into account this amount of difference in consumption with the use of smart materials, it is clear that a significant amount of energy consumption will be saved in the building sector. became. In addition to the saved cost, this item will also reduce the amount of pollution caused by energy production and its consumption in the building. Therefore, the need to use smart materials in new constructions, especially thermochromic concretes, is clear to prevent unnecessary heat exchange. In future research, the type and composition of these materials can be investigated in the surrounding walls, as well as the use of other smart materials in buildings and their impact on energy consumption.

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