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Article

Simulation and analysis of energy consumption in all types of residential complexes and choosing the best form from the perspective of sustainability

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ABSTRACT

Energy demand in residential buildings is growing with the immigration of people to urban areas. This study simulates and analyses five different types of residential buildings. The possibility of using a solar thermal system is studied, and then five choices are ranked with the PSI method, which is a mathematical approach. For HVAC simulations, Design builder software, and solar simulations, T*Sol software is used. The results show that in terms of heating load, towers and skyscraper types of residential buildings demand more energy, with 3.67 MW and 3.62 MW, respectively. In terms of cooling, towers and surrounding types need bigger values than others, with 1.84 MW and 1.82 MW, respectively. Solar simulations indicate that the highest solar fraction with no area limitations belongs to the sky scrapper type with 26.9 percent, while collector efficiencies of all types are between 9.9 and 11.6 percent. However, with rooftop areas in each type, the highest solar fraction belongs to linear and surround types both with 24.6 percent. Mathematical analysis shows that by taking into account the importance of heating load and solar fraction for all types, the best form of residential buildings to use is a mixed type with the first rank.

1. Introduction

1.1 The importance of urban energy consumption and methods of analysis

According to the probable scenario, more than 80% of the world's population will live in cities by 2050 [1]. About two-thirds of the world's energy consumption comes from cities. For this reason, cities have a significant role in the consequences of energy consumption, including climate change, and therefore, optimization in them can have a great impact on achieving the environmental goals set in international agreements [2]. Buildings in cities account for more than 40% of energy consumption. For this reason, to reduce greenhouse gases to the desired amount, special attention should be paid to this sector [3]. Recent research shows that urban design can positively affect energy consumption, such as the distribution of buildings and urban areas, maximum use of sunlight, and the development of multi-use areas [4]. In regions such as Asia, the Middle East, and Africa, where populations are growing rapidly, the compact urban form combined with transportation planning can encourage crowding and prevent high carbon emissions during travel. Therefore, in addition to the fact that in densely populated areas, higher density is inevitable, in terms of energy consumption and carbon emissions will be better than scattered urban patterns. Therefore, special attention to urban residential complexes is of particular importance. With proper design and proper layout of complexes, energy efficiency can be increased desirably [5]. In recent years, energy modeling of urban buildings has been recognized as a new approach to identifying, supporting, and improving sustainable urban development plans and energy optimization measures in cities. With the help of this tool, a better understanding of the general situation of energy consumption in the building and applying design modifications can be used to achieve more favorable conditions. Because of this, various models and tools have been developed and become more advanced hybrid models [6]. Designing and operating urban buildings as a group (from a city block to a district to an entire city) rather than as single individuals requires simulation and optimization to account for interactions among buildings and between buildings and their surrounding urban environment, and for district energy systems serving multiple buildings with diverse thermal loads across space and time [7]. Regulations corroborate the importance of retrofitting existing building stocks or constructing new energy-efficient districts. Thus, there is a need for modeling tools to evaluate energy scenarios to manage better and design cities, and numerous methodologies and tools have been developed [8]. Research activities in this field have flourished in recent years and have created a stronger urban database that leads to GIS, light and range detection, and building hourly energy demand profiles for current and future conditions. This is a testament to the importance of modeling urban buildings. Depending on the availability of energy consumption data for historic buildings, a variety of modeling, simulation, and calibration methods, as well as applications, have been proposed [9]. Researchers worldwide are working on energy modeling and control to develop strategies that lead to an overall reduction in building energy consumption. One of them is developing control strategies and an efficient computational energy model for the studied building. Modeling methods for modeling the energy systems of buildings have been developed and adopted and have shown their ability to provide more accurate and comprehensive information about buildings [10].

1.2 Energy supply and sectors

Today, the most usable and economical forms of energy are fossil fuels, especially oil products and natural gas [11]. The importance of using renewable energy is improving due to the increasing use of energy and the fact that these forms of energy are not renewable. On the other hand, the means of effective energy use are vastly considered and so are being researched often. This caused broader and more thorough studies of energy use that have led to the study of sectors including residential, hospital, commercial, official, industry, and transportation.

1.3 Residential sector

The major use of energy in OECD countries belongs to the industry sector. However, in non-OECD countries, the major use of energy is considered for the residential sector [12]. From a different point of view, oil-exporting countries have a lower price of energy use because of the abundance of energy supplies. However, the performance of energy-related machines is not usually optimal. Immigration to bigger cities exists because of the location of major facilities in these cities and more work opportunities. So, one of the leading residential solutions to accommodate people is using residential complexes. Thus, in non-OECD and oil-exporting countries, the importance of energy use optimization and renewable energy studies are hugely favorable, especially for the residential sector and, in big cities, for residential complexes.

1.4 Solar energy

Solar is one of the renewable energies which, because of numerous advantages, is considered recently to supply the energy need. One of the main advantages of using solar energy is the absence of much pollution that fossil fuels emit [13]. However, there are some disadvantages including timing and climatic limitations, storage, and expensive equipment which caused researchers to study these systems more and more recently. There are multiple parameters to classify solar energy; but mainly, it is divided into two parts of active and passive solar energy. Passive solar is when there is no solar energy equipment used and solely by architectural means, the energy is stored and eventually used. However, active solar always has energy-gaining and systematic equipment to procure the energy needed. The active systems can be divided into space heating, domestic hot water heating, electricity supply, desalination, and solar dryers. Buker et al. [14] reviewed the applications of building integrated solar thermal collectors in their paper. Based on the scenarios reviewed in the paper, passive solar heating combined with building construction and energy-efficient applications can reduce space heating demand by 30%. On the other hand, active solar systems can reduce fuel demand for hot water and space heating from 50% to 70% for hot water and 40% to 60% for space heating. It is also estimated that about 30-40% of global heat demand can be met with solar thermal energy and 20% of Europe's heat demand. There are many types of thermal collectors, but their applications remain limited due to reliability, cost, and building integration issues. Therefore, significant research is needed mainly in heat absorber design and construction, material and coating selection, energy conversion and effectiveness, cost reduction, performance testing, system control, and building integration facilities. Therefore, the use of collectors, along with optimization in their design and usage, can play a significant role in energy efficiency. Karami et al. [15] investigated residential buildings as one of the largest energy consumers due to their valuable potential for energy savings. They specifically looked at the combined solar thermal systems that supply the energy needed for domestic hot water and space heating and evaluated their key role in reducing building energy consumption. They investigated the effect of climatic conditions on the thermal performance of a hybrid solar system using dynamic simulation by TRNSYS. For this purpose, the performance of the system in five different climate zones, including hot-dry, cold-dry, medium-humid, hot-semi-humid, and hot-humid, has been considered. Based on the obtained results, the energy needed for hot water consumption in all climatic regions except for the temperate-humid and cold-dry climate regions can be supplied to a large extent through solar energy. Their findings confirmed that the energy consumption of the building could be significantly reduced by using the combined solar system as a heating system, resulting in significant energy and economic savings. Qerimi et al. [16] investigated the use of solar energy for building hot water supply in Kosovo. Since the electricity produced in most of the electricity produced in Kosovo is produced from fossil fuel, the use of renewable energy, especially in buildings, was considered one of the promising solutions to save non-renewable resources. About 41.4% of the total consumption in Kosovo, 15% of this energy is used for domestic hot water. This energy demand can be significantly reduced by using improved building construction techniques and the use of RES sources, especially solar heat. For the cases they chose in their work, they obtained data related to solar fraction, solar contribution, CO_2 avoided, collector temperature, financial analysis, etc., using TSOL 2018 software. They proposed replacing conventional water heaters with domestic solar water heaters (DSWH). The results of this paper show that DSWH is economically feasible in Pristine and can lead to fuel savings and CO2 emission reduction.

Tang et al. [17] investigated the use of solar energy to heat water in residential buildings. They said that in South Africa (SA), up to 40% of household energy consumption is used for water heating, and in this regard, the use of renewable energy, especially solar energy, can help reduce the energy crisis in this country. In their study, they investigated the use of solar water heaters (SWH) at the household scale for the first time using climate data for 21 cities in South Africa. The technical and environmental evaluation was performed by TSOL PRO 5.5 on two types of an evacuated tube (ET) and flat plate (FP water heater). In addition, these cities were ranked using GAMS 24.1 and two types of DEA methods. The results indicate that the efficiency of evacuated tube SWHs is better than flat plate SWHs in all cities and if we use an FP water heater, the average solar fraction is 95.93%, which avoids the emission of about 23.5 tons of CO2 annually. These values for ET water heaters are 99.16% and 24.4 tons per year, respectively. Therefore, the results confirmed that the use of solar collectors can make a significant contribution to providing the heat needed by households. Supplying sufficient electrical energy while reducing greenhouse gas emissions is one of the major concerns of policymakers and scientists all over the world. In Saudi Arabia, local authorities are increasingly aware of the necessity of reducing the environmental impact of nonrenewable energy by exploring alternative sustainable energy sources and improving buildings' energy efficiency. Recently, building-integrated photovoltaic (BIPV) technology has been regarded as a promising technology for generating instantaneous sustainable energy for buildings. To achieve a substantial contribution regarding zero energy buildings, solar energy should be widely used in residential buildings within the urban context [18].

Due to the nature of the problem investigated in the present paper, where various technical and economic criteria are discussed, a method to optimize the selection is used. The multi-criteria optimization problem for the solution using the PSI (Parameter Space Investigation)-method is formulated as a generalized problem of nonlinear optimization [19]. Different attributes of building types, including orientation, size, windows and doors areas, etc., were studied before architecturally. However, the impact of most of these attributes on energy consumption has not been studied. In this study, the impact of five types of buildings on energy consumption and solar micro-generation is investigated. In this research, the simulation, optimization, and analysis are done for different forms of residential complexes and also the possibility of using solar energy is studied. Although simple architecture is used for each apartment in all of the buildings, the arrangement of these apartments is different in each case. So, the novelty of this study is that one would be able to decide which type of building is the best to build in terms of energy based on four main parameters of heating load, cooling load, solar fraction, and collector efficiency.

2. Literature review

Wang et al. [20] Studied the effect of urbanization on residential energy consumption. Using panel data from 136 countries between 1990 and 2015, they examine the impact of urbanization on residential energy consumption around the world, and how the impact varies from region to region, taking into account regional heterogeneity and stages of urbanization. Our findings show that the impact of urbanization on residential energy consumption in different areas at different stages of urbanization is very different. Most sub-Saharan Africa is in the process of accelerating urbanization, characterized by rapid population migration to urban areas without economic growth. This feature of urbanization leads to a reduction in total consumption. In contrast, urbanization in developing regions in Asia and the Middle East, and North Africa, coupled with emerging economies, could increase total residential energy consumption. Surprisingly, for highly urbanized areas, including the developed regions of the world, Latin America and the Caribbean, and developing regions in Europe and Central Asia, the impact of urbanization is due to the small gap between urban and rural energy consumption in the residential sector is based on these findings. , We offer four key policy proposals, including evaluating the financial viability of cost-benefit home energy transmission plans, developing a set of custom options for home energy use, and the regular transition process, encouraging bottom-up plans for adoption. Clean energy in the residential sector, and sharing a public monitoring and planning platform. Accordingly, the importance of using tools such as software modeling of urban residential neighborhoods, which are the main components of cities, becomes more apparent. Given that standards are usually observed in the design and construction of any building, what can be further examined is the juxtaposition of several buildings and their impact on the use of natural energy, such as wind and solar. Be. Therefore, the study of a single building alone cannot provide a correct understanding of the state of energy demand as well as possible optimizations in urban areas.

Bahgat et al. [21] Presented a classification based on the urban characteristics of open spaces (urban valley urban pattern, building distribution, and outdoor shape) and energy consumption and thermal comfort, which also took into account the effect of vegetation and complementary materials. Also, the optimal value of the mentioned features was developed to achieve the desired urban features. Urban characteristics of open spaces and their optimal values in the five main urban patterns of residential complexes (block, staircase, courtyard, staircase, and linear) in two climatic regions, hot, dry, and hot humid, which can be used as a guide-based urban model. Used energy and comfort. Urban planners and planners can use this to select the most appropriate urban features according to their preferred weather conditions and urban patterns in residential complexes (such as block, stair, court, stair, and linear). Urban valley, density, distribution of buildings, and the shape of space and their sub-characteristics help to achieve energy-efficient and comfortable outdoor spaces. Determining these features by observing the values according to the urban design guide, which is based on studies conducted in this field, will guarantee welfare and comfort. In this paper, the effect of these factors was examined by quantitative and specific criteria. Reinhart et al. [22] Reviewed various building energy modeling methods. Their findings indicate that significant progress has recently been made toward the development of simulation workflows to estimate the overall energy consumption of operational buildings across neighborhoods. Given the insights that can be gained from such simulations for planning, design, and policy decisions, the level of effort required to set up and implement such models seems justifiable. However, several challenges remain for UBEM (Urban Building Energy Modelling) to differentiate itself as a reliable urban planning tool. The greatest residual uncertainty for UBEM simulations is related to the precise definition and description of ancient types that reliably represent a building warehouse. Due to the very limited access to building energy consumption measurements and also the general lack of knowledge about the thermal properties of buildings, it is often not possible to estimate the simulation uncertainty nor to calibrate a UBEM to reduce the error. To address this problem, model makers need access to building energy audit data as well as measured energy consumption in selected and audited buildings. While privacy concerns often prevent companies from sharing such datasets, some companies have begun to build in-house calibrated UBEMs to predict future demand profiles. The resulting archetype patterns do not violate anyone's privacy and can, therefore, be shared with the public. Some city and state governments, representing another key stakeholder group, have already enacted laws requiring the use of building energy from selected types of buildings to make them public.

Franco et al. [23] Examined India as the world's fastest-growing economy and home to nearly one-fifth of the world's population to highlight the importance of urbanization to energy consumption. Urbanization improves the quality of life of the people and, at the same time, promotes economic growth. However, it also increases energy consumption and can cause an energy crisis. Urbanization also has a significant effect on carbon dioxide (CO_2) emissions. They empirically examined the temporal, dynamic, and causal relationships between urbanization, energy consumption, and emissions. Increased energy consumption and greenhouse gas emissions are also being considered in the context of rapid urbanization. To address these problems, the study recommends a set of measures and a set of strategies, including measures to reduce energy intensity and emission intensity through continuous monitoring, information feedback systems, the introduction of industrial energy quota management, and incentives for facilities. Energy efficiency is turning off inefficient devices. Installation and commissioning of smart residential buildings. Reducing distribution and transmission losses by investing in smart grids is also highly recommended.

Hachem et al. [24] Presented a study of ways to increase energy efficiency in multi-story residential buildings. Montreal, Canada, was selected for this study. Energy performance is measured by the balance between consumer demand and electricity generation using integrated PV systems. In this study, the focus was on increasing electricity production by solar cells. In this study, buildings were considered to have very high energy efficiency and comply with the principles of passive solar design. The buildings under study included - low-rise (3-5 floors), medium (6-9 floors), and high (up to 12 floors), with eight apartments on each floor. In addition to the roof, PV was used in some of the facades. The simulation results using the Energy Plus building simulation program showed that the apartments are generally very efficient in terms of cooling and heating, but their use of active solar energy is limited. In this study, they concluded that a three-story building could generate about 96 percent of its total energy consumption if the roof design was optimized for solar energy production. On more than 3 floors, other measures are needed to increase energy production. The implementation of PV systems in 50% of the southern facade and 80% of the eastern and western facades, in addition to the advanced design of the roof surface (folding plate), allows the production of electricity up to 90% of the energy consumption of a 4-story building. This study shows that investing in advanced facade design (such as folding curtain walls) can significantly increase electricity generation and approach zero and surplus net energy status in buildings with eight floors.

Choi et al. [25] Studied the energy consumption characteristics of high-rise apartment buildings through a series of case studies and resident surveys. They reached the following conclusions: (1) High-rise apartment buildings can be classified based on residential or mixed-use residential buildings and the form of the building. (2) In assessing the characteristics of electricity consumption based on building use, residents of mixed-use apartments showed more active heating management behavior and adjusted their indoor stay more actively, but they consumed more electricity, especially in summer than those Who live in public residential apartments. (3) For the characteristics of electrical energy consumption, according to the shape of the building, plate buildings consume less energy than tower-type buildings. And the latter consumed 1.48 times more electricity than the former in common areas. (4) When evaluating the characteristics of liquefied natural gas consumption according to the shape of the building, it can be seen that plate buildings consume 10% more gas than high-rise buildings. (5) CO2 in mixed-use buildings is higher than emissions in public residential buildings.

Tereci et al. [26] Examined the effects of urban configuration, building typology, and building standards on energy consumption. They concluded that the density and material of the building cover have a significant impact on the energy performance of the town and should be given special attention in the urban design process. One of the most important factors in the energy demand of buildings is their arrangement. They looked at this and found, for example, that a row house in the middle of a block needed 17 percent less heating than a corner house. In addition, the location of the yards is important; Yard forms lead to so much mutual shading between buildings that the most deprived apartments with very low solar benefits require up to 80% more heating. If the glazing ratio increases in all facades, the heating demand usually increases by 10 to 20%, while the changes in the southern façade alone do not have a significant effect on the heating demand due to the balancing of profits and losses. In heating-dominated climates, the combined demand for heating and cooling energy increases slightly with increasing site density (6%). In climates with comparable heating and cooling energy demand, the optimal site density between completely shadowless open spaces and high density There is a site. For a given fixed-size metropolitan area, multi-family homes have the lowest initial energy demand and CO_2 per capita, while single-family homes have the highest. Due to low density and fewer people in single-family urban areas, absolute energy consumption and greenhouse gas emissions are the lowest for this urban structure. In general, it can be said that the results of their work showed that depending on the prevailing heating or cooling needs, the shape of the building blocks, as well as the appropriate type of material, will be different and for the construction of neighborhoods or residential complexes should be considered these Topics to be considered.

Dorer et al. [27] showed in their research that for buildings in an urban environment (compared to independent buildings), urban microclimate can have a significant effect on heat exchange and, thus, on the energy demand of buildings, depending on the geometry and structure of the building. In the case of the presented street valley, the effects of solar radiation and high waves had the greatest impact, followed by the effects of UHI and convective heat exchange on both the surface and the shear layer of the valley to free flow. To model the climate of larger urban areas, a multidimensional approach was proposed, ranging from meteorological scale models to precise modeling of radiant heat exchange and convection at the micro scale, with links to individual buildings and surface elements in building energy simulation It covers the city. The results of their research also confirmed the importance of how buildings are located in an urban area.

Hong et al. [28] examined the wind environment of the pedestrian surface and the thermal comfort around the buildings, and the wind pressure on the facade with numerical studies by SPOTE. It is generally assumed that apartments in individual buildings experience better ventilation with the experience of wind deflection on one facade and separation of airflow on the other. However, when buildings are grouped in different configurations, the airflow depends on the type of arrangement and their interactions: including the different patterns of building layout and arrangement of trees, as well as the orientation of the building according to the wind. From the simulated results, it is concluded that the high views of the building, which are parallel to the prevailing wind direction, can accelerate the horizontal eddy airflow at the edges, where such a flow can enhance the convective exchange efficiency of hot air. Low altitude and cold weather at high altitudes and a pleasant windy environment and thermal comfort are achieved at the pedestrian level. In addition, it has been observed that configurations with a square central space articulated by buildings and oriented towards the prevailing wind can be exposed to airflow and improve air movement. They quantitatively evaluated the outdoor wind environment and thermal comfort of the pedestrian surface around six hypothetical building design patterns and tree arrangements. From another perspective, it reflects the significant impact of architectural design and tree planting on the microenvironment around buildings. It also emphasizes the importance of micro-climate design, for example, conducting an environmental assessment of the options available in the building design phase and greening the landscape in a residential area. In addition, a pleasant outdoor heating environment with the shading of trees and buildings can be used as an additional criterion for assessing the energy efficiency of residential buildings. This article, with the approach of numerical studies, showed that the interactions of adjacent buildings in the designs should be considered and the best layout should be determined according to the intended conditions and objectives.

Faizi et al. [29] Examined the orientation of the building as one of the most important factors affecting the rate of direct energy absorption. They analyzed this issue with Ecotect software for four types of residential buildings in Mehr housing complexes in Tehran, Iran, where shadows, solar radiation, access to light, and thermal simulation were analyzed. The results showed that the type 1 building (Length width ratio and length orientation in the north direction) has the best performance in terms of shade and type 2 (With an approximately equal length and width and an angle of 30 degrees to the north) has the best in terms of solar radiation. On the other hand, buildings with a large surface area of translucent layers, such as windows in the south and east, can use more daylight to penetrate during the day. In addition, they made the following conclusions regarding the best placement model:

- Lowest width-to-length ratio along the north
- Having the maximum level of south-facing walls
- Design the most transparent layers in the south, east, west, and north. In lateral order
- They also suggested genres for different sections

3. Methodology

In this study, several different residential sites have been considered to simulate the energy model used. A solar thermal system is used in each case to supply the energy demand of domestic hot water. The demand-side simulation is done using Design Builder software, and the supply-side simulation is done using T-Sol software. The location of each building type is Edmonton, Alberta, Canada. Figure 1 shows the location of Edmonton City.

Figure 1. Location of Edmonton city

The climate in Alberta has three different regions. The northern part of Alberta is located in region 1, the middle part is located in region 2, and the southern part is in region 4. The city of Edmonton is located in zone 2, where the climate is usually cold and dry. Also, the wind speed is severe through the winter. So, the main design priorities conclude in protecting from cold air and wind during cold seasons and using natural ventilation in summers. The procedures done in this study are visible in Figure 2. As is shown, the study includes two sides of HVAC and solar systems. Each will be discussed further.

3.1 Demand side

Five different residential sites are considered; each has different properties in some categories, including shape, height, width, and total site area. However, the base architecture of every building at each site is the same to distinguish the reason for different energy answer characteristics based on the above categories after simulation. A total number of 320 identical residential units are considered at each site. Every single unit is either 141 m^2 or 148 m^2, and 8 units are used to form a floor of residential buildings. The staircase area is 18 m^2, and there are two sets of voids placed in each building, which are 10.43 m^2 in case of area. There are four windows located at each orientation of each unit to gain the maximum passive solar energy needed. The basic architecture plan is shown in Figures 3-9 show the site view of each type of building and arrangement. The sites are categorized as Skyscraper, linear, mixed, towers, and surroundings.

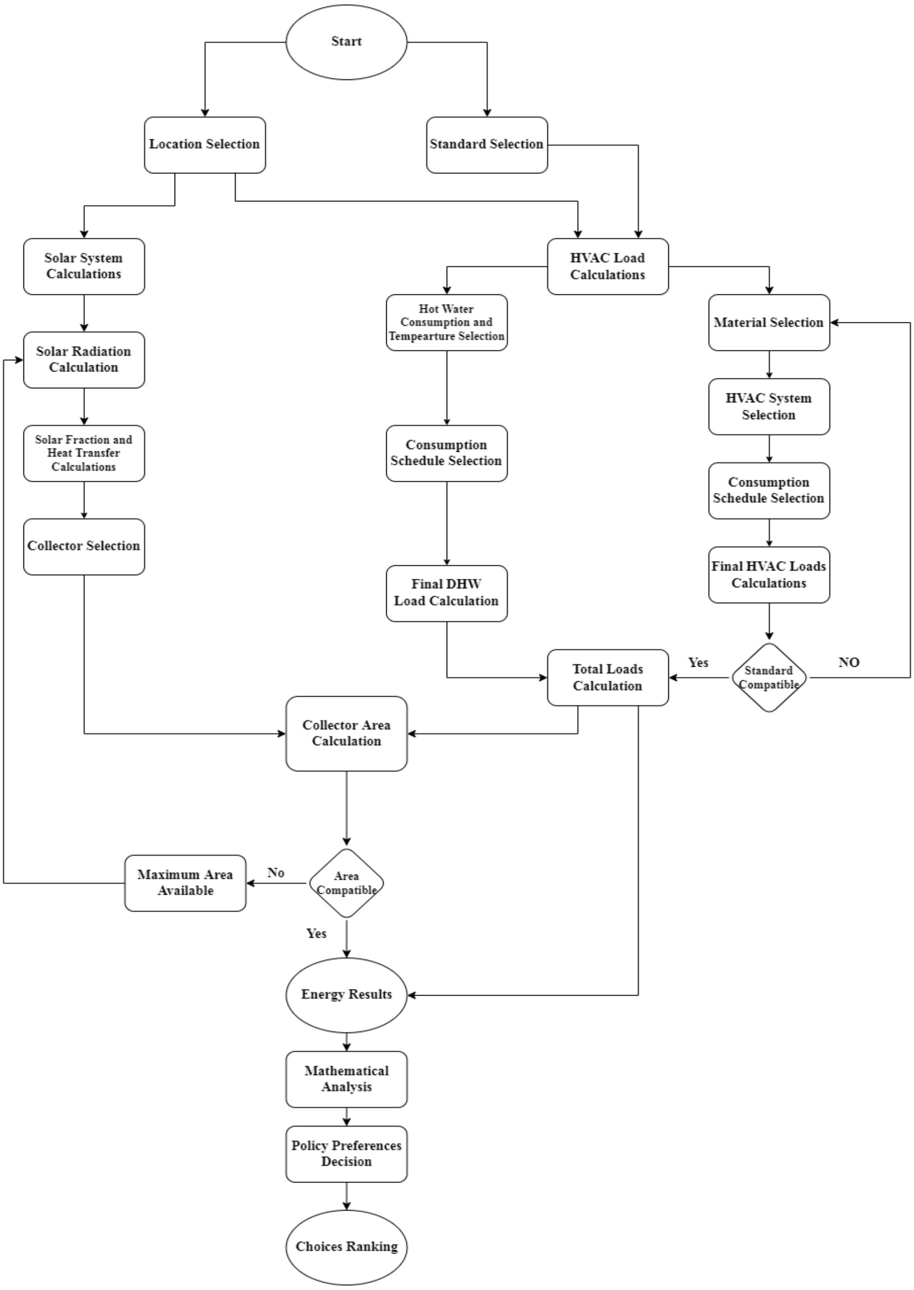

Figure 2. Basic schematic of the current study

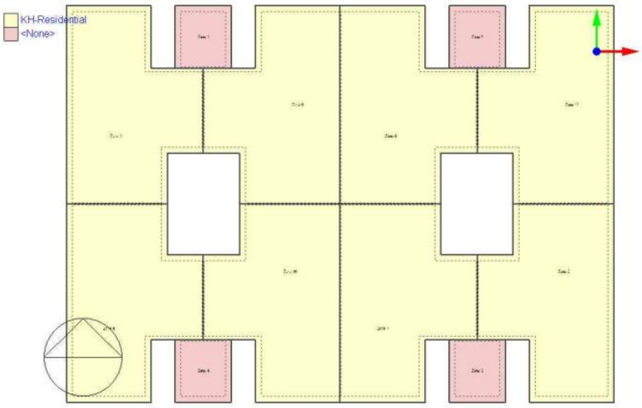

Figure 3. The basic architecture of each floor

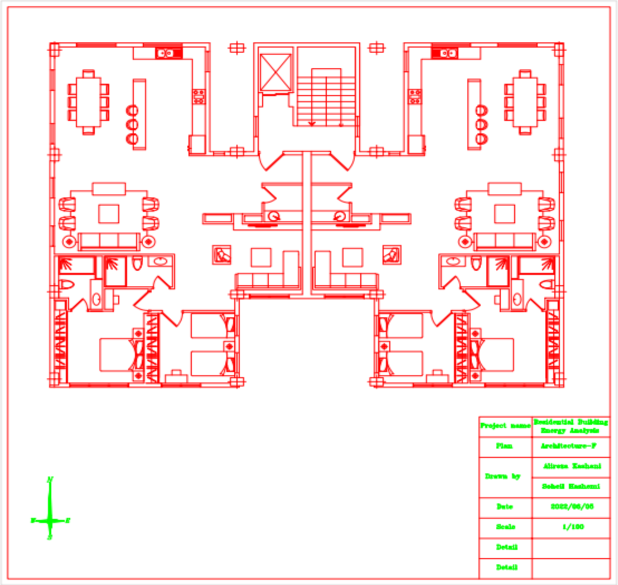

Figure 4. Detailed quarter of each floor

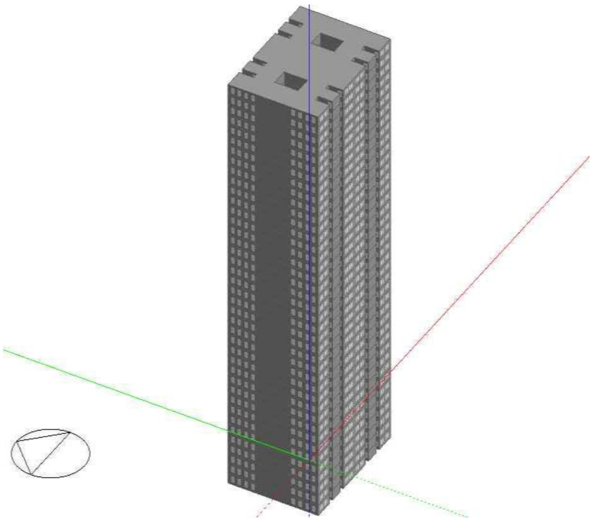

Figure 5. Skyscraper type

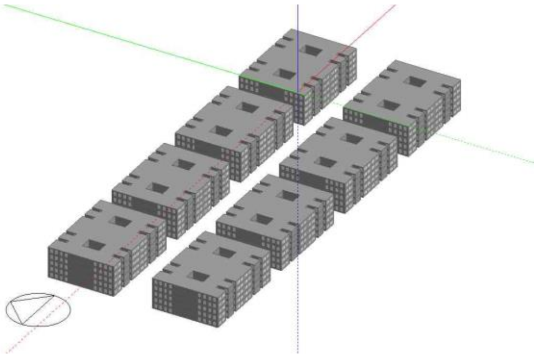

Figure 6. Linear type

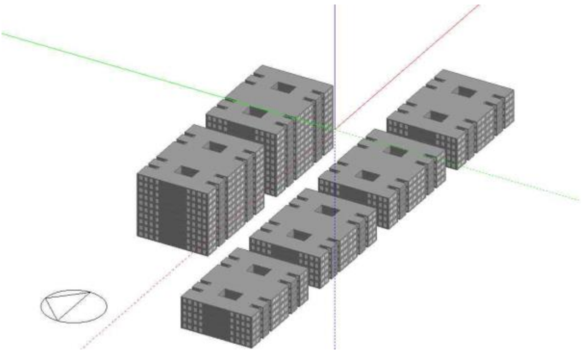

Figure 7. Mixed type

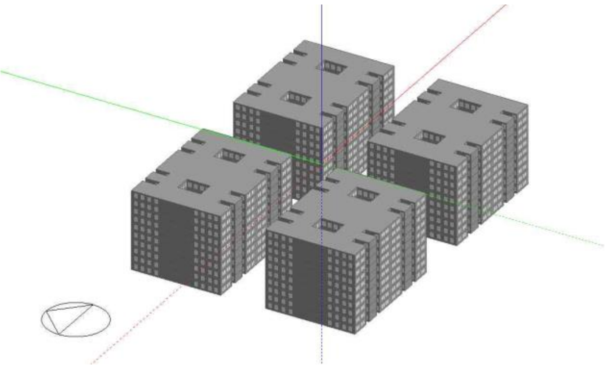

Figure 8. Towers type

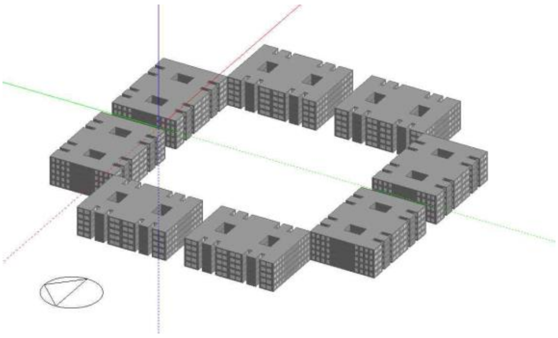

Figure 9. Surround type

3.2 Design builder

To calculate the energy use of each scenario, all mechanical and electrical simulations should be done to measure the related loads and then the heating and cooling design. Heating and cooling loads include heat transfer to or from one or more unconditioned zones to the conditioned zone through the building envelope, walls, ceiling, floor, doors, and windows. They also include infiltration, internal heat gains and losses, hot water gains and losses, solar gains, ventilation, etc. There are numerous types of heating and cooling systems to use in different kinds of buildings. The most common system is a boiler for heating and a chiller for cooling. Also, considering the usage of the building, which is residential in this case, scheduling is crucial in different parts of the system, including occupancy, HVAC, lighting, etc. [30].

$$Q_{HW} = c_p \rho_{HW} \dot{V}_{HW} (T_{HW} - T_{CW})/1000 \tag{1}$$

$$Q_{SH} = \frac{\overline{UA}(T_R - T_A)}{1000} \tag{2}$$

Equations 1 and 2 illustrate the loads calculated where c_p is the specific heat coefficient (J/kg.K), ρ is density (kg/m^3), V is the volumetric flow rate (m^3/h), T is the temperature (K), U is the overall heat transfer coefficient (W/K.m^2), and A is the area (m^2). Subscripts HW, SH, CW, R, and A mean hot water, space heating, cold water, room, and ambient, respectively.

3.3 T*Sol modelling

To simulate the solar energy parts of the alternatives used in the study, a dynamic simulation is needed. T*Sol software is a program that allows one to accurately calculate the yield of a solar thermal system dynamically over the annual cycle. T*Sol can optimally design solar thermal systems, dimension collector arrays, and storage tanks. The software is vastly used by researchers and designers in numerous studies and also experimental projects. In T*Sol, calculations are performed based on the balance of energy flows and provide yield prognoses according to the hourly meteorological data provided. The solar collector used is a flat plate type, and thus, the equations will be as follows [31].

$$S = I_b R_b (\tau\alpha)_b + I_d (\tau\alpha)_d \frac{(1+\cos\beta)}{2} + (I_b + I_d)(\tau\alpha)_g \rho_g \frac{(1+\cos\beta)}{2} \tag{3}$$

$$F_{sol} = 1 - \frac{Q_{aux}}{Q_{req}} \tag{4}$$

$$Q_c = A_c F_R [I_c(\tau\alpha) - U_c(T_i - T_a)] \tag{5}$$

$$\eta = F_R(\tau\alpha) - F_R U_c (\frac{T_i - T_a}{G_t}) \tag{6}$$

Where S, Q, η, F, I, R, τ, α, β, FR, and Gt are solar energy flux collected (W/m^2), heat output (W), collector efficiency, solar fraction, solar radiation intensity (W/m^2), fraction cosθ.cosβ Transmissivity factor, absorptivity factor, tilt angle (°), heat removal factor, and solar irradiance at the collector plane, respectively. Subscripts b, d, g, sol, aux, req, c, i and a means beam, diffuse, ground-reflected, solar, auxiliary, required, collector, incoming, and ambient.

$$\dot{Q} = \dot{m}(h_o - h_i) \tag{7}$$

Equation 7 demonstrates energy conservation in the solar system. Where Q, m, ho, and hi are heat rates transferred to the working fluid (W), flow rate (kg/s), and outgoing and incoming fluid enthalpy (J/kg), respectively [31].

3.4 PSI method

Because buildings may be ranked differently for different parameters, the PSI method is used to implement weighting and rank all choices accordingly [32]. Equations 8 to 12 illustrate normalized data, standard data deviation, deviation difference, parameter weight, and, finally, weighted data.

$$R_{ij} = \frac{x_{ij}}{x_j^{max}} \tag{8}$$

$$PV_j = \sum_{i=1}^{N} [R_{ij} - \bar{R}_j]^2 \tag{9}$$

$$\varphi_j = 1 - PV_j \tag{10}$$

$$\omega_j = \frac{\varphi_j}{\sum_{j=1}^{M} \varphi_j} \tag{11}$$

$$I_j = \sum_{j=1}^{M} (R_{ij} \times \omega_j) \tag{12}$$

4. Results and discussion

4.1 Design builder

The simulations are done using logical assumptions at different parts of the software. Four people in each apartment unit are considered. Their occupancy schedule is defined to be present early morning, late afternoon, and nighttime. Temperature preferences are indicated in Table 1.

Table 1. Temperature assumptions

Heating set point °C	Heating set back °C	Cooling set point °C	Cooling set back °C
22	18	25	30

Figure 10 shows the external walls consisting of 30 mm brick, 30 mm cement, 350 mm masonry, 50 mm polyurethane foam, and 50 mm gypsum plasterboard which leads to an R-value of 3.066 m^2-K/W. Also, the top floor's roof consists of 20 mm bitumen, 150 mm MW glass wool, 200 mm air gap, and 13 mm plasterboard which leads to an R-value of 4.162 m^2-K/W.

Figure 10. External walls structure

Windows are double glazed 2×3 mm + 6 mm air gap with no shading and are defined into two groups of 1.5 m and 3 m in length. Lighting is considered to be 7.5 W/m^2 in all areas while the working plane height is considered to be 0.8 m from the floor. The lighting schedule is also considered when needed. An HVAC system is considered for all buildings. Four-pipe fan coils, shaped like Figure 11, are used in each conditioning zone. Heating is supported by a boiler(s), while cooling is supported by an air-cooled chiller(s). Mechanical and natural ventilation, domestic hot water, and control systems are other parts of the HVAC system. Based on the HVAC schedule, when there is low occupancy, the HVAC system reduces to 50% of the maximum capacity.

The heating and cooling loads of each building type are calculated. All other assumptions are considered with the energy code of Canada and the software default values. According to Figure 12, it can be seen that the heating load is the highest in the case of towers, followed by skyscrapers.

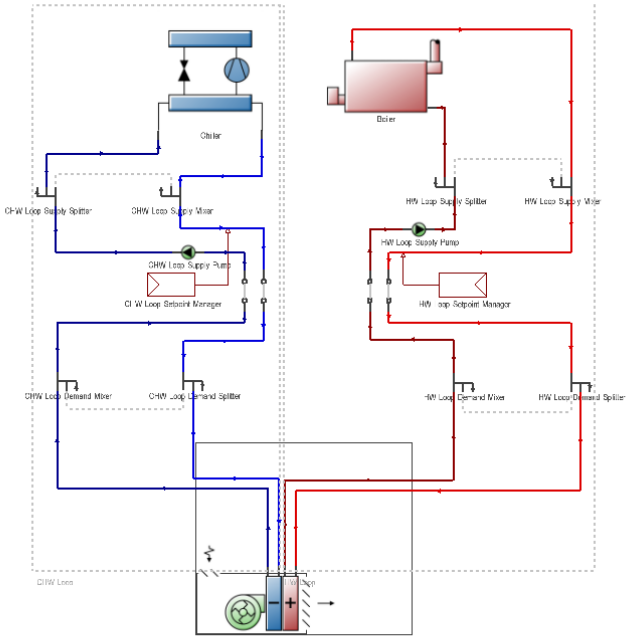

Figure 11. HVAC system diagram

The reason for this issue is the benefit of these two plans from sunlight. It is clear that the middle and back faces of the towers receive the least radiation. The proximity of the towers together helps to reduce the heating requirement to some extent, but benefiting from the energy of the sun's radiation is more effective. The next rank is the cooling load of the linear and surrounding arrangement, which is almost equal to each other due to the same number of floors and the shape of the buildings. The advantage of these two structures compared to towers and skyscrapers is mainly due to the ability to receive more energy from the sun; In addition, the neighborhood of the building also has a positive effect. The combined mode has the lowest cooling load among these 5 modes. This arrangement has the advantages of towers and linear arrangement together. In this way, the combination of four buildings with a lower height in one row and two towers in the other row keeps the amount of solar energy received by all buildings at an optimal level, and their proximity also reduces cooling energy demand compared to a skyscraper.

According to Figure 12, regarding the required cooling load, the arrangement in the form of towers requires more energy. After that, the environmental arrangement and in the next ranks are linear, combined, and skyscrapers. In a skyscraper, since there is only one roof, much less heat is absorbed through it than in other cases. Also, due to its height, during the day, more shade is created on its lower floors on the north side, and this also helps to reduce the need for cooling. In the linear layout, even though more roof surface is exposed to sunlight, the shading of nearby buildings protects many surfaces from direct radiation and reduces the need for cooling. In the combined mode, both the roof level is lower than the linear one, and we have almost the same shading effect compared to the linear one, and for this reason, the cooling load was the lowest in this mode. In the environmental arrangement, unlike the linear arrangement, more parts face direct radiation, and therefore the effect of the proximity of the buildings is less than in other cases, which has increased the need for cooling. Arrangement in the form of towers, although the roof area is less than the ambient condition, the side surfaces are more exposed to direct radiation, and for this reason, it requires more energy for cooling.

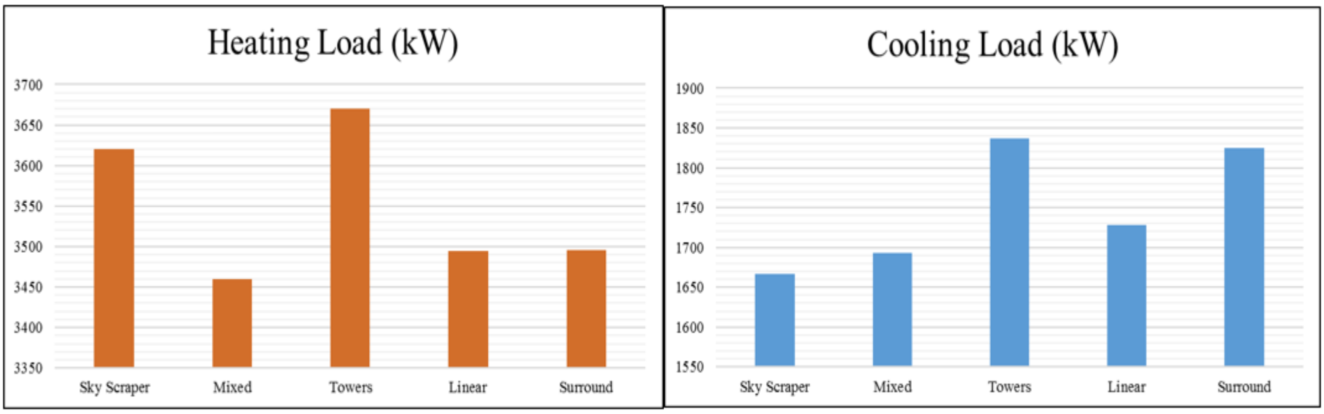

Figure 12. Heating and cooling loads

Figures 13 to 17 illustrate the amount of each fuel and each heating or cooling gain of each building during the year. As shown, the amount of gas used for heating is reduced during warmer seasons. Where the electricity demand for cooling increases in the same period. The amount of heating needed is much more than the amount of cooling during the year because of the location of the project, which has a cold climate. Towers and mixed-type need higher values of heating in cold climates.

Figures 13 to 17 also show the gains of each type, and it is obvious that the heating procedure is positive during the year. On the other hand, ventilation and infiltration cause a negative external air to gain all year. This means that the possibility of natural ventilation, especially in summer, is available, which is considered in this study. Also, the passive solar gain from exterior widows causes less heating needed in temperate months of the year. Thus, having air-sealed windows with no shading in most of the living areas of each apartment could help the heating load needed throughout the year; which is also considered.

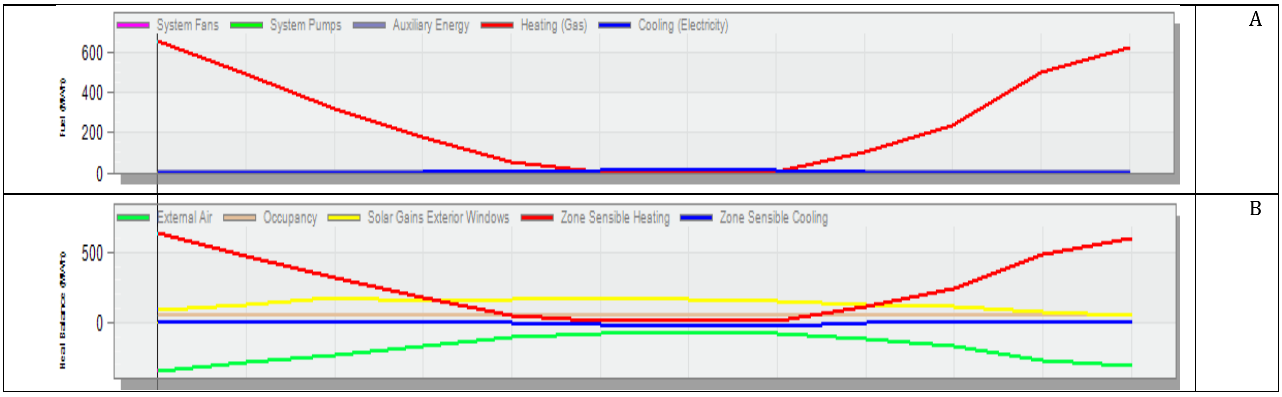

Figure 13. Fuels (A) and heat gains (B) of Skyscraper type

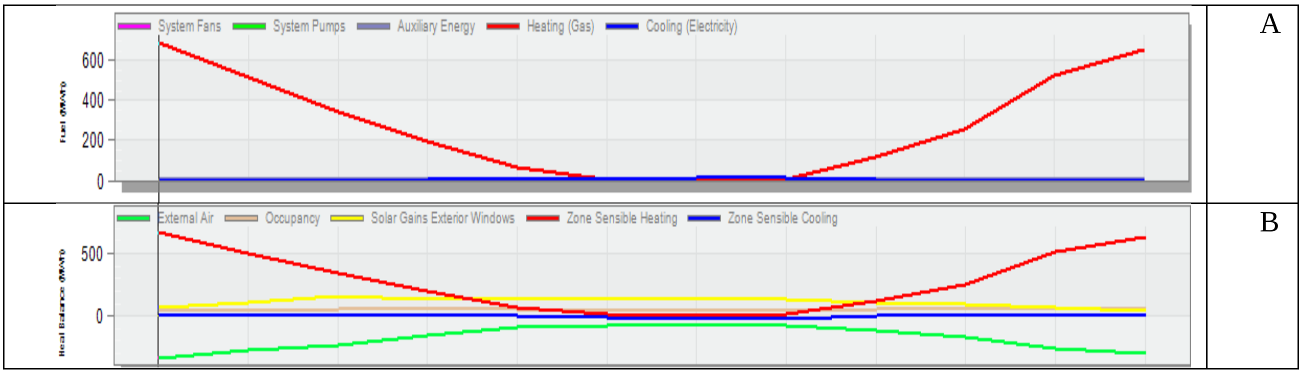

Figure 14. Fuels (A) and heat gains (B) of Mix type

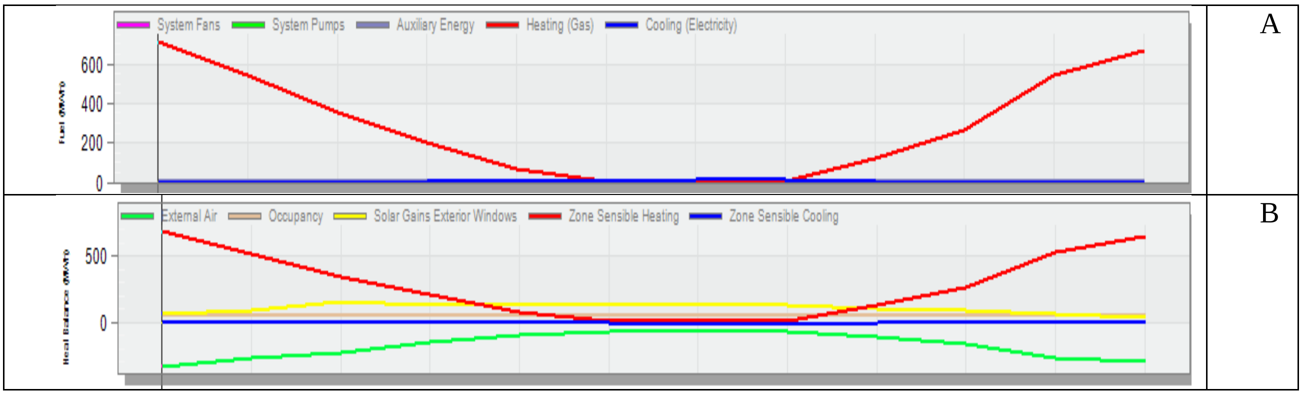

Figure 15. Fuels (A) and heat gains (B) of Linear type

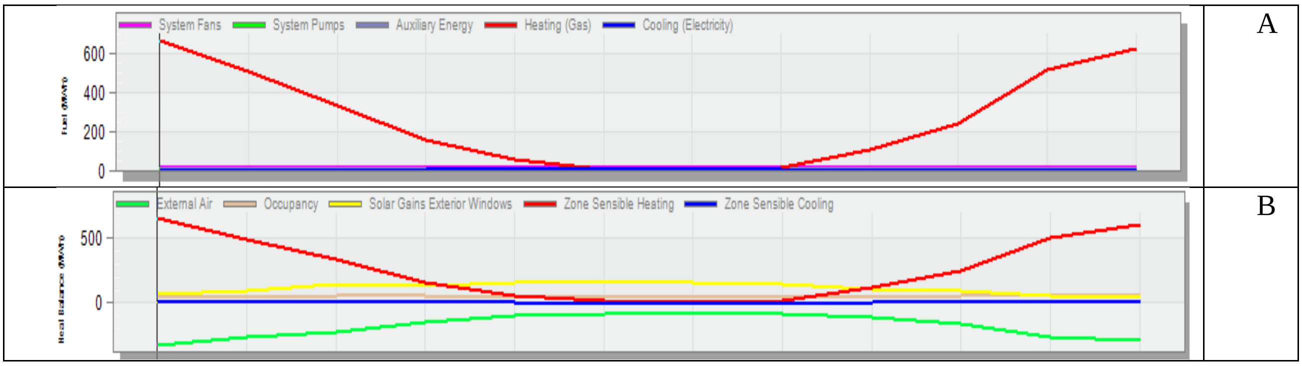

Figure 16. Fuels (A) and heat gains (B) of Surround type

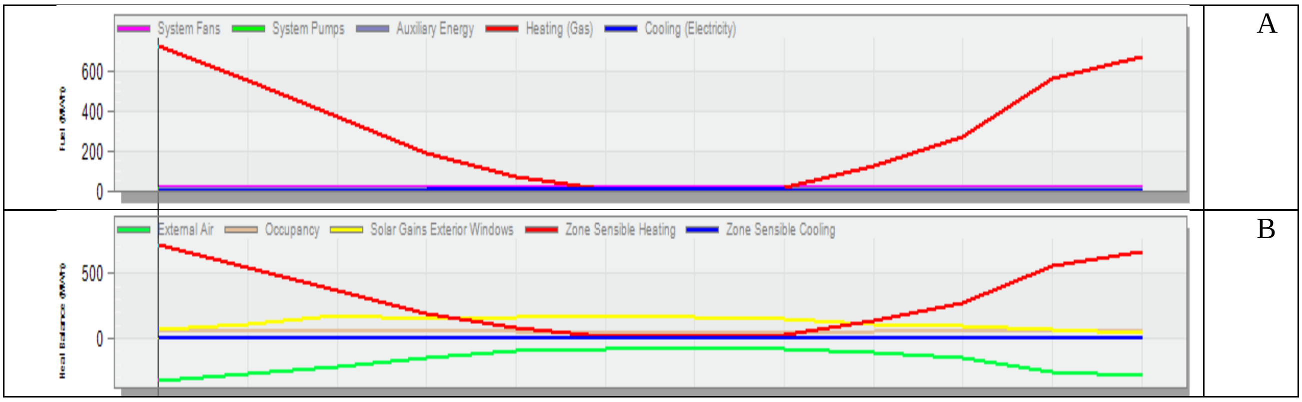

Figure 17. Fuels (A) and heat gains (B) of Towers type

4.2 T*Sol

In the present study, five alternatives are simulated, and assumptions are indicated in Table 2. As shown in Figure 18, flat plate collectors are used alongside two storage tanks with volumes of 182 and 29 m^3 and a natural gas-burning boiler. The working fluid in the collector loop is a mixture of 60% water and 40% ethylene-glycol. The space heating working fluid temperature is 40 °C before heat exchange and 25°C after heat exchange. The windows' heat flux is considered 5 W/m^2. First, the maximum solar fraction is calculated based on the space heating loads. Table 3 shows the value of solar fraction for different options. As it is known, skyscrapers have the highest amount. This is because in a skyscraper that has a higher height, more levels of sunlight are received, and there is no building in its vicinity. After that, the linear, environmental, and combined models have the same values, and the towers have a lower solar fraction than the others. In this way, for providing heat, the skyscraper can have better potential and the others are in the next category. However, the problem is that to achieve this fraction, a larger surface is needed to install the collectors. The maximum solar fraction is yielded when there is enough surface area to accommodate the solar collectors. The collector required for this purpose is also calculated. This can be seen in Table 4.

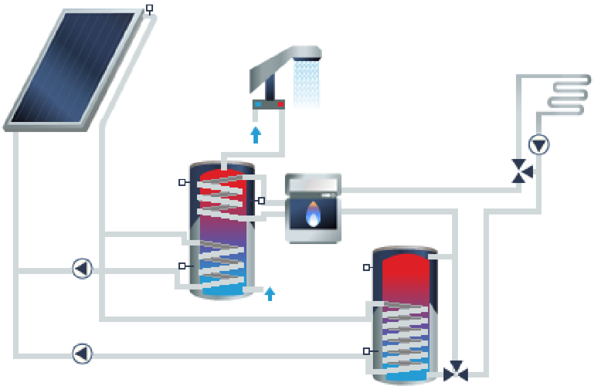

Figure 18. Schematic of the solar system used

In this table, the level of the collector needed to achieve the maximum fraction is stated: the skyscraper needs the highest amount, and then the towers and other buildings are placed with almost the same values. In terms of feasibility, the level that the building can provide for the installation of collectors is important. In this article, the collectors that can be installed on the roof are desired, and therefore, the roof surface of the buildings is the available space for this work. It is clear that the skyscraper, despite having relatively higher potential, does not give many possibilities to use this potential due to having only one roof. Based on the structure of each building type, the maximum area possible for each case is calculated by the surface area of the rooftop. Available surface values for installing solar collectors are listed in Table 5. As expected, horizontal arrangements have the largest roof areas, followed by the combined towers and skyscrapers. The above contents are summarized in Figures 19 and Figure 20.

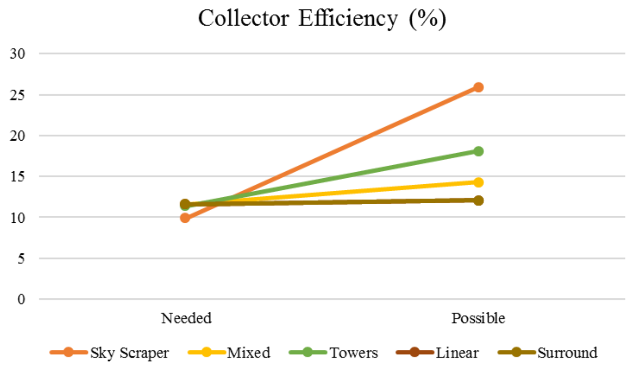

Figure 19. Solar fraction based on the areas possible and needed

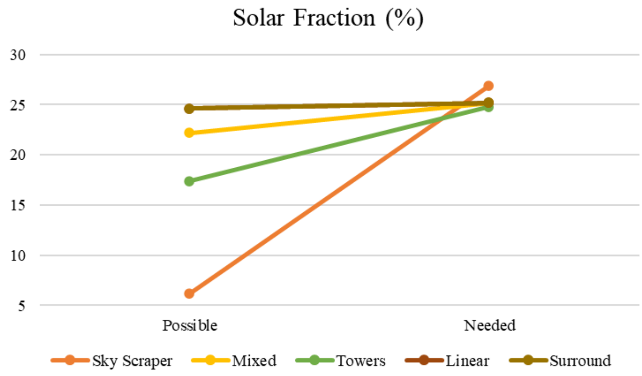

Figure 20. Collector efficiency based on the areas possible and needed

Based on both area values above for each case, the space heating solar fraction for each case is calculated and shown in Figure 19. In this Figure, the maximum amount of solar fraction and the amount that can be achieved based on the roof surface of different situations are drawn. According to Figure 19, it can be seen that these two values are very close in the linear and surrounding states, and the maximum amount of energy can be absorbed by the solar collectors. However, the distance between these two values is less in the compound and towers and is very large in the skyscraper. Also, Collector efficiency based on the areas possible and needed is shown in Figure 20, in which trends are as expected.

Because of the reduction of collector efficiency by increasing solar fraction, the optimum amounts possible could be calculated considering the importance of each parameter to the decision-makers. Adding heating and cooling loads to the decision-making procedure chooses between scenarios even harder. A PSI method of mathematical optimization is considered to choose the building type correctly. The method automatically calculates the best weighting possible for each parameter and then ranks the choices accordingly. The parameters consist of heating load, cooling load, solar fraction, and collector efficiency. The first two parameters are cost values, and the latter are gain parameters. So, in order to correctly use the mathematical method, solar fraction and collector efficiency are changed to be cost parameters in the program.

Tables 6 to 10 indicate the cost, normal, PV, weight, and result matrices, where parameters of heating load (HL), cooling load (CL), cost of collector efficiency (1-CE), and the cost of solar fraction (1-SF) are located in columns, and building types of sky scrapper (SS), mix (MI), towers (TO), linear (LI), and surround (SU) are located in rows. The amounts stated are calculated with equations 8 to 12. As can be seen in Table 10, the skyscraper has won the first rank. After that, there are, in order, the mixed arrangement, linear, towers, and surround. Based on this; by weighting the criteria in the multi-criteria ranking and the results, the skyscraper is selected as the optimal option.

Table 2. T*sol software assumptions

Consumption usage	Hot water temperature	Location	Climate	Mean Outside temperature	Min outside temperature
Residential	50 °C	Edmonton, AB, Canada	Cold	2°C	-35.64°C

Table 3. Maximum solar fraction

Building type	Sky Scrapper	Mixed	Towers	Linear	Surround
Solar fraction (%)	26.9	25.2	24.8	25.2	25.2

Table 4. Collector area needed to yield maximum solar fraction

Building type	Sky Scrapper	Mixed	Towers	Linear	Surround
Collector Area Needed (m^2)	12865	9752	10413	9878	9878

Table 5. Maximum area possible for the installation of collectors

Building type	Sky Scrapper	Mixed	Towers	Linear	Surround
Collector Area Possible (m^2)	1157.75	6947	4631	9262	9262

Table 6. Cost matrix

1-SF	1-CE	CL	HL	Decision cost Matrix
0.731	0.741	1666.93	3620	SS
0.748	0.857	1693.13	3460	MI
0.752	0.819	1837.31	3670	TO
0.748	0.879	1728.2	3495	LI
0.748	0.879	1824.72	3495	SU
0.752	0.879	1837.31	3670	Max

Table 7. Normal cost matrix

1-SF	1-CE	CL	HL	Normal Cost Matrix
0.972	0.843	0.907	0.986	SS
0.995	0.975	0.922	0.943	MI
1.000	0.932	1.000	1.000	TO
0.995	1.000	0.941	0.952	LI
0.995	1.000	0.993	0.952	SU
0.991	0.950	0.953	0.967	Mean

Table 8. PV cost matrix

	1-SF	1-CE	CL	HL	PV Matrix
	0.000	0.011	0.002	0.000	SS
	0.000	0.001	0.001	0.001	MI
	0.000	0.000	0.002	0.001	TO
	0.000	0.003	0.000	0.000	LI
	0.000	0.003	0.002	0.000	SU
Sum	0.000	0.017	0.007	0.002	Sum
3.973	1.000	0.983	0.993	0.998	1-PV

Table 9. Result weight matrix

1-SF	1-CE	CL	HL	Weight Matrix
0.252	0.247	0.250	0.251	

Table 10. Result matrix

Gain Rank	Result Matrix	HL	CL	1-CE	1-SF	Sum
1	SS	0.25	0.227	0.209	0.245	0.93
2	MI	0.24	0.23	0.241	0.25	0.96
4	TO	0.25	0.25	0.23	0.252	0.98
3	LI	0.24	0.235	0.247	0.25	0.97
5	SU	0.24	0.248	0.247	0.25	0.98

Although, decision makers can have different weighting preferences considering the location of the project or fuel-related and renewable energy policies. Thus, different weightings can also be considered. The choice of one could be the most important of heating load and solar fraction. The results are calculated in Tables 11 and Table 12. As can be seen in Table 12, the ranking has been changed, and the skyscraper is second. The first ranks belong to the mixed arrangement. Others also changed and respectively are linear, surround, and towers. It shows that according to the condition and priorities in a different situation, in which weights are different, rankings can vary. But by comparing Table 10 and Table 12 we can see that the two first rankings are similar, but the order is changed which shows that those are most probably the best options.

Table 11. Preference weight matrix

1-SF	1-CE	CL	HL	Weight Matrix
0.3	0.1	0.1	0.5	

Table 12. Preference result matrix

Rank	Result Matrix	HL	CL	1-CE	1-SF	Sum
2	SS	0.49	0.0907	0.0843	0.292	0.96
1	MI	0.47	0.0922	0.0975	0.298	0.959
5	TO	0.5	0.1	0.0932	0.3	0.993
3	LI	0.48	0.0941	0.1	0.298	0.969
4	SU	0.48	0.0993	0.1	0.298	0.974

5. Conclusions

In this paper, the issue of energy in the building was investigated. As one of the largest energy consumers and greenhouse gas emitters, the residential sector needs special attention in terms of improving the energy consumption situation. Considering the general trend of the world towards the rapid growth of urbanization, which will mainly be in residential complexes, the examination of these complexes has become one of the important matters in the field of energy. In line with the present article, the literature on the subject was reviewed and the various trends that were noticed by the researchers in the design and implementation of the different schemes for complexes were examined. In general, most researchers confirmed that residential complexes are better than detached houses. They also mentioned the use of solar energy as a good solution to reduce the need for fossil fuel consumption. To improve the conditions of energy consumption in buildings, there are various solutions of passive and active methods that can be improved to a great extent by using them. In this article, more than the factors involved in architecture, the focus has been on examining the effect of different types of arrangements on each other. The city of Edmonton, which is located in region 2 according to the ASHRAE classification, was chosen for modeling. This region has a cold and dry climate. Also, the wind speed is strong in winter. Therefore, the main priorities of the design are to protect the cold air and wind in the cold seasons and to use natural ventilation in the summer. These are considered in the modeling. In addition, to actively use solar energy, the usability and improvement rate of solar collectors were also analyzed. Therefore, five types of arrangement linear, towers, mixed, skyscraper, and surrounding were proposed, which did not differ from each other in terms of interior design and cooling and heating systems, and the only difference was in the number of floors and their arrangement together. These options were modeled with relevant details in design builder software and the results were investigated. Also, modeling of the use of solar collectors was done with the help of T*sol software. The results showed that, for example, the skyscraper option, although it has a favorable situation in terms of the required cooling load and also the potential of receiving solar energy, due to the lack of roof surface that can be used for installing collectors, it cannot use a large part of this energy, Of course, it is clear that this is inevitable in engineering matters and it is very difficult or even impossible to optimize all the different criteria, including economic, environmental, operational capability, etc. For this reason, since the problem of determining the optimal option is a multi-criteria problem, to compare the options, the PSI optimization method with two weighting methods was used. The results indicated that the first two options are skyscrapers and mixed, and other options are in the next categories. Therefore, it can be recommended that the builders of the complex choose one of the two layout types.

Ethical issue

The authors are aware of and comply with best practices in publication ethics, specifically with regard to authorship (avoidance of guest authorship), dual submission, manipulation of figures, competing interests, and compliance with policies on research ethics. The authors adhere to publication requirements that the submitted work is original and has not been published elsewhere.

Data availability statement

The manuscript contains all the data. However, more data will be available upon request from the authors.

Conflict of interest

The authors declare no potential conflict of interest.

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