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ARTICLE

# Analysis and Evaluation of Thermal-cooling Loads of Office Buildings Using Carrier Software in Iran

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ABSTRACT

The importance and necessity of energy saving in the world have been discussed for many years, but achieving a logical and transparent solution is still one of the main challenges and problems of the world's economy. The rapid growth of energy consumption in the last two decades has caused the security of the domestic energy supply of buildings to face serious problems. In this research, first by entering parameters such as the type of materials, doors and windows, and the type of soil on the floor connected to the ground, etc. in the heat and cold load calculation software (HAP Carrier) as the design calculations and then in the second step entering the specifications inferred from the Iran's national building code as a reference for energy saving calculations, calculations are performed and compared as the first criterion, and finally these two outputs are compared. The actual energy consumption and determination of the building energy consumption index are determined as another criterion, as well as the degree of deviation from the actual consumption. The results showed that the theoretical method and the thermal and refrigeration load calculations of the Zanjan Gas Company building have 6% difference in cooling load but the heating load is about 34% different, which means for cooling loads, the theoretical model can be used with high accuracy but for heating loads, the national building code needs fundamental changes.

## 1. Introduction

Buildings are the primary source of energy consumption globally and locally [1]. In 2015, existing buildings accounted for approximately 30% of global energy final consumption and 28% of energy-related greenhouse gas emissions [2]. Large buildings, which are different from ordinary buildings such as residences and offices, have enclosed spaces with high internal height, but to some extent, they are used by internal occupants [3]. This type of build-

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ing today in metropolises such as airport terminals [4-6], railway stations [7], commercial buildings [8], stadiums [9], theaters [10], buildings industries [11] are extensive. Multiple openings and heat sources in these large spaces can lead to complex indoor airflow and heat transfer.

Energy consumption in the construction sector is even higher in cities with large blocks of commercial buildings. In 2015, for example, buildings in Hong Kong accounted for 64% of the city's total final energy consumption, of which commercial buildings alone accounted for 43% of the final energy consumption [12].

Minor et al. [13] simulated a variable volume air conditioning system for cooling mode in an existing office building. They used a building simulation package to simulate. Existing office building design information, the actual number of internal load sources such as occupants, lighting, office equipment, etc., are used in the building simulation package. The simulation results showed that 71.1% of the total simulated power consumption data is in the range of 15% of the experimental data. Some off-band data are due to possible errors related to differences in the solar data used for a location 40 km from the experimental site. It was found that 90.6%~94.7% of the indoor temperature experimental data are in the range of 1.5% °C of the simulated data, and 88.3%~91.3% of the indoor relative humidity data are in the range of 18% of the simulated data. Zhao et al. [14] implemented variable refrigerant air conditioning in office buildings. In this paper, the energy consumption of the VRF system was compared with two conventional air conditioning systems, namely variable volume air system (VAV) and fan coil with new air system (FPFA). A public office building is used to accommodate various types of heating, ventilation, and air conditioning (HVAC) systems. This work focuses on the energy consumption of the VRF system in office buildings and helps the designer evaluate and decide on HVAC systems in the early stages of building design. The simulation results show that the energy-saving potentials of the VRF system are expected to reach 22.2% and 11.7%, respectively, compared to the VAV system and the FPFA system.

Lee and Sumati [15] reviewed past efforts in solar air conditioning systems with the absorption of lithium bromide and water. Researchers have made several efforts to improve the performance of solar air conditioning (chiller) subsystems. It can be seen that the inlet temperature of the chiller generator is the most crucial parameter in the design and construction of the solar air conditioning system. While collector selection, system design, and arrangement are other factors affecting system performance. Chou et al. [16] aimed to evaluate the thermal comfort environment in an office building by conducting a 100% outdoor air system with the help of a liquid and indirect cooling dryer. This research provides a way to evaluate the thermal environment through a set of energy simulations using the TRNSYS 17 program, integrated with the Engineering Equation Solving Program (EES). Supply air temperature (SA) is estimated according to the seasonal performance modes of LD-IDECOAS estimated in previous research. Indoor air conditions are estimated on the assumption that the auxiliary humidity systems maintain the relative humidity of the room air in the specified values. Then, the predicted mean votes (PMV) values are estimated using the given indoor environment conditions. A detailed analysis of the impact of indoor weather conditions on PMV is presented in this paper. In addition, the simulation results for LD-IDECOAS were compared with those for a variable volume air volume (VAV) system to evaluate the thermal environment in a building served by LD-IDEAS. This study concludes that the use of LD-IDECOAS in an office building can create energy savings with an acceptable level of thermal comfort.

Che et al. [12] examined the energy consumption and interior environment with a reinforced air conditioning system. Reinforcement measures included a sensor-based building management system, an outdoor dehumidifier, and a two-stage particle purification system. Field measurements were performed in winter and summer to assess thermal comfort and indoor exposure to air pollutants in the retrofitted area. An experiment is designed to evaluate the benefits of updated filters in the face of ambient particles during the summer. By combining all these measures, the refurbished air conditioning system reduced energy consumption by 50% while reducing acceptable internal thermal comfort. Pei Peng et al. [17] presented an energy radiant air conditioning system containing a sidewall of the roof and investigated the ACERS composite heating performance of the sidewall of the roof with an air source heat pump by field test. The results show that the hybrid system can meet the heating needs of office buildings in south-central China and can save energy. Meanwhile, the temperature gradient in the roof ACERS is smaller than the sidewall ACERS due to the more significant heat transfer due to air infiltration. Temperature distribution and simulated CFD show that furniture shelter affects the indoor heating environment and should not be ignored in practical engineering. This research shows the possibility of winter heating using ACERS in office buildings. It is helpful for air conditioning engineers to design and use different types of ACERS and realize the integration of air conditioning in winter and summer in this area.

Layeni et al.'s [18] economic analysis of design and engineering of two widely used air conditioning (AC) systems, mini-split, and variable refrigerant flow, in the building of the new engineering complex under the same internal and external conditions for a whole year using program software Carrier hourly analysis for cooling load estimation and net present value analysis for economic analysis of both systems. Both systems are directly air conditioning. Therefore, the cooling load estimation was selected from the Toshiba (Mini Split System) selection list using the ASHRAE transfer function method embedded in the software carrier equipment used in the analysis. In contrast, the equipment for the VRF system was used using similar Toshiba was selected. Zhang et al. [19] proposed a rule-based communication rule extraction method to improve data mining performance and automatically filter out useless rules of ventilation data. It consists of three steps: data preprocessing, extraction rule, extraction rule, and post-extraction. In the data preprocessing phase, a method based on core density estimation has been developed to filter waste automatically. Furthermore, a method based on kernel density estimation has been developed to convert numeric data to batch data automatically. Evaluations are performed using the historical operational data of the chiller plant of a commercial building. The results show that the proposed data preprocessing approaches are effective in identifying the data evolution and evolution. Moreover, the proposed comparison-based method can automatically filter 54.98% of the extracted communication rules, which is useless for detecting operational problems.

The interior design air parameters set in the current design standards are based on human thermal comfort without fully considering the energy efficiency of the building. Jan Ding et al. [20] analyzed the interior design parameters from thermal comfort and energy consumption perspectives, respectively. By conducting field tests on existing buildings and collecting design information from maps and descriptive files, the indoor air parameters of 140 public buildings in China were examined. Typical public buildings (small office buildings, large office buildings, and shopping centers) were selected for the simulation study. Based on the research results, simulation models for three types of public buildings have been developed to make the assumptions more relevant to the actual situation. The relationship between the predicted mean vote and energy consumption of the simulation models was analyzed. From the analysis of research and simulation results, it can be seen that the relative humidity of the design in winter does not easily affect the internal heat and energy consumption of the building. In contrast, the relative humidity of the design in summer, indoor air temperature, and average votes are predicted that they are related to the level of internal thermal comfort and energy consumption of the building. Also, to improve the current design standards, interior design air parameters contribute to low energy consumption and comfortable surface. Chen Liu et al. [3] showed that air conditioning systems have a significant effect on air infiltration in large space buildings. A CFD model was created from a railway station with conventional air conditioning systems, for example, mixed ventilation (MV), displacement ventilation (DV), and radiant floor with displacement ventilation (RF + DV). The air infiltration rate in these cases was compared when the operating temperature in the occupying area was the same under heating/cooling conditions, respectively. It is found that a uniform vertical temperature distribution under heating conditions and a significant thermal classification under cooling conditions to reduce the potential air infiltration rate is consistent with RF + DV.

In the continuation of the previous researches, in this article, the building of Zanjan Gas Company will be studied. This case will be investigated in 12 months of the year, and the heat and refrigeration load of this building will be calculated through the usual formulas in heat transfer and the carrier software, and the amount of load will be calculated in two methods together. The two methods will be compared and analyzed to see if Iran's national building codes can be still used or need revisions.

## 2. Case Study

The building in question is located in Zanjan, the capital of Zanjan province, located at 48.29 longitudes and 36.21 latitudes. Its average altitude is 1600 meters above sea level. The climate of this city is dependent on the altitudes, and on average, it has been freezing for six months. The average rainfall in Zanjan is 246 mm per year [21].

The entire infrastructure of the building is 3360 square meters, and it has been constructed on five floors with a basement floor. This office building with office use includes 60% of office space, 21% corridor, 7% restaurant, and other building spaces allocated to meeting rooms, warehouse, archive, prayer hall, etc. Working hours are 7:30 to 16, and the number of employees is about 105 people [22]. The predominant lighting system is fluorescent lamps with independent control, and the building has an engine room.

The architecture of buildings and the materials used in the walls are essential characteristics in the amount of energy waste of the building and therefore should be considered [23]. The exterior and interior walls of these buildings are made of common building materials (building materials are based on the information obtained). The executive details of the components of these buildings are as follows in Tables 1 to 3 [24].

**Table 1.** Thickness of materials used in the outer wall of the central building of Zanjan Gas Company (mm)

| Brick facade | Mortar | Solid brick | Plaster |
|---|---|---|---|
| 30 | 20 | 300 | 25 |

**Table 2.** Thickness of materials used in the roof of the central building of Zanjan Gas Company (mm)

| Mosaic | Mortar | Slope pockets | Clay block | Plaster |
|---|---|---|---|---|
| 20 | 20 | 50 | 250 | 40 |

**Table 3.** Thickness of materials used on the floor of the central building of Zanjan Gas Company (mm)

| Marble | Mortar | Concrete | blockage |
|---|---|---|---|
| 20 | 20 | 100 | 300 |

## 3. Methodology

In the following, a comprehensive study of heating and cooling systems such as heating and cooling systems and energy consumption of computers and printers and other electrical equipment, as well as lighting and its effect on office temperature and other parameters such as The number of clients and its effect on ambient temperature and the role of translucent walls in providing light and temperature loss inside the building number one of Zanjan Gas Company and knowing that the analysis of thermal and refrigeration load of the building, especially with multi-story volumetric dimensions requires - is a large volume of data. With a simple technical analysis of one of the tables of Carrier PAH software, it is found that in the northern hemisphere for zones whose windows are facing west and east, the peak this time in summer afternoons and mornings occur in July and August, and for zones facing south, the peak this time is in autumn and early winter. Zones with north windows receive direct sunlight. They do not and therefore do not change much in their radiation loads during the year. Heat and heat dissipation is due to the high SEC (Energy Consumption Index) and determining the actual consumption and needs of energy. Meanwhile, according to ASHRAE standards and with the climatic conditions of Zanjan, with maintaining the relative humidity of about 45% to 50%, the indoor temperature can be set at 25.5 degrees Celsius in summer and 18.3 degrees Celsius in winter. Article 19 of the National Building Code states that the standard temperature is 28 °C for summer and 20 °C for winter.

The basis of design and analysis of thermal and refrigeration load in buildings and heat transfer environment and as you know the heat transfer in a building is done through three radiation-convection-conduction and heat and refrigeration load in a building is divided into the following sections.

**Transfer loads** (through heat transfer from the external walls of the building) depend on the temperature of the outside and inside air and the coefficient of the external walls.

**Radiation loads** (through windows and skylights): Geographical location, the space around the building, the direction of the zones, the amount of surface and glass material of windows, and the color of the outer shell of the building and curtains depend.

**Internal loads** (including loads due to lighting, people, and internal loads of other miscellaneous equipment): Generally, these types of loads are exothermic and increase the heat of the room throughout the year.

**Loads due to air infiltration**: These loads are exothermic in summer and cause cold transfer inside the building in winter.

The importance and value of heat and cold analysis of a building let us begin with a simple example. In two buildings with the same volume and area, but in the first building with ordinary materials such as 12-inch (30 cm) thick compression brick and cream-colored travertine exterior facade and internal gypsum coating, heat transfer coefficient from the walls u = 0.24 $W/m^2 \cdot k$ will be the second building with the same area, volume and location, but with 20 cm hollow clay brick materials and 1-inch insulation (compressed polystyrene) in the middle with the same facade of travertine exterior stone and gypsum interior, total heat coefficient u = 0.08 $W/m^2 \cdot k$, i.e. a significant reduction in heat transfer of the second building compared to the first building by 300%, if the double-glazed window with profile and double glazing instead of the usual metal window with profile and single-glazed glass If used, the heat dissipation will be reduced by up to 40%, i.e. energy consumption with a constant temperature in a building will be about 3.5 times that of another building with the same area and infrastructure only by studying the heat transfer from the walls or shell of the building. Today, the role of computing software in industry and construction and Brexit research centers is not hidden; the advantage of using carrier software over manual computing is as follows:

- High speed of calculations;
- High accuracy of calculations;
- Accurate determination of heating and cooling load to select the best and most cost-effective devices required by the building cooling and heating supplier;
- The possibility of separating and calculating the heat and cold load for each building space;
- Possibility of simulation of heating and refrigeration

systems;
- Possibility of analyzing the required load of the building on an hourly basis;
- Calculations related to solar energy and temperature of dry and wet winter and summer plan hourly and monthly;
- Accurate and realistic analysis of building costs and help with the issue of energy auditing.

## 4. Modeling

First, the design parameters are given to the software, which are shown in Figure 1:

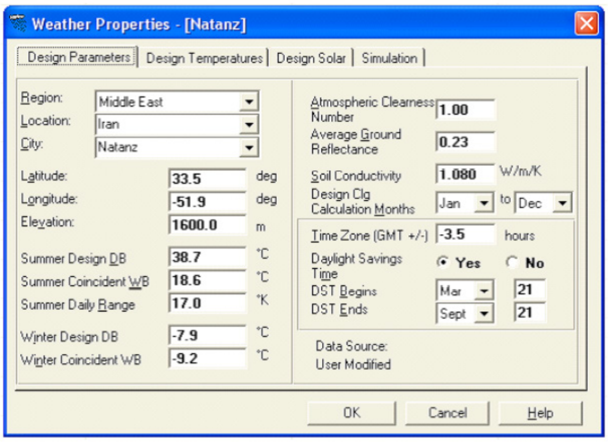



**Figure 1.** Input form of design parameters

1) City and Location, Region: Used to define design climate data using the P.A.H program database. If the city in question does not exist in the program database data, the data can be entered directly.

2) Longitude and Latitude: These parameters represent the geographical coordinates for the location of the building. These values are used to calculate solar energy.

3) Elevation: This parameter affects the psychometric calculations of the building because the density and psychometric properties change with altitude relative to sea level.

4) Dry design summer temperature, humid summer temperature, and daily temperature changes in summer (Summer Design DB, Summer Coincident WB, and Summer Daily Range): Temperature and humidity diagrams are used to configure cryogenic load calculations. Dry summer temperature design indicates the maximum daily air temperature, and humid summer temperature represents the humid air temperature at the maximum summer dry temperature.

5) Dry temperature of winter design and wet temperature of winter design: (Winter Design DB, Winter Coincident WB) These parameters determine the temperature and humidity conditions for thermal load calculations. Dry winter temperature indicates the minimum daily temperature, and humid winter temperature indicates the humid air temperature at minimum winter dry temperature.

6) The Clearness Atmospheric number is used to adjust the daily solar data in standard mode to the conditions where the air is dirty or foggy. The values of this number for different conditions are shown in Table 4.

**Table 4.** Air cleanliness coefficient for different climatic conditions

| Air clean conditions | Air cleanliness coefficient |
|---|---|
| Very clean weather | 1.15 |
| Normal weather | 1 |
| Dirty and foggy weather | 0.85 |

7) Earth Reflection Ground Average, the calculation of the reflected radiation from the impact of solar energy on the earth that is absorbed by the building, is used. The values of this parameter are shown in Table 5.

8) Conductivity Soil: This part is used to calculate the heat transfer from the ground and its values are extracted from Table 6.

9) Design Cooling Calculation Months: This parameter specifies the months for which cryogenic load analyzes are performed. If the user does not change this option, refrigeration load calculations are performed for all months of the year.

10) Time zone: Used to set solar charts for local time. This parameter indicates the time difference between the project location and the origin time (Greenwich).

11) Daylight Saving Time, DST Begins, and DST Ends: This parameter indicates whether the local time of the project location changes during the months of the year. For example, in Iran, in April, the clocks are moved forward for one hour, and at the end of September, the clocks return to their original state. This parameter affects the relationship between the solar graph and the local time.

12) Data source: This parameter indicates the source or reference used to enter the weather data. When weather data is entered directly by the user, it is the source of the data (User Modified).

### 4.1 Design Temperatures

This section contains information about daily humidity and temperature changes at different hours of the day to calculate the refrigeration load. The tables in this section can be used to view or modify the design temperature or humidity. This section contains two tables: Min/Max Monthly table.

**Table 5.** The average ground reflection coefficient

| Ground reflection coefficient/ Surface type | °70 | °60 | °50 | °40 | °30 | °20 |
|---|---|---|---|---|---|---|
| Fresh concrete | 0.34 | 0.33 | 0.32 | 0.32 | 0.31 | 0.31 |
| Old concrete | 0.25 | 0.23 | 0.23 | 0.22 | 0.22 | 0.22 |
| Green grass | 0.31 | 0.28 | 0.25 | 0.23 | 0.22 | 0.21 |
| Rubble | 0.20 | 0.20 | 0.20 | 0.20 | 0.20 | 0.20 |
| Glazed roof sprinkled with sand | 0.14 | 0.14 | 0.14 | 0.14 | 0.14 | 0.14 |
| Parking lined | 0.12 | 0.11 | 0.10 | 0.10 | 0.09 | 0.09 |

**Table 6.** Convective ground transfer coefficient.

| Soil Moister | °F.thermal Conductivity, Btu/h | | |
|---|---|---|---|
| Content, mass | Sand | Slit | Clay |
| Low,<4% | 0.17 | 0.08 | 0.08 |
| Medium,4to20% | 1.08 | 0.75 | 0.58 |
| High,>20% | 1.25 | 1.25 | 1.25 |

## 4.2 Solar Energy Design

This weather data entry form section shows the maximum solar energy absorbed by walls with different directions for refrigeration design days. To modify the profiles, the coefficient on the left side of each row is used. Coefficients are more significant than one increase in solar radiation, and coefficients less than one decrease the solar radiation. Solar energy design parameters are shown in Figure 2.

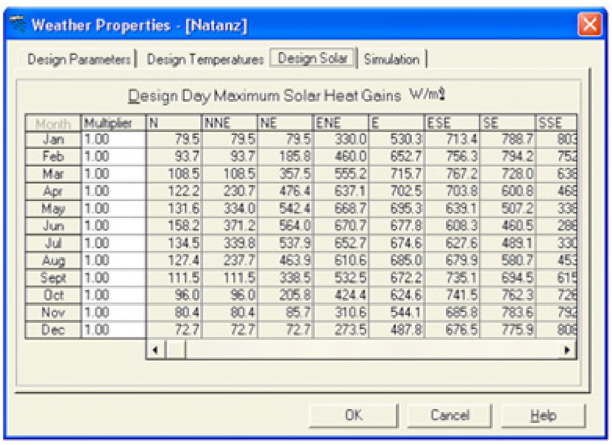



**Figure 2.** Design of solar energy form

## 4.3 Enter Space Information

1) General data (General): This section includes the name of the space, the total area of the infrastructure of the desired space, the average height of the roof, and the weight of the building. Classifications of building in terms of space information is shown in Table 7.

**Table 7.** Classification of building types

| Grouping | Building weight (kg/m$^2$) | Building weight (lb/ft$^2$) |
|---|---|---|
| Style | Less than 145.5 | Less than 30 |
| Medium | 146.5-342 | 30-70 |
| Heavy | 342-634.7 | 70-130 |

2) Internal loads (internals): This part of the data entry form contains information about the heat obtained from lamps, work lamps, electrical equipment, number of people, and other loads.

Lighting Overhead lamps: This item describes the specifications of general lighting lamps. Because lamps generate radiant and displacement heat, the type of lamp and its consumption must be determined to calculate the lamps' thermal load. Four quantities must be entered to enter the data of overhead lamps:

A: Type of lamp installation (Type Fixture): They are installed in the following three ways: Hanging Free lamps. Unvented Recessed lamps that are slightly sunken inside the ceiling but vented recessed.

B. Wattage: This item shows the power consumption of lamps and is entered in watts per square meter or watts. It should be noted that when fluorescent lamps are used, the coefficient of lamp power should be multiplied due to the presence of transformers. This coefficient is usually between 1 and 2, and a coefficient of 1.25 is often used.

J. Schedule: This table shows the hourly performance of the lamps. A new table can be created to import the lamp performance table, or previously defined tables can be used.

Lighting Task: This option allows you to define another type of lamp in space. These lamps are of hanging type and lamps embedded in walls or corridors.

Electrical Equipment: This item includes all electrical equipment installed in the space. These types of equipment include copiers, computers, printers, kitchen equipment, industrial machines, etc.

People: The number of people must first be entered (Occupancy) in each space in this option. To do this, you can enter the number of people directly or enter the ratio of the number of people per square meter or square feet of building infrastructure.

The HAP program defines seven types of activity levels, which are Rest and Seated, Work Office, Work Sedentary, Medium Work, Heavy Work, Dancing, Athletics.

Miscellaneous loads: This option includes tangible and hidden loads from non-electrical equipment. For example, gas appliances and kitchen steamers. In this option, the maximum tangible and latent heat of nectar production by these pieces of equipment and the table related to their hourly operation during the day and night should be entered.

Doors, windows, and walls (Windows, Doors, Walls): This part of the space data entry form contains vertical exterior walls and windows, exterior awnings, and exterior doors. This information is used to calculate loads from walls, windows, and doors. In this section, the total surface of the walls, the direction of the walls, the number of doors, the number and type of windows are specified. In the following, the type of structure that contains information about the material of walls, windows, doors, and canopies can be determined. Entrance form of walls, windows and doors are shown in Figure 3.

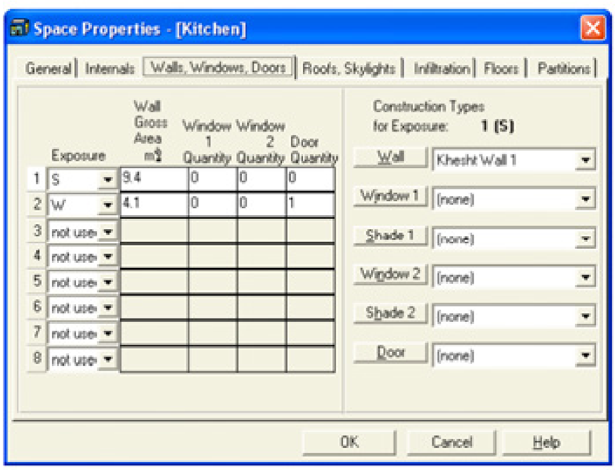



**Figure 3.** Entrance form of walls, windows and doors

## 4.4 Roof, Skylights

This part of the space data entry form contains information about horizontal or sloping ceilings and skylights used in them. The columns of this table contain different properties of the roofs: Exposure Roof, Area Gross Roof, Slope Roof, Quantity Skylight, and Type Construction.

## 4.5 Infiltration

In this section, the amount of infiltrating air can be entered through doors and windows. This amount of infiltrating air is used to calculate tangible and latent refrigeration loads and heat loads. Spatial data have the following options: air infiltration for cooling load calculations (Cooling Design), air infiltration for thermal load calculations (Heating Design), energy analysis (ACH infiltration frequency).

## 4.6 Floors

This part of the space data entry form contains information about heat transfer through the building floor. The options in this section include floor type only, Above Unconditioned Space, Above Conditioned Space, Slab floor on Grade, and Slab floor. Slab floor below Grade the HAP program assumes that heat transfer from floors located in ventilated areas is negligible. After determining the type of floor, the floor area (Area Floor), total floor heat transfer coefficient, the external environment (Perimeter Exposed), thermal insulation coefficient of ground wall insulation, maximum and minimum temperature of ventilated space, depth of insulation wall, and floor depth and depth Insert the insulation wall.

## 4.7 Partitions

This form contains information about heat transfer through walls and ceilings adjacent to unventilated spaces or spaces with significant temperature differences.

## 4.8 General Information

In this section, four options should be defined: system name (Air system name), equipment type (Equipment type) such as undefined, Package Rooftop units, vertical packages (Units Vertical Packaged), air conditioner with water Chilled Water AHU, Units Terminal, Type System Air, Number of zones, Air Ventilation, Direct Ventilation, Air Ventilation Common (System Ventilation Common).

## 4.9 Standard Ventilation System (System Ventilation Common)

This section should specify the amount of outside ventilation air, blowers, coils, and ducts connected to the standard ventilation system.

## 4.10 System Components

This section contains information about central equipment in the ventilation system, such as blowers, coils, and air distribution systems.

### 4.11 Central Cooling Coil

This section contains information about the central refrigeration coil, its controls, and its size and capacity specifications. Criteria Sizing Air Supply, Coil Bypass factor, Cooling Source, Schedule Cooling, Capacity control, Types of controllers: A: Constant temperature, Constant rot. Fan cycled, B: constant Temperature, fan on (constant temp. Fanon, B: rotation or staging of the compressor, fan on (cycled or staged compressor, fanon), D: reset Temperature reset by the highest zone demand (Temp. Reset by most significant zone demand), and Temperature reset by the outdoor air schedule (Temp reset by outdoor air schedule).

### 4.12 Central Heating Coil

This section contains information about the central heating coil, its controls, and its size and capacity specifications. The contents of this data vary depending on the type of system and equipment selected. The options available in this section are from the data entry form of the air conditioning system, such as the central refrigeration coil section.

### 4.13 Calculation of Heat Transfer Coefficient of Walls

The main factor in studying the thermal quality of materials is the parametric material called thermal conductivity, which is one of the physical properties of materials. Increasing the thermal conductivity increases heat loss. Dividing the thickness of the element by this coefficient results in thermal resistance [25].

$$R = \frac{x}{h} \tag{1}$$

In this regard, R is the thermal resistance, x is the wall thickness, and k is the thermal conductivity. The total heat transfer coefficient of the wall is obtained from the following equation [25]:

$$U = \frac{1}{\frac{1}{h_i} + R_1 + R_2 + \ldots + \frac{1}{h_0}} \tag{2}$$

In this regard, U is the total heat transfer coefficient of the wall, 1/hi is the thermal resistance of the indoor air layer and 1/ho is the thermal resistance of the outer air layer, and R2, R1, etc. are the thermal resistance of different wall elements. Table 8 (Iran's national building regulations) presents the physical properties of the materials used in the buildings to obtain an analysis of the thermal resistance of the relevant component.

**Table 8.** Physical characteristics of building executive materials

| Material specifications | Density($kg/m^3$) | Thermal conductivity coefficient(W/m·K) |
|---|---|---|
| Plaster | 1200 | 0.5 |
| Perforated brick | 1300 | 0.78 |
| Solid brick | 1850 | 1.1 |
| Clay block | 550 | 0.5 |
| cement block | 2100 | 1.3 |
| Mortar | 1950 | 1.15 |
| Ordinary concrete | 2300 | 1.75 |
| Cement | 2000 | 0.95 |
| Plaque facade brick | 1850 | 1.75 |
| Aluminum composite | 1000 | 0.27 |
| Slope pockets | 1500 | 0.52 |
| Waterproofing | 1050 | 0.23 |
| Pure asphalt | 2100 | 0.7 |
| Mosaic | 2300 | 1.75 |
| Marble | 2590 | 2.9 |
| ceramic | 1900 | 1.175 |
| blockage | 2300 | 1.8 |
| glass wool | 52 | 0.037 |
| Rock wool | 30 | 0.047 |
| Polystyrene | 10 | 0.047 |

As can be seen from the comparison of thermal coefficients of building elements, the use of new materials such as clay blocks instead of traditional materials such as solid bricks reduce the heat transfer coefficient and accordingly reduces the heat loss of the wall, which plays an essential role in saving energy.

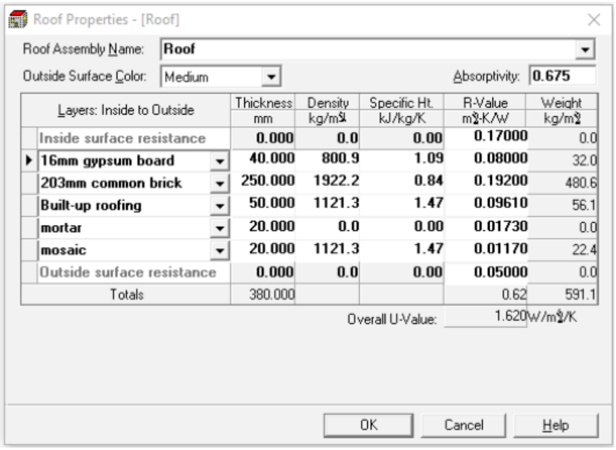
Calculation of thermal conductivity of windows: The total heat transfer coefficient for conventional windows, which are essential elements of heat dissipation in buildings, is obtained from Tables 1-17 of Tabatabai Engineer's calculations equal to 0.65 $Btu/hr{\cdot}ft^2{\cdot}F$ [26]. Information of the roof layers is shown in Figure 4.

Calculation of thermal conductivity of external walls (external wall):

$$U_{tot}=1/(1/h_i+R_1+R_2+R_3+R_4+1/h_o) =1/0.535=1.869\approx1.87(W/(m^2{\cdot}k)) \tag{3}$$

Calculation of thermal conductivity of the roof of the building:

$$U_{tot}=1/(1/h_i+1/R_1+1/R_2+1/R_3+1/R_4+1/R_5+1/h_o)=1/0.6171=1.62\ (W/(m^2{\cdot}k)) \tag{4}$$



Roof Properties - [Roof]

Roof Assembly Name: Roof

Outside Surface Color: Medium   Absorptivity: 0.675

| Layers: Inside to Outside | Thickness mm | Density kg/m³ | Specific Ht. kJ/kg/K | R-Value m²-K/W | Weight kg/m² |
|---|---|---|---|---|---|
| Inside surface resistance | 0.000 | 0.0 | 0.00 | 0.17000 | 0.0 |
| 16mm gypsum board | 40.000 | 800.9 | 1.09 | 0.08000 | 32.0 |
| 203mm common brick | 250.000 | 1922.2 | 0.84 | 0.19200 | 480.6 |
| Built-up roofing | 50.000 | 1121.3 | 1.47 | 0.09610 | 56.1 |
| mortar | 20.000 | 0.0 | 0.00 | 0.01730 | 0.0 |
| mosaic | 20.000 | 1121.3 | 1.47 | 0.01170 | 22.4 |
| Outside surface resistance | 0.000 | 0.0 | 0.00 | 0.05000 | 0.0 |
| Totals | 380.000 | | | 0.62 | 591.1 |

Overall U-Value: 1.620 W/m²/K

OK   Cancel   Help

**Figure 4.** Enter the information of the roof layers

Calculation of floor thermal conductivity:

$$U_{tot}=1/(1/h_i +1/R_1 +1/R_2 +1/R_3 +1/R_4)$$
$$=1/0.4175=2.4\ (W/(m^2\cdot k)) \quad (5)$$

The thermal conductivity of basement walls connected to the soil is 0.1, and in cold load calculations (in summer), we consider the heat transfer from the floor connected to the ground to zero. The temperature of Zanjan city in winter is –9 degrees Celsius, and the earth temperature is 13.6 degrees Celsius. With the above specifications and referring to Table 1-B, page 22 of Tabatabai's engineering calculation book, and after intervening the heat losses from the underground unit 1.35 Btu/hr·ft$^2$·F and the underground walls is 2.7 Btu/hr·ft$^2$·F.

The indoor temperature for the office environment will be 77 degrees Fahrenheit, and if the outdoor temperature is between 0- and 20-degrees Fahrenheit, the basement and unheated room temperature will be 32 degrees Fahrenheit.

Calculation of thermal conductivity of partitions:

$$U=1/(1/h_i +R_2+R_3+R_4+1/h_o)$$
$$=1/0.47=2.127(w/(m^2\cdot k)) \quad (6)$$

The amount of tangible and latent heat from the stove (for the water heater space) is 3200 Btu/h of tangible heat and 800 Btu/h of latent heat for each stove flame.

Temperature of ventilated spaces: The lowest is 38.5 degrees Fahrenheit in winter, and the highest is 84.5 degrees Fahrenheit in summer.

After extracting the executive details of the building from the plans and the information, the heat transfer coefficients of the external walls of the building were calculated as follows:

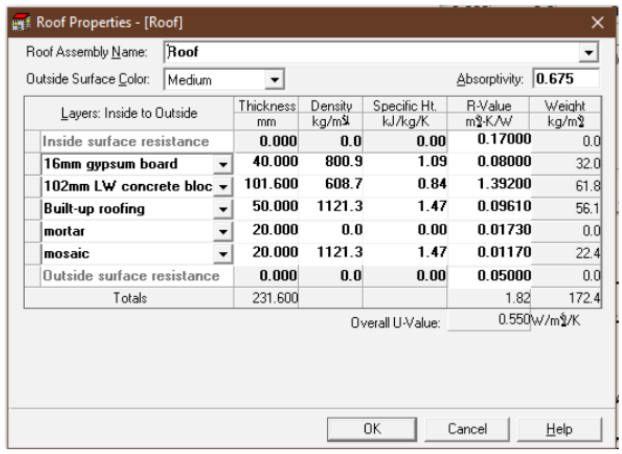
Heat transfer coefficient calculations: Heat transfer coefficient of building walls and the roof are shown in Table 9 and Figure 5 respectively.

Exterior walls: In the software, by changing the R of the cement block from 0.272 to 0.646 m$^2$·K/W, we reach the reference U, which is equal to 1.1 W/m$^2$·k.

Ceiling: Also, by changing the R of the roof block from 0.19 m$^2$·K/W to 1.39 m$^2$·K/W from U design, which is equal to 1.62 W/m$^2$·k to reference U, which is equal to 0.55 W/m$^2$·k is reached.

**Table 9.** Heat transfer coefficient of building walls of Zanjan Gas Department

| building | Heat transfer coefficient(W/m$^2$·°C) |
|---|---|
| Wall | 1.87 |
| ceiling | 1.62 |
| Floor | 2.4 |



Roof Properties - [Roof]

Roof Assembly Name: Roof

Outside Surface Color: Medium   Absorptivity: 0.675

| Layers: Inside to Outside | Thickness mm | Density kg/m³ | Specific Ht. kJ/kg/K | R-Value m²-K/W | Weight kg/m² |
|---|---|---|---|---|---|
| Inside surface resistance | 0.000 | 0.0 | 0.00 | 0.17000 | 0.0 |
| 16mm gypsum board | 40.000 | 800.9 | 1.09 | 0.08000 | 32.0 |
| 102mm LW concrete bloc | 101.600 | 608.7 | 0.84 | 1.39200 | 61.8 |
| Built-up roofing | 50.000 | 1121.3 | 1.47 | 0.09610 | 56.1 |
| mortar | 20.000 | 0.0 | 0.00 | 0.01730 | 0.0 |
| mosaic | 20.000 | 1121.3 | 1.47 | 0.01170 | 22.4 |
| Outside surface resistance | 0.000 | 0.0 | 0.00 | 0.05000 | 0.0 |
| Totals | 231.600 | | | 1.82 | 172.4 |

Overall U-Value: 0.550 W/m²/K

OK   Cancel   Help

**Figure 5.** Calculation of heat transfer coefficient for the roof

Translucent walls (windows): By changing the value of the heat transfer coefficient (U) of the design from 3.69 m$^2$·k/W to the reference U, which is equal to 3.4 W/m$^2$·k, we use it in reference calculations.

Main entrance door: not used in calculations due to lack of an external wall.

Adjacent walls of uncontrolled spaces (such as partitions) and the first floor: thermal conductivity in the design calculations of 2.217 W/m$^2$·k and 2.4 W/m$^2$·k to the reference U, which is equal to 0.7 W/m$^2$·k, respectively changes.

Floors and walls in contact with soil (basement): In the design calculations, the value of U for the basement floor unit is equal to 7.6 W/m$^2$·k according to the ground temperature and other parameters, which is entered into the program in the reference project 2.56 W/m$^2$·k. That the U of the basement walls in the design calculations is twice the U of the design for the basement unit and is equal to 2 * 7.6 W/m$^2$·k = 15.3 W/m$^2$·k. So the value of the U of the basement walls in the reference calculations can be. Also, 2 times the reference U for the floor unit and 2 * 2.56 = 5.12 W/m$^2$·k were considered.

## 5. Results and Discussion

It is necessary to explain that to get the software's output, we need to define the air conditioning system to simulate thermal and refrigeration loads, so for this purpose, we have defined and simulated a two-pipe fan coil system for this purpose project. The high number of spaces (72 spaces) and the limited space in each zone (50 spaces for each zone) have inevitably divided the system into two zones, but the specifications and input parameters are the same in both zones. According to Figure 6, the amount of heat load required for heating is 332546 W, and the total tangible cooling load is 534492 W.

According to Figure 7, the amount of heat load required for heating (Heating) is equal to 218670 W, and the total tangible and hidden cooling load (Cooling) is equal to 490888 W.

| | DESIGN COOLING | | | DESIGN HEATING | | |
|---|---|---|---|---|---|---|
| | COOLING DATA AT Aug 1500<br>COOLING OA DB / WB 34.5 °C / 22.1 °C | | | HEATING DATA AT DES HTG<br>HEATING OA DB / WB -16.1 °C / -16.7 °C | | |
| ZONE LOADS | Details | Sensible (W) | Latent (W) | Details | Sensible (W) | Latent (W) |
| Window & Skylight Solar Loads | m² 337 | 35262 | - | m² 337 | - | - |
| Wall Transmission | m² 1279 | 29145 | - | m² 1279 | 82321 | - |
| Roof Transmission | m² 876 | 12212 | - | m² 876 | 48905 | - |
| Window Transmission | m² 337 | 12734 | - | m² 337 | 42792 | - |
| Skylight Transmission | m² 0 | 0 | - | m² 0 | 0 | - |
| Door Loads | m² 0 | 0 | - | m² 0 | 0 | - |
| Floor Transmission | m² 944 | 8623 | - | m² 944 | 22256 | - |
| Partitions | m² 1043 | 13894 | - | m² 1043 | 32679 | - |
| Ceiling | m² 52 | 693 | - | m² 52 | 1630 | - |
| Overhead Lighting | W 120453 | 99601 | - | 0 | 0 | - |
| Task Lighting | W 0 | 0 | - | 0 | 0 | - |
| Electric Equipment | W 143218 | 127427 | - | 0 | 0 | - |
| People | 224 | 11828 | 13458 | 0 | 0 | 0 |
| Infiltration | - | 27857 | 14871 | - | 71731 | ١٠- |
| Miscellaneous | - | 7034 | 3957 | - | 0 | 0 |
| Safety Factor | ٥٪ / 5% | 19315 | 1614 | 10% | 30231 | 0 |
| **Total Zone Loads <<** | - | **405625** | **33899** | - | **332546** | ١٠- |
| Zone Conditioning | - | 463104 | 33899 | - | ٢٥٨٨٠- | ١٠- |
| Plenum Wall Load | 0% | 0 | - | 0 | 0 | - |
| Plenum Roof Load | 0% | 0 | - | 0 | 0 | - |
| Plenum Lighting Load | 0% | 0 | - | 0 | 0 | - |
| Exhaust Fan Load | L/s 0 | 0 | - | L/s 0 | 0 | - |
| Ventilation Load | L/s 1844 | 22801 | 13080 | L/s 1844 | 27297 | ١٠- |
| Ventilation Fan Load | L/s 0 | 0 | - | L/s 0 | 0 | - |
| Space Fan Coil Fans | - | 600 | - | - | ٤٠٠- | - |
| Duct Heat Gain / Loss | 0% | 0 | - | 0% | 0 | - |
| **Total System Loads <<** | - | **486505** | **46979** | - | **817** | ١٠- |
| Terminal Unit Cooling | - | 486505 | 47987 | - | 0 | 0 |
| Terminal Unit Heating | - | 0 | - | - | 0 | - |
| **Total Conditioning <<** | - | **486505** | **47987** | - | **0** | **0** |
| **Key:** | **Positive values are clg loads<br>Negative values are htg loads** | | | **Positive values are htg loads<br>Negative values are clg loads** | | |

**Figure 6.** Software output for design calculations:

| | DESIGN COOLING | | | DESIGN HEATING | | |
|---|---|---|---|---|---|---|
| | COOLING DATA AT Aug 1500<br>COOLING OA DB / WB 35.0 °C / 22.2 °C | | | HEATING DATA AT DES HTG<br>HEATING OA DB / WB -16.1 °C / -16.7 °C | | |
| ZONE LOADS | Details | Sensible (W) | Latent (W) | Details | Sensible (W) | Latent (W) |
| Window & Skylight Solar Loads | m² 337 | 34256 | - | m² 337 | - | - |
| Wall Transmission | m² 1279 | 14704 | - | m² 1279 | 48464 | - |
| Roof Transmission | m² 876 | 4101 | - | m² 876 | 16614 | - |
| Window Transmission | m² 337 | 12368 | - | m² 337 | 39431 | - |
| Skylight Transmission | m² 0 | 0 | - | m² 0 | 0 | - |
| Door Loads | m² 0 | 0 | - | m² 0 | 0 | - |
| Floor Transmission | m² 944 | 2627 | - | m² 944 | 7514 | - |
| Partitions | m² 1043 | 6429 | - | m² 1043 | 14476 | - |
| Ceiling | m² 52 | 238 | - | m² 52 | 536 | - |
| Overhead Lighting | W 120453 | 99601 | - | 0 | 0 | - |
| Task Lighting | W 0 | 0 | - | 0 | 0 | - |
| Electric Equipment | W 143218 | 127427 | - | 0 | 0 | - |
| People | 224 | 11828 | 13458 | 0 | 0 | 0 |
| Infiltration | - | 28933 | 15046 | - | 71755 | 0 |
| Miscellaneous | - | 7034 | 3957 | - | 0 | 0 |
| Safety Factor | [illegible] / 5% | 17477 | 1623 | 10% | 19879 | 0 |
| **Total Zone Loads <<** | - | **367023** | **34084** | - | **218670** | **0** |
| Zone Conditioning | - | 418269 | 34084 | - | [illegible] | 0 |
| Plenum Wall Load | 0% | 0 | - | 0 | 0 | - |
| Plenum Roof Load | 0% | 0 | - | 0 | 0 | - |
| Plenum Lighting Load | 0% | 0 | - | 0 | 0 | - |
| Exhaust Fan Load | L/s 0 | 0 | - | L/s 0 | 0 | - |
| Ventilation Load | L/s 1844 | 23617 | 13188 | L/s 1844 | 27317 | 0 |
| Ventilation Fan Load | L/s 0 | 0 | - | L/s 0 | 0 | - |
| Space Fan Coil Fans | - | 600 | - | - | [illegible] | - |
| Duct Heat Gain / Loss | 0% | 0 | - | 0% | 0 | - |
| **Total System Loads <<** | - | **442486** | **47272** | - | **7** | [illegible] |
| Terminal Unit Cooling | - | 442486 | 48402 | - | 0 | 0 |
| Terminal Unit Heating | - | 0 | - | - | 0 | - |
| **Total Conditioning <<** | - | **442486** | **48402** | - | **0** | **0** |
| :Key | Positive values are clg loads<br>Negative values are htg loads | | | Positive values are htg loads<br>Negative values are clg loads | | |

**Figure 7.** Software output for reference calculations

By comparing the software output of "design calculations" and "reference calculations", the difference between the current consumption and the accepted consumption (according to section 19 of the National Building Regulations) is obtained. The amount of heat required for heating mode (available) (load Heating) is 332546 W, and the total tangible and hidden cooling load (load Cooling) is equal to 534492 W, while the amount of heat load required for heating for reference mode (saving and acceptable) (Heating) is equal to 218670 W and the total of tangible and hidden cooling load (Cooling) is equal to 490888 W. So, the difference between the design mode (existing) and the reference mode (saving and acceptable) for heating equals about 52%, and the cooling mode about 9.8%, shows the difference with the acceptable mode.

Checking the building energy consumption index: The energy consumption index in the building indicates the amount of energy consumed annually by different parts per building infrastructure unit, which is obtained from the following relationship. Energy consumption index standards are shown in Table 10.

$$SEC = \frac{Energy\ section\ Relevant\ section(kwh)}{Building\ infrastructure(m^2)} \quad (7)$$

**Table 10.** Energy Consumption Index Standard [27]

| Building conditions from the perspective of energy consumption | SEC(KWh/m$^2$) |
|---|---|
| Excellent | Less than 100 |
| Acceptable | Between 100 and 200 |
| There is a problem and it should be checked | Between 200 and 300 |
| It has many problems and requires Fundamental changes | Between 300 and 400 |
| Completely unacceptable | More than 400 |

For example, we consider the space of the contract regulation unit (304) with dimensions of 24 square meters as an example for calculating the energy index. The energy consumption index of this space is as follows:

$$SEC=(2.381*24)/24*100=238.1 \quad (8)$$

which is not acceptable according to the standard table of energy consumption index. That is, it has a problem and should be investigated. Now for comparison, we have to calculate the reference calculations for the same space.

The energy consumption index of this space is as follows:

$$SEC = (1.925 * 24) /24*100=192.5 \quad (9)$$

which is acceptable according to the standard table of energy consumption index. The software output is 26356 Btu/h. The manually calculated heat load for this space is 28022 Btu/h. From these two numbers, it can be concluded that manual calculations with the software are about 6.3% different. By comparing the number obtained from manual calculations and comparing it with software output, we see that there is no significant difference between manual calculations and software

## 6. Conclusions

By analyzing the software output for heating and cooling calculations, it is concluded that the energy consumption is different with what is emphasized in the existing Iran's National Building Regulations that all the construction engineers are required to comply with it. However, to the fact that the city of Zanjan is located in a cold region and the need for heating energy is high, in the case of cooling, with 6% difference of the theorical method and design calculations national building code can be used with high accuracy, but in the case of heating, the difference with the real design state is about 34%, which is not acceptable at all.

Energy-saving opportunities are a set of measures that reduce energy consumption in the building. Energy-saving opportunities can be divided according to which part of the building has a direct effect. In this category, energy-saving opportunities can be divided into three parts:

- Building architecture
- Building mechanics
- Building electricity

By analyzing the outputted data from the design method some suggestions related to the mechanical part of the building can be given.

- It is recommended to insulate the facility with prefabricated fiberglass with factory aluminum coating, with a thickness of 25 mm and a thermal conductivity of 0.0375 W/m$^2$·k, and elastomeric pipe insulation with a thickness of 9 mm and a thermal conductivity of 0.0351 W/m$^2$·k be used.
- To provide comfort conditions, the indoor temperature in summer is 23.8 degrees Celsius and in winter is 21.5 degrees Celsius. According to ASHRAE standards, the room temperature can be set at 25.5 degrees Celsius in summer and 18.3 degrees Celsius in winter. Iran's national building code states that the standard temperature is 28 °C for summer and 20 °C for winter which needs to be changed according to ASHRAE standards.
- It is also recommended to use the schedule of facilities operation method in Table 11.

**Table 11.** Schedule of facility operation

| Device | Device turn-on time | Device turn-off time | Days when the device is turned on |
|---|---|---|---|
| Hot water boiler and chiller | 4:30 | 15 | All days except holidays |
| Pumps | Automatic | Automatic | All days except holidays |

- It is recommended that the periodic inspection of the facility be done according to the comprehensive mechanical facility repair program and the manufacturer's instructions for wall insulation with 5 cm thick polystyrene insulation and a density of 20 kg/m$^3$, roof with 5 cm thick polystyrene insulation. Cm and density of 20 kg per cubic meter should also be done. It is also recommended to seal around doors and windows and use unique springs or electrical systems to close the doors.

## Conflict of Interest

There is no conflict of interest.

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