# Influence of Ceiling Height on Heating Energy Consumption in Educational Building

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***Abstract*— Ceiling height plays a vital role on energy consumption in indoor spaces especially educational buildings due to the constant energy usage in there. One of the greatest challenges in architecture is to plan a living environment which has thermal comfort for users with least or without electromechanical device usage. In this study, we investigate whether a ceiling height should be applied in designing a non-residential building in order to reduce the energy demand for heating or not. This study investigates a standard classroom with a south facing window as a model in Tabriz. We seek to answer which ceiling height must be selected among the variation of ceiling heights for reducing heating energy consumption in order to decrease global warming whereas creating a classroom which has sense thermal comfort? This paper presents a method of evaluating the influence of the ceiling height on reducing the heating energy consumption by Energy Plus. Energy Plus is one of the most well-known energy simulation software tools. In this paper, we consider one possible strategy for designing energy efficient classroom, however, there are more strategies that have influence on energy consumption for users. We found signs of directed effects of the ceiling height on heating energy consumption. Results indicated that heating energy consumption is reduced 1% for each 10 cm of ceiling height reduction. In other words, the heating energy consumption will be increased by adding ceiling height. Finally, achieved correlation confirms the relationship between heating energy consumption and ceiling height.**

***Keywords*— Ceiling Height, Heating Energy Consumption, Modeling, Thermal Comfort.**

## I. Introduction

A Cross the world energy demand has increased along with impacts on environment such as ozone layer depletion, acidification, and global warming[1]. Worldwide crisis confronting humankind is diminishing energy reserves. One of the greatest challenges in architecture is to plan a living environment which has thermal comfort for users with least or without electromechanical device usage such as fan, AC, air cooler, etc.[2]. One of the least monitored sectors in control and management of GHG emissions is Architecture, Engineering and Construction (AEC)[3]. About 40% of the global energy consumption is spent in built environment[4], [5]. Therefore, Energy consumption in the building is among the most well-known that set to become a vital factor in those lessening energy resources. A building retains thermal energy from the outdoor environment through various mechanisms of radiation and convection. The intensity of this heat flow will depend on wall thickness, heat capacity of the material, density and thermal conductivity. Furthermore, there will permanently be a pair of psychometric and relative humidity at each time inside the building that effect on thermal comfort. according to ASHRAE Standard 55—thermal environmental conditions for human occupancy, is ‘‘to specify the combinations of indoor space environment and personal factors that will produce thermal environmental conditions acceptable to 80% or more of the occupants within a space’’[6].Alongside the second thermodynamic regulation, the phenomenon of convection occurs, the air molecules have a natural movement in which hot layers, with lower densities than cold layers, tend to rise. Consequently, the temperatures in the upper regions tend to be higher from the cold layers through the environments[7]. According to authors have studied, as it shows in Figure 1, there are two forms of ceiling height has been shown. The ceiling height of the left one is higher than the right side. According to the physical laws and empirical observations, human can sense much warmer in the right thermal zone. So, in the cold climate we can reduce the ceiling height to have thermal comfort because the higher layers are nearer from the users. Based on this phenomenon, Ceiling height is one of the key factors in decreasing the energy demand of buildings.

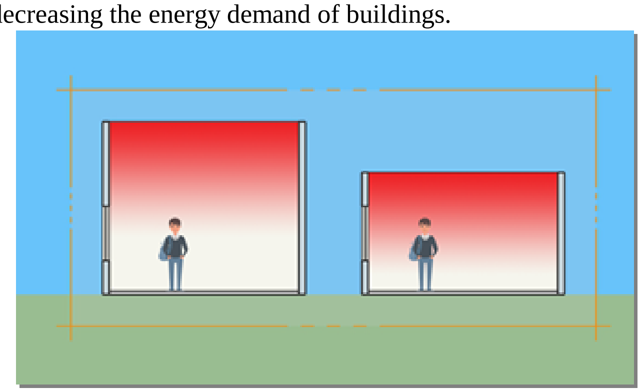

Fig. 1: The influence of ceiling height in order to second thermodynamic regulation

Kr'uger and Zannin[8] stated that the indoor environmental quality of classrooms has a countless influence on the quality of teaching. In the terms of global warmings, some researchers have suggested green schools in the type of educational buildings. ‘‘Green schools” is defined as a school building or facilities for generating an environment which provide healthy

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and favorable to saving energy, resources and money as well as learning. On the other hand the Green campus without K-12 schools is a higher education community which is enlightening enhancing environmental quality ,conserving resources, energy efficiency and by educating for creating healthy living and learning environments and sustainability[9]. People who might benefit from reading this work may be green building—architects, designers, consultants, producers of building products and construction companies—and researchers in environmental impact of buildings.

## II. BACKGROUND

Several complex studies have been conducted in several climates about environment thermal behavior. This study has indicated the influence of ceiling height as a key factor on thermal comfort. Thermal comfort is one of the fundamental aspects of indoor environmental quality and it is strongly related to occupant satisfaction and energy use in buildings[10]. Hashimoto and Yoneda (2009) studied on the variation of ceiling heights and their impacts with thermal load and ventilation through monitoring buildings with CFD software–Computational Fluid Dynamics – and elaborated the results. The consequences presented that the higher level of air layers is closer to the thermal comfort. In addition, the results of Lam and Chan (2000), Zhai and Chen (2004), and Zou, Opara and McKibbin (2005) and Katsiris Stamou (2005) in their respective researches analysis by software CFD on thermal environments presented temperatures stratifications giving the heights in a direct proportion with the distance to the floor. numerous conclusions possibly will be applied for further cases, the results of each one characterizes a specific context. Guimares et al. (2013) initiated the impact of ceiling height in thermal comfort of buildings at Brazil as a hot weather location. The ceiling height has been varied of 2.4(m)", 2.8m and 3m. Results showed that temperature increases 1 (ºC)" per each 20 (cm)". Upper and lower layers of the indoor environment can reach up to 4 (ºC)". Although few researchers have addressed the issue of ceiling height, A neglected area in the field of influence of ceiling height on heating energy consumption in the cold climate still have not been dealt with in depth. This paper sheds new lights on reducing the heating energy consumption by conducting the variation of ceiling height[7].

In this research the heating energy in the standard classroom is simulated by EnergyPlus in the city of Tabriz which has a cold climate and reduction of the energy consumption is desired. Tabriz is located in north-west of Iran and the heating energy consumption is found to be substantially higher than cooling energy consumption. In this model, we select the classroom by their highest usage. Our proposed framework is comparing the variation of the ceiling height in each month as a key architectural planning. This is not to say that the only factor for reducing the heating energy consumption is ceiling height, rather it plays a vital role on energy consumption in indoor spaces.

## III. METHODOLOGY

The operational energy consumption of a building is directly related to the thermal parameters of its building envelope[11]. Moreover, there are some design strategies which effect on energy consumption in buildings such as thickness of insulations, construction of materials, usage of passive and active solar design strategies, shadings, dimension of opening areas, colors, the reflects of the materials, and so on. The objective of this study is to find the influence of ceiling height on heating energy consumption which not only does provide thermal comfort, but also can reduce the heating energy demand.

These results vary a lot due to distinct regional characteristics such as climates, and types of the building (whether be residential or non-residential). The classroom which is investigated is devised based on Neufert standards. The classrooms with special courses for secondary schools is determined to be 40-45m2[12]. Ration of window area to floor area equals to 20%. This case study is located in Tabriz, a city in North-West of Iran. The output of Climate Consultant 6.0 developed by UCLA Energy Design Tools Group has been taken to predict best design strategies[13] and determine the thermal comfort indoor temperature in Tabriz. In this software the human thermal comfort is defined primarily by dry bulb temperature and humidity. It is adopted by Ashrae standard 55 and current handbook of fundamental model which means thermal comfort is based on dry bulb temperature, clothing level (clo), metabolic activity (met), air velocity, humidity, and mean radiant temperature. We assumed that mean radiant temperature is close to dry bulb temperature. The zone in which most people are comfortable is calculated using the PMV (Predicted Mean Vote) model. In residential settings people adapt clothing to match the season and feel comfortable in higher air velocities and so have wider comfort range than in buildings with centralized HVAC systems. This software has referred that, ASHRAE Standard 55 is also known as the PMV (Predicted Mean Vote) model. It is an experimentally derived algorithm that considers dry bulb temperature, humidity, air velocity and metabolic activity. It has two comfort zones for summer and winter clothing and the slightly sloped temperature limits account for the fact that in dryer air people are more comfortable at slightly higher temperatures. With this model Climate Consultant assumes that mean radiant temperature (MRT) is roughly equal to dry bulb temperature. According to Figure 2, the gray color in the diagram shows the comfort zone in summer and winter. Therefore, in this simulation the heating set point for the thermostat is considered 20.3 and the cooling set point is 24.3.

According to the hypothesizes in Climate consultant V6.0, Comfort (Using ASHRAE Standard 55) with winter cloth value of 1.0, summer cloth value of 0.5. Activity level daytime is 1.1. Predicted percent of people satisfied is 90. Comfort lowest and highest winter temperature is 20.3 and 24.3 degree Celsius, respectively. Likewise comfort highest summer temperature is 26.7 degree Celsius. Maximum humidity is 84.6 %. The PMV model is the basis for analysis in this case in Climate Consultant Software. Minimum indoor velocity to affect indoor comfort is 0.2 (m/s)". Maximum comfortable velocity is 1.5 (m/s)". Maximum perceived temperature reduction is 3 degrees Celsius. Maximum and minimum wet bulb temperatures are 20.0 and 6.6 degree Celsius respectively[13].

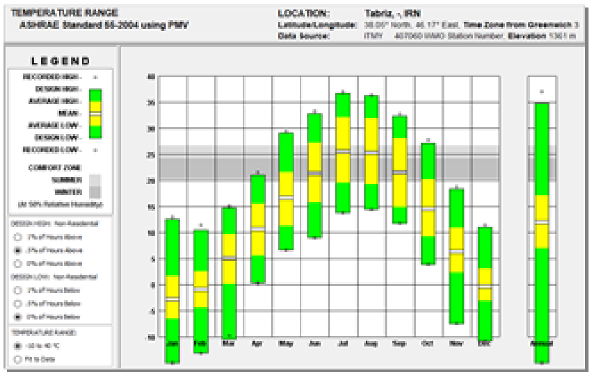



Fig. 2: Comfort zone and the variation of temperature

## IV. Background Information of the Building and Assumptions

The classroom illustrated in Figure 3, is located in the city of Tabriz. It is a non-residential building of concrete structure system with a gross floor area (GFA) of 42 (m2)". The classroom has following characteristics: Window head height that is defined in ASHRAE as a distance from the floor to the top of the glazing [6]is equal to 2.6(m)". All the windows and doors are kept closed in all the three rooms during the study. Table I demonstrates the parameters with their values. In Table II, the detail of surfaces and glazing material are elaborated.

TABLE I: The Characteristic of the Classroom

| Parameters | Values |
|---|---|
| Latitude | 38.05 North |
| Longitude | 46.17 East |
| Altitude | 1361(m)" |
| Obstruction | NO |
| dimension | 6(m)" (width)*7(m)" (length) |
| Wh (window height) | 1.5(m)" (fixed) |
| Window sill height | 1.0(m)" (fixed) |
| Terrain | City |
| Constant heating setpoint | 20.3 |
| Constant cooling setpoint | 24.3 |
| Data source for climate | ITMY 407060 WMO station number |
| Solar distribution | Full Exterior |

TABLE II: The Characteristic of the Material of the Classroom

| Parameters | Values |
|---|---|
| Material of the surfaces | M13 200mm lightweight concrete (selected as Ashrae_2005_HoF_materials)<br>Roughness: medium rough<br>Thickness:0.20(m)"<br>Conductivity: 0.53 (w/mk)"<br>Density: 1280 (kg/ m3)" |
| Window material glazing | Clear 12(mm)"<br>Optical Data type: Spectral Average<br>Thickness: 0.012(m)"<br>Solar transmittance at normal incidence: 0.653<br>Front side solar reflectance at normal incidence: 0.064<br>Back side solar reflectance at normal incidence: 0.064<br>Visible transmittance at normal incidence: 0.841<br>Front side visible reflectance at normal incidence: 0.077<br>Back side visible reflectance at normal incidence: 0.077<br>Infrared transmittance at normal incidence:0<br>Conductivity: 0.9 (w/mk)" |

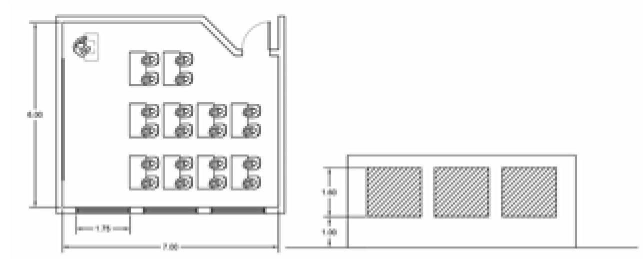


Fig. 2: The Plan and Elevation of Classroom

## V. Goal and Scope

Nowadays, with the assistance of a series of computer programs, calculation of the energy used in the building is much easier than ever[14]. Energy Plus analyses were performed on the group of classrooms south oriented on the ground. This study was carried out by EnergyPlus V8.6 to figure out the energy consumption of the thermostat in the thermal zone. Modeling and simulation procedure in EnergyPlus are based on solving equations of energy conservation using the nodal approach and employing a well-established and validated simulation engine. In modeling buildings, EnergyPlus takes into account various characteristics and specifications including building orientation and geometry, energy systems, building services, thermal envelope, constructions, occupancy behavior and the location weather conditions[15]. A model of the building design is carried out in the simulation program Energy Plus. Energy Plus is a whole building energy simulation program to model both energy consumption for heating, cooling, ventilation, lighting and plug and process loads and water use in buildings. Energy Plus is one of the most known energy simulation software tools. Its development began in 1996, sponsored by the Department of Energy (DOE) in United States of America (USA)[16].

## VI. Results and Discussions

The variation of ceiling height conducted vary between 3 to 4 meters. According to this Figure, the result of the heating energy demand was 0 on July and August, therefore there is not requirement to use the heating equipment. Moreover, the heating energy demand on September was negligible. Although the heating energy demand on October, June and May was lower than 222 (kWh)", the heating energy demand on April, March, February, January, December and November were limited to 2699.50.

Table VI show different rates in these months. The influence of variation of ceiling height (CH= ceiling height (m)") on, heating energy consumption (Zone Air System Sensible Heating Energy (kWh)") is illustrated in Table VI.

According to Table VI, the hottest months in this climate are July, August, and September. In June, the heating energy consumption was fluctuated between 12 and 15.51 based on the variation of the ceiling heights. The school starts on these specific months which are the coldest months in Tabriz. Therefore, we categorized the results in 3 Sections. Each section indicates the heating energy consumption for the thermostat. The first section considered January, February, and March. Second section chosen April, May, and June. Finally, the last section selected October, November, and December. The tables III, IV, and V merged these diagram into one diagram to show the different rate of heating energy consumption in order to the variation of ceiling height parameter.

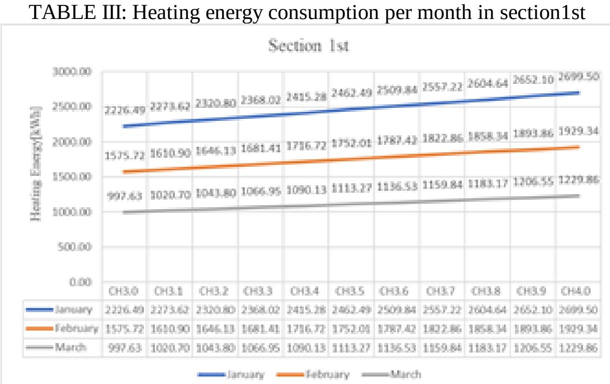
TABLE VI: The Zone Air System Sensible Heating Energy [kWh](Monthly) for different ceiling height [m] (CH).

| Heating Energy [kWh]/(Monthly) | CH3.0 | CH3.1 | CH3.2 | CH3.3 | CH3.4 | CH3.5 | CH3.6 | CH3.7 | CH3.8 | CH3.9 | CH4.0 |
|---|---|---|---|---|---|---|---|---|---|---|---|
| January | 2226.49 | 2273.62 | 2320.80 | 2368.02 | 2415.28 | 2462.49 | 2509.84 | 2557.22 | 2604.64 | 2652.10 | 2699.50 |
| February | 1575.72 | 1610.90 | 1646.13 | 1681.41 | 1716.72 | 1752.01 | 1787.42 | 1822.86 | 1858.34 | 1893.86 | 1929.34 |
| March | 997.63 | 1020.70 | 1043.80 | 1066.95 | 1090.13 | 1113.27 | 1136.53 | 1159.84 | 1183.17 | 1206.55 | 1229.86 |
| April | 492.02 | 503.67 | 515.37 | 527.10 | 538.86 | 550.59 | 562.43 | 574.30 | 586.20 | 598.14 | 610.03 |
| May | 92.09 | 94.28 | 96.49 | 98.71 | 100.95 | 103.18 | 105.45 | 107.75 | 110.05 | 112.38 | 114.68 |
| June | 12.00 | 12.34 | 12.68 | 13.02 | 13.37 | 13.71 | 14.07 | 14.42 | 14.78 | 15.15 | 15.51 |
| July | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| August | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| September | 0.11 | 0.10 | 0.09 | 0.08 | 0.07 | 0.06 | 0.05 | 0.05 | 0.04 | 0.04 | 0.03 |
| October | 181.54 | 185.45 | 189.39 | 193.36 | 197.36 | 201.34 | 205.39 | 209.47 | 213.57 | 217.70 | 221.81 |
| November | 875.11 | 894.44 | 913.80 | 933.19 | 952.62 | 971.99 | 991.49 | 1011.01 | 1030.56 | 1050.14 | 1069.65 |

This section presents the results of the analysis of the heating energy consumption characteristics by month per unit area of the classroom in Tabriz.

Section 1st: January, February, and March

TABLE III: Heating energy consumption per month in section1st




January:

$$y = 47.304x + 2178.9$$

$$R^2 = 1$$

February:

$$y = 35.365x + 1540.1$$

$$R^2 = 1$$

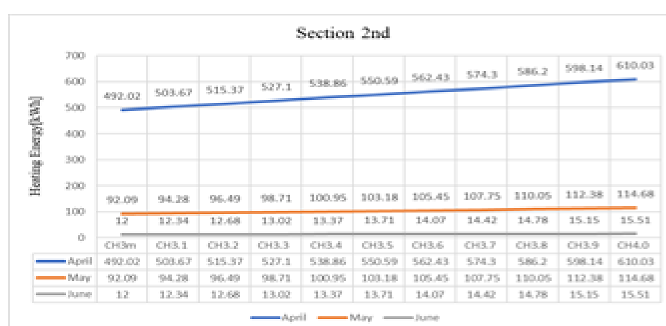
March:

$$y = 23.226x + 974.14$$

$$R^2 = 1$$

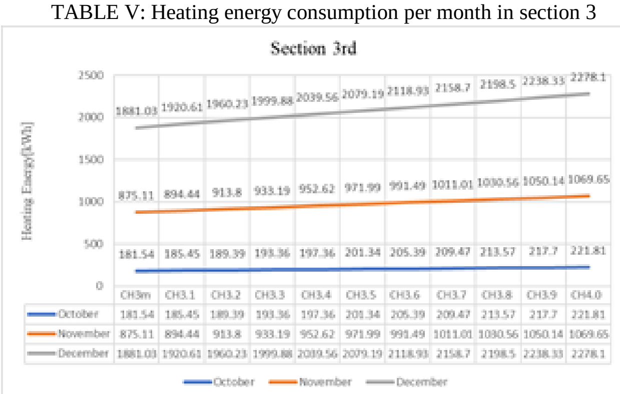
Section 2nd: April, May, and June

TABLE IV: Heating energy consumption per month in section 2



April
y = 11.804x + 479.97
$R^2 = 1$
May
y = 2.26x + 89.714
$R^2 = 0.9999$
June
y = 0.3508x + 11.628
$R^2 = 0.9998$
Section 3rd: October, November, and December

TABLE V: Heating energy consumption per month in section 3




October
y = 4.0288x + 177.32
$R^2 = 0.9999$
November
y = 19.457x + 855.44
$R^2 = 1$
December
y = 39.71x + 1841.1
$R^2 = 1$

The heating energy consumption is illustrated by the height of the roof per month at three sections 1, 2, and 3. In these three sections, the highest thermal heating energy consumption was in January on 1st section, in April on 2nd section, and in October on 3rd section. Not only did these three months have the highest heating energy in their own section, but the growing trend of heating energy consumption has been more in their own section than other months. Also, at 1st section, the heating energy consumption per month is relatively higher than the other two sections. Also, the heating energy consumption in December on 3rd section, June on 2nd section, and March on 3rd section have minimal heating energy consumption and lowest possible slope changes, respectively than any other months in their own section.

Diagram shows that:

1. In this climate, the heating energy consumption is directly proportional to the height of the roof.

2. The slopes of the graph in each cluster indicates the increase in energy consumption towards that month. This slope is positive in all three cases and is between 0.3508 and 47.304. On this basis, there may be more steep heating energy consumption in a month, such as the difference between steeper in April and less steep as in June in 2nd section.

3. As the slope of the graph shows less, it indicates that the consumption of heating energy at different heights changes moderately in this month. Conversely, as the slope of the graph shows more, it indicates that the heating energy consumption at differing heights differs dramatically in this month and as a result, the reduction in the height of the roof would be found as a vital role to decrease the heating energy consumption in such months.

4. In spite of the variation in heating energy consumption towards the ceiling height, we can reduce the heating energy consumption in this climate by reducing each 10 (cm)" in the ceiling height.

As the ceiling height reduces, the users perceive spaciousness of the classroom will decrease. Al-Zamil revealed that the application of significant colors, such as furniture or painting, wall paper or covering of natural material has been an essential portion of interior design. Another way of perceive spaciousness is acquisition of the artificial light, on the other hand people have tendency to care less about the influence of artificial light as a tool. Moreover, designer should specially have consideration on controlling the natural light[17].

This result shows that the classroom which ensures adequate environmental conditions for the building users is needed to consider the influence of variation of ceiling height on energy performance. The final decision was to design low-height ceiling in order to decrease heating energy consumption in the cold climate. The results of simulations were confirmed that the ceiling height has direct influence in the heating energy consumption in this climate and by decreasing the ceiling height we can reduce the hearing energy demands 1% for each 10 (cm)". Thereby, by reducing the ceiling height 1 meter, the heating energy consumption would decrease 10%. We can decrease the environmental impacts by reducing the heating energy consumption for all the buildings by designing low-height ceiling buildings.

## VII. Conclusion

Ceiling height is one of the key factors in reducing energy consumption. To optimize the energy consumption of the thermal zone in Tabriz, at first, we should locate the glazing façade at the south façade, next designing low ceiling height that can reduce the energy consumption of the thermostat. The calculation results were compared versus the heating energy consumption due to the variation of ceiling height during 9 months: October, November, December, April, May, June January, February, and March. Results show that for each 10 (cm)" we can reduce 1% of energy demand for the thermostat. The reduction of ceiling height causes a small increase in indoor temperature.

A simulation to assess the influence of ceiling height in cold climate using Energy plus was developed. We conclude that the ceiling height has a direct influence on the energy consumption. It enables the architects to design energy efficient and get close to sustainable approaches. Through the climate consultant V6.0, the comfort lowest winter temperature and comfort highest summer temperature calculated by PMV model were carried out to determine the cooling and heating set points for thermostat. The scale was simulated for a classroom as a non-residential building in Tabriz. The great application of this scale is for students, teachers and staffs. The target audience of the paper is practitioners in green building—architects, designers, consultants, producers of building products, and construction companies—and researchers in lifecycle assessment, energy, and environmental impact of buildings. As a future work, we can reduce the ceiling height in the classrooms by using false ceiling. In future work, it is suggested to design a false ceiling to be able to be disassembled. It is also recommended to analysis the variation of ceiling height in another type of buildings from each climate data.

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