Designing a dormitory with emphasis on renewable energy

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Abstract. The majority of universities provides on- and off-campus residential quarters for students during their studies which enables them to keep connected to other students and focus on their studies usually with a small amount of money. The manner of designing a dormitory has a direct impact on the performance of the students and therefore requires a lot of attention. This includes but not limited to a mostly independent and private quiet room maintaining good indoor air quality through adequate ventilation and air conditioning. Undoubtedly, the most important aspect of such a place is saving energy in a way that does not influence the quality of student's life. The type of usage of such buildings causes different presence time and different ideas about the lights and temperature's set point. In this paper, we will discuss aspects of designing a dormitory as well as optimization of occupants comfort and energy efficiency using renewable energies such as solar energy to produce electricity, wind energy for natural ventilation and above all using architectural techniques to lower the energy consumption.

1. Introduction
Over the past few decades, the boom of energy demand in the Building sector led to climate change and global warming. Student dormitory is a very important facility which have to be provided by university. University should not only provide accommodation but also other supporting facilities [1]. It has been estimated that buildings are responsible for 40% of energy consumption and 36% of CO2 emissions in the Europe [2], [3]. To meet our goals, developing more eco-friendly sustainable design concepts offers the greatest opportunity to reduce the negative impacts on our environment.

2. Characteristics and physical location
The project is in a land inside the Islamic Azad University of Tehran, Science & Research Campus. In northern part of Tehran, capital of Iran, which is in Hot-dry with cold winters climate. [4] The average annual temperature is 17.1°C. It is located 35.69 latitude and 51.42 longitude and it is situated at elevation (average) 1178 meters above sea level.
The main feature of the vernacular buildings of hot-dry with cold winters is the provision of more open spaces. Central courtyard is very suitable for summer to keep the coolness and humidity of night and give refreshment during the summer days. It is also suitable for winter to protect the rooms from winter winds [5].

3. Design standards
According to the university's standard, we have considered at least 12 m2 per student as separate bed rooms, in six-room flats, each contains a kitchen, dining area and provide one separate WC with small wash hand basin and shower
➢ WC Minimum 1200mm x 1000mm.
➢ Wash hand basin (typically 500mm x 420mm) with cupboard under.
➢ Minimum 800mm x 800mm shower enclosure.

A full, typical student bedroom, including all interior finishes, trim, furnishings, windows, doors, heating, cooling and fresh air delivery units [6].

Martin Heilweil [7] prepared a listing that embraces most of the conditions cited by others. In somewhat abbreviated form they are as follows:
➢ Provision for either solitary study, or study with a minimum of others
➢ A place exclusively devoted to study
➢ Is free from distractions and movements of others
➢ Is free from noises from such sources as telephones, plumbing, and typing
➢ Is equipped with personal control of heat, light, and ventilation

4. Building envelope

The building envelope’s impact on energy consumption should not be underestimated. Globally, space heating and cooling account for over one-third of all energy consumed in buildings, rising to as much as 50% in cold climates and over 60% in the residential sub-sector in cold climate countries. Therefore the building envelop should have the following standards:

- High levels of insulation in walls, roofs, and floors, to reduce heat losses.
- High-performance windows, with low thermal transmittance for the entire assembly (including frames and edge seals) and climate-appropriate solar heat gain coefficients (SHGC).
- Highly reflective surfaces, including both white and “cool-colored” roofs and walls, with glare minimized.
- Properly sealed structures to ensure low air infiltration rates, with controlled ventilation for fresh air
- Minimization of thermal bridges (components that easily conduct heat), such as high thermal conductive fasteners and structural members, while managing moisture concerns within integrated building components and materials. [8]
4.1. Walls
The structural performance of the building materials also requires careful consideration to all of its component including walls. Wall is a structure that refers to an area, carries a load, or provides shelter and security. Recent studies show that one of the best material to be used in constructions is light expanded clay aggregate (Leca). They can be used as a primary material in the mix design of low density building blocks and panels. Expanded clay block (Leca blocks Figure 2) and panel walls deliver lightweight, yet, robust building construction solutions. Leca blocks are prefabricated elements, made of lightweight concrete mixed with cement, sand and water, and produced in rotary kiln at about 1200˚C. Using of Leca aggregate results in decreasing the concrete density. Due to its lightness and structure, the material has good thermal and acoustic insulation and fire-proofed stability. It is therefore used mainly in the construction of basement walls, floors, internal partition walls and ceilings. [9]

![Figure 2. Leca block](image)

Hassan et al. [9] have done a comparative investigation on U-value (thermal transmittance) of some common materials. The results show that Leca block wall has lower U-value than the timbre wall. Technically, Leca block contains air-filled pores with the air-filled clayey cells, which contribute to its insulation properties. A pure solid Leca block has not significantly large thermal insulation, but in combination with sufficiently thick insulation, the structure will have sufficient insulation to meet the requirement for passive houses. The insulation in Leca block consists of polyurethane (PUR) produced by foaming a blowing agent. With this formed gas in a closed cell system, the insulation capacity will be improved. [9]

4.2. Fenestration (windows)
Improved building design can also offer significant potential to reduce the demand for lighting in buildings, through building orientation and advanced fenestration technologies such as dynamic windows. With better use of natural lighting and adoption of highly efficient lamp technologies, buildings energy consumption for lighting could be reduced by 40% in 2050 compared to current levels. [10]

While it is difficult to estimate, windows are most likely responsible for 5% to 10% of the total energy consumed in buildings in OECD countries. They fulfil multiple functions, including access to the building, outlook, entry of daylight and safety egress, and in many cases they provide ventilation as a fresh air inlet. In most cases, windows should let in as much light as possible, but this needs to be balanced by the fact that heat gain in summer needs to be minimized, while in winter it should be maximized. One of the challenges for windows is to optimize the heat flow depending on the season. If outdoor temperature is cold, the window should retain heat in the building, minimize losses and let in as much solar radiation as possible. On the other hand, if the temperature inside the building is too hot and cooling is needed, the windows should keep out heat from the sun and provide opportunities to shed heat from the building [10]. Three components define the thermal transmittance of a window (UW): the glass panes, the frame (fixed or operable), and the spacer between panes (multi glazed windows) [11].
4.2.1. Glass panes
Common glass panes are transparent to solar radiation in the range of wavelengths from ultraviolet to the near infrared (from 0.3 to 2.5 μm), with a maximum peak in the visible range (about 42% of the solar energy is emitted in the range of 0.38–0.74 μm wavelengths) [11]. An effective way to control the temperature gain through glass panes is to have smart glazing windows. Smart glazing can be divided into two major categories: non-electrically activated (photochromic and thermo-chromic) and electrically activated types. The most popular and most complicated is electro-chromic. The electrically activated devices have the advantage of automatic control but they are very expensive and they use electricity (approx. 5 W/m²) Figure 3.

Figure 3. ELECTROCHROMIC Glass

Thermo-chromic laminated glazing (TLG) is a “smart” glazing that regulates the entry of light on a programmable and automatic basis. No electrical power, or other power is needed to operate the thermo-chromic system. Use of thermo-chromic material allows the creation of “intelligent” windows and facades Figure 4. These techniques allow building, with extensive glazing, to adapt dynamically and continuously to ever changing climatic conditions – and thereby minimize energy requirements. Thermo-chromic materials are affordable and have a service life of over dozen years. [12]

Figure 4. Sunlight-Responsive Thermochromic Window Systems
Source: OFFICE of ENERGY EFFICIENCY & RENEWABLE ENERGY

4.2.2. Frames
The frames can be classified according to the system of beaten into three categories:

- Windows with single beaten
- Windows with double or triple stop beaten
- Window frame with open joints.
The frames with single stop profile have a simple single seal, which has to guarantee air and water tightness; therefore, it is generally not reliable, especially in the presence of high external pressure, when the wing tends to inflect the frame itself causing the detachment of the gasket. At this purpose, the sealing of windows with double or triple stops should be preferred. On the other hand the frame material plays a key role in saving energy, the best type for this purpose is unplasticized polyvinyl chloride (UPVC). Multi–Chamber UPVC contributes to excellent thermal and sound insulation Figure 5.

![Multi–Chamber UPVC window frame](www.diypvcwindows.com)

**Figure 5.** Multi–Chamber UPVC window frame www.diypvcwindows.com

5. **Automatic window rolling shutters**

A rolling shutter device as a component of a window system provides protection from direct sun and overheating in summer, and thus, reduces the cooling loads for the building and reduces the heating loads by preventing direct exposure of window to cold wind in winter, provides protection from glare Figure 6. Most commercially available windows cause heat loss in winter and heat gain (e.g., solar heat gain) in summer, and are usually not integrated with the other building systems. Blinds installed in these windows are occasionally part of the day lighting and thermal systems Figure 7. [13]

![Window rolling shutters](www.dustymars.net)

**Figure 6.** Window rolling shutters www.dustymars.net
5.1. Overhangs
Roof overhangs have several important functions: they can protect exterior doors, windows, and siding from rain; they can shade windows when solar heat gain is undesirable; and they can help keep basements and crawl spaces dry. Overhang should be designed in a way that provides shade well into summer and full sun through the winter [15]. Donald Watson et al. [16] believed that size of overhang can approximately be calculated according to (1).

\[ W = \frac{H}{SLF} \]

Where \( W \) is size of overhang, \( H \) is the height from the beneath of the overhang to the bottom of the window and SLF is coefficient which is obtained according to the table.

| Window directions | Latitude 25 | Latitude 30 | Latitude 35 | Latitude 40 | Latitude 45 | Latitude 50 | Latitude 55 |
|-------------------|-------------|-------------|-------------|-------------|-------------|-------------|-------------|
| East              | 0.8         | 0.8         | 0.8         | 0.8         | 0.8         | 0.8         | 0.8         |
| South East        | 1/9         | 1.6         | 1.4         | 1.3         | 1.1         | 1.0         | 0.9         |
| South             | 10/1        | 5.4         | 3.6         | 2.6         | 2.0         | 1.7         | 1.4         |
| South West        | 1/9         | 1.6         | 1.4         | 1.3         | 1.1         | 1.0         | 0.8         |
| West              | 0.8         | 0.8         | 0.8         | 0.8         | 0.8         | 0.8         | 0.8         |

Figure 7. Louvered Blind [14]

Figure 8. Overhang [13]
6. **Lighting**

Light is the stimulus that influences most the human perception, but also the psychophysical wellbeing of the individual in everyday life [17]. On the other hand lighting accounts for a substantial amount of a building’s energy budget. Estimates vary in the literature, with percentages from 20% to 40% being reported [18]. Hence the best solution which is energy efficient and durable is Light-Emitting Diode (LED). While recommended for studying is 500 lux/m², a 50 watt LED lamp produces 6000 lux which is enough for 12 m². Meanwhile using motion sensor to turn off unnecessary lights would be beneficial.

7. **Energy-electricity generation**

While the project has a land of 13600 m² and considering 3600 m² for the installation of outdoor equipment (HVAC etc.), we can have 10000 m² to be used to install sustainable energy generation devices such as Photovoltaic (PV) or solar cells. PV systems behave in an extraordinary and useful way: They react to light by transforming part of it into electricity. Moreover this conversion is novel and unique, since photovoltaic [19]:

- Have no moving parts (in the classical mechanical sense) to wear out.
- Contain no fluids or gases (except in hybrid systems) that can leak out, as do some solar-thermal systems
- Consume no fuel to operate
- Have a rapid response, achieving full output instantly
- Produce no pollution while producing electricity
- Can be made from silicon, the second most abundant element in the earth's crust
- Have a relatively high conversion efficiency giving the highest overall conversion efficiency from sunlight to electricity yet measured
- Have wide power-handling capabilities, from microwatts to megawatts
- Have a high power-to-weight ratio making them suitable for roof application
- Are amenable to on-site installation, i.e., decentralized or dispersed power

The two major type of solar cells are mono-crystalline and polycrystalline which mono-crystalline are more expensive but Shuvajit Roy et al. [20] proves that they are the most efficient in comparison to others.

| Table 2. Solar cell comparison www.solarcells.com |
|-----------------------------------------------|
| Mono-cry stalline | Poly-crystalline | Amorphous (Thin Film) | CdTe (Thin Film) | CIS/CIGS (Thin Film) |
| Typical Module Efficiency | 17-22% | 14-18% | 7-9% | 10-14% | 11-13% |
| Best research efficiency | 25.0% | 20.4% | 13.4% | 19.6% | 20.8% |
| Area required for 1 kWp | 6-9m² | 8-9m² | 13-20m² | 11-13m² | 9-11m² |
| Lowest price/watt (module only) | $0.75/watt | $0.55/watt | $0.69/watt | $0.59/watt |
| Temp. Resistance | 10-15% perf. drop in high temps | More tolerant than mono | Tolerates extreme heat | Tolerates extreme heat | Tolerates extreme heat |

Table shows that using 10000 m² of the project (including remaining land and building roofs) can roughly obtain 1.5MW of sustainable power which is considerable amount.

8. **Cooling heating and ventilation**

Thermal comfort is important for both health and performance of occupants. In 1970s, Fanger proposed the PMV (Predicted Mean Vote) model based on heat balance of human body, and this model indicated that people’s thermal sensation can be estimated by measuring air temperature, relative humidity, air velocity, mean radiant temperature (MRT), clothes insulation and metabolic rate.
Nowadays, PMV model has been adopted by ASHRAE Standard and ISO Standard. However, PMV model is also challenged by the theory of adaptive comfort which was developed since 1970s, because PMV model overestimates or underestimates actual sensation of occupants in the environment deviating from moderate condition, especially in naturally ventilated buildings [21].

Space heating, water heating and space cooling account for nearly 55% of global buildings energy use and represent the single largest opportunity to reduce buildings energy consumption in most regions of the world. A systems approach, including integration of heating and cooling needs with improved building envelopes, is necessary to achieve higher energy efficiencies and a low-carbon heating and cooling supply [10].

Geothermal technology (heat pump) taps the stored energy in the earth’s crust. These systems use the earth’s relatively constant temperature to provide heating, cooling, hot and cold water for homes or commercial buildings. For closed loop systems, water or an antifreeze solution is circulated through pipes buried beneath the earth's surface. During the winter, the fluid is heated from the earth and carries the heat through the system and into the building. During the summer, the system reverses the heat cycle in order to cool the building by pulling heat from the building; carrying it through the system and placing it in the ground [22].

**Figure 9. Geothermal Heating and Cooling Systems www.ozarker.org**

A heat pump is a device that forces the movement of heat from a low-temperature medium to a higher temperature medium Figure 9. A GSHP transfers energy to and from a ground or water source to provide heating or cooling. In heating mode, the energy produced by this technology is considered partially renewable because solar and geothermal energy is mediated through the ground or water source. Depending on the generation source of electricity, the energy can be fully renewable. A GSHP system is typically composed of a ground loop (tubing that passes through a ground or water source, transferring energy to circulating fluid), a heat pump (a mechanical system that allows for the extraction of energy from the ground-loop fluid), and a heat distribution system (the system that distributes heat throughout a conditioned space).

8.1. Benefits of geoeXchange
GeoeXchange technology has several benefits, including:
Low Operating Cost - The efficiency of the heat pumps operating under moderate loop temperatures provides the basis for high efficiency and low operating cost. The cost to move energy around the building is also low, as heat pumps are placed at each space. There is no need to circulate large amounts of air around the building to transport energy, nor is there a need to reheat air to maintain comfort in certain areas of a building.
Simplicity – The distributed nature of the system makes it easy to understand. A heat pump located at each space will provide independent heating and cooling. The operation of one heat pump does not affect any other heat pump. Control simply requires turning the unit on or off in response to the area that needs heating or cooling.
Low Maintenance – The heat pump itself is a packaged unit no more complex than typical residential air conditioning equipment. The components are the same as those used for outdoor applications that have much wider operating ranges and exposure to the weather. Diagnosing problems has become easier due to the distributed nature of the system. Any problem is typically closely related to the equipment serving the particular space.

No Supplemental Heat Required – Heat pumps can meet all of the space loads, including ventilation loads. Ventilation air can be tempered by separate heat pumps and/or conditioned with heat recovery equipment.

No Required Exposed Outdoor Equipment – The ground heat exchanger is buried and the heat pumps are located inside the building. Vandalism, noise, and visual screen problems are eliminated. Designers do not have to supply space on the roof for equipment, making options such as standing seam metal roofs or large sloped roofs possible.

Low Environmental Impact – No fossil fuels need to be consumed on site. Pollution can be best mitigated at a central power plant where electricity is produced. As the efficiency of electricity production or renewable power generation increases, so does the environmental efficiency of the heat pump system.

Level Seasonal Electric Demand – With winter heat pump operation displacing fossil fuel use, and summer heat pump operation occurring at moderate, more efficient loop temperatures, the electric demand is more consistent throughout the year so the average price of electricity is reduced.

Longer Life Expectancy - Both the American Society of Heating Refrigerating and Air-Conditioning Engineers (ASHRAE) and the Electric Power Research Institute have concluded, based on independent research studies, that the appropriate service life value for ground source heat pump technology is 20 years or more. This benchmark is the current industry standard.

![Figure 10. Heat pump][23]

8.2. Solar water heating
A solar hot water heater heats the same amount of water for a fraction of the cost Figure 11. A solar hot water heating system’s performance is dependent on the intensity of the sun in its location. The cost of solar water heating from large plants is four to six times lower than that of heat from small plants [24]. Therefore it can be considered to assist the providing the running hot water of the dormitory. Solar water heating features parallel rows of transparent glass tubes Figure 12. Each tube contains a glass outer tube and metal absorber tube attached to a fin. The fin’s coating absorbs solar energy but inhibits radiative heat loss. These collectors are used more frequently for commercial applications [25].
Figure 11. Solar water heating

Figure 12. Solar water heating function [25]

8.3. Passive cooling techniques
Natural ventilation is a passive cooling method, can reduce building energy consumption, so by a high degree of attention. The study of the law of air flow and the influence on the thermal environment in the students' dormitory under the condition of natural ventilation is an important condition to ensure the environment of scientific design dormitory [26].
There are four design methods available for natural ventilation systems:

Figure 13. Relationships between building openings and airflow [23]
Cross flow (no corridor), the simplest natural ventilation system with no obstacles on either side of the prevailing wind (i.e. windows of similar size and geometry open on opposite sides of the building) Figure 14.

![Cross flow ventilation](www.abec.co.uk)

**Figure 14.** Cross flow ventilation [www.abec.co.uk](http://www.abec.co.uk)

Wind tower (wind catcher/wind extractor), the positive-pressure side of the wind tower acts as a wind catcher and the negative-pressure side of the wind tower acts as a wind extractor.

![Wind tower ventilation](commons.wikimedia.org)

**Figure 15.** Wind tower ventilation / [commons.wikimedia.org](http://commons.wikimedia.org)

Stack (or buoyancy), simple flue, a vertical stack from each room, without any interconnections goes through the roof; this allows for air movement based on density gradients

![Stack ventilation](www.passivent.com)

**Figure 16.** Stack ventilation [www.passivent.com](http://www.passivent.com)

Stack (or buoyancy), solar atrium, a large stack that heats due to solar radiant loading, which induces air movement due to density (temperature) differentials; without radiant loading, the atrium provides minimal ventilation Figure 17.
9. Conclusion
This study presents a functional method to design a dormitory on the bases of renewable energy. Building envelope including walls, windows, and shutters are chosen concerning the energy saving aspect. We chose LECA Blocks to be used in walls to have considerable insulation meeting the requirement for passive houses. Different parts of windows have been studied. Frames are designed to use Multi–Chamber UPVC which contributes to excellent thermal and sound insulation. Glass panes are thermo-chronic laminated smart glazing which controls the sun light. We recommend using Automatic window rolling shutters to prevent direct sun and overheating in summer. Roof overhangs used to shade windows when solar heat gain is undesirable. LED lamps have been recommended to decrease the amount of energy used. We applied Mono-crystalline solar cells to generate energy. An energy efficient cooling, Heating and Ventilation has been considered.

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