Available online www.jsaer.com

***Journal of Scientific and Engineering Research*, 2021, 8(4):13-29**

Research Article

ISSN: 2394-2630
CODEN(USA): JSERBR

Investigation of Building Envelop Design for Hot-Humid Climatic Conditions in Saudi Arabia

Saleh Ben Lasoad[1], Abobakr Al-Sakkaf[2,3]*, Saleh Baharetha[1]

[1]Department of Architecture and Building Sciences, College of Architecture & Planning, King Saud University, Riyadh, Saudi Arabia
[2]Department of Architecture & Environmental Planning, College of Engineering & Petroleum, Hadhramout University, Mukalla, Yemen
[3]Department of Building, Civil, and Environmental Engineering, Concordia University, Montreal, QC, Canada
*Corresponding Author Email: abobakr.alsakkaf@concordia.ca

Abstract This paper studies the insulation materials in the building envelope design for hot-humid climate. Moreover, the investigation process starts by applying the hypothetical thermal performance and simulation modeling of the buildings. Thus, moisture management performance of external walls of buildings under the climate of Saudi Arabia was investigated. Furthermore, the recent studies pointed to four other possibilities with respect to external wall systems and their varied moisture attributes. Hence, the impact of the *k*-value change due to moisture on the building thermal load and cooling energy performance of a residential building is then assessed utilizing detailed building energy simulation software. As a result, the overall building energy performance is less affected by the *k*-value change of the moist fiberglass insulation under hot–humid conditions. The higher wetting conditions prevail the effect of *k*-value change on the building cooling energy continues to be limited although the impact of the roof on monthly cooling load is more pronounced especially during the summer months when as much as an 8% increase occurs. To sum up, this research will help architects and civil engineers to evaluate building envelop performance.

Keywords Building envelope, climate, energy, sustainability, environmental control

Introduction

Exterior walls proper design is vital to generate a sustainable and healthy built environment. However, there are many methods available for achieving suitable moisture design. Recently, many new wall systems and material have been introduced. Therefore, long term moisture management performance for those new wall systems and materials is required. One of the most important functions of the building envelope is, therefore, to control physical environmental factors such as heat, light and sound in order to achieve the desirable comfort conditions for the user with a minimum of energy consumption.

The proper selection and design of buildings wall systems is very important to achieve the best moisture performance conditions and minimize energy consumption. There are Sources of moisture problems in hot-humid climate housing such as: use of wet materials in construction, capillary rise of ground moisture, leakage of rainwater or melted snow, condensation of water vapor and leakage of piped water [1], [2]. The purpose of the research is to find a good moisture performance exterior wall system with an optimal transfer rate of heat in Dhahran which has hot-humid climate conditions. Properties of the building envelope such as function, position, dimensions and orientation should be taken into account.

In the field of building design and construction, the need to ensure moisture maintenance over the lifetime of a building has been further reinforced by the introduction of different novel materials and wall designs. Issues with moisture management in a building, especially in arid regions, can arise from water leakage, increase in moisture content in the flooring or the application of wet or humid materials during the construction phase of the building [3]. For many building occupants, indoor comfort is a very essential factor, which in itself is influenced by the interplay between the building envelope and environmental elements such as sound, heat and light [1], [2]. It is therefore evident that the choice of wall for a building is crucial not only to promote indoor comfort, but also to establish conditions that will enable energy efficient moisture management. In this study, a wall system, with efficient moisture management and heat transfer for the Kingdom of Saudi Arabia, is sought. Factors such as purpose, positioning, size and orientation of the wall are considered in order to identify the most influential factors with respect to moisture management in a building.

Literature Review

Building enveloped is generally composed of a variety of elements. The most recurrent elements are walls, fenestration, roofs, thermal insulation, and air tightness [4]. Walls are a major part of a building envelope. They provide thermal protection and reduce incoming noises. One parameter that provides insight into the effectiveness of walls is the thermal resistance (R-value). The R-value impacts the consumption of energy by a building. Additionally, walls that possess thermal insulation are highly susceptible to surface condensation especially when the air humidity is greater than or equal to 80% [5], [6]. A variety of walls are available for buildings including passive solar walls [7], lightweight concrete walls [8], ventilated walls [9], and latent heat storage walls [10]. Each has its unique uses and properties. Fenestrations are the doors and windows in a building. Their main role is to provide the users with light and means to mitigate and control the internal temperature of the building [4]. An important aspect of fenestrations is glazing, which currently exists in a variety of forms that provide different impacts on the building envelope such as aerogel glazing [11], vacuum glazing [12], and switchable reflective glazing [13].

Roofs are another element of the building envelope. Roofs protect from solar radiation and other environmental elements. Roofs heavily contribute to the gain and loss of heat in buildings [4]. A variety of roofs exist in the market providing a wide range of advantages. The available technologies include masonry [14], lightweight [15], ventilated [16], and green roofs [17]. Thermal insulators are materials that are embedded in the building to retard and control the heat flow in the building. A wide variety of insulators are available in the market today and their selection is dependent on the heat flow that will be blocked [18]. Finally, airtightness represents the movement of air within the building. This is mainly done through openings and cracks within the building system. Any form of air dissipation or infiltration in the controlled space will cause the heating and ventilation systems to consume more energy to provide the required levels of comfort. Accordingly, the higher the airtightness, the less the energy consumed by the building [19].

Literature Review

The weather of Dharan

Dhahran is located in Eastern Saudi Arabia on the Arabian Gulf coast. It is located at latitude 26°16'N, longitude 050°10'E, and with elevation of 17m. Dhahran's climate is characterized by extremely hot, humid summers, and cool winters. Temperatures can rise to more than 50 °C in the summer, coupled with extreme humidity (85-100 per cent), given the city's proximity to the Arabian Gulf. Dhahran holds the record for the highest dew point ever recorded in the world. On July 8th, 2003 the dew point was 35 °C. The air temperature at the time was 42 °C giving a heat index of 78 °C. It also holds the record for the highest temperature recorded in the country 51 °C In winter, the temperature rarely falls below 2 °C or 3 °C with rain falling mostly between the months of November and May. The Shamal winds usually blow across the city in the early months of the summer, bringing dust storms that can reduce visibility to a few meters. These winds can last for up to three months.

The temperature, precipitation and delighting condition of Dhahran is shown in Figure 1 below. The yellow section shows when the sun is up, and how this changes over the year. Use the time-of-day scales, on the left and right, and the month scale on the top and bottom, to tell approximately when sunrise and sunset occur. The sunrise and sunset times shown in the chart are approximate. They are accurate for the latitude, and show the precise amount of daylight, but the rise and set times may be offset (up or down in the chart) since I don't have an automated way of matching time zones to longitudes. The charts are made assuming that the location is in the middle of an evenly spaced time zone.

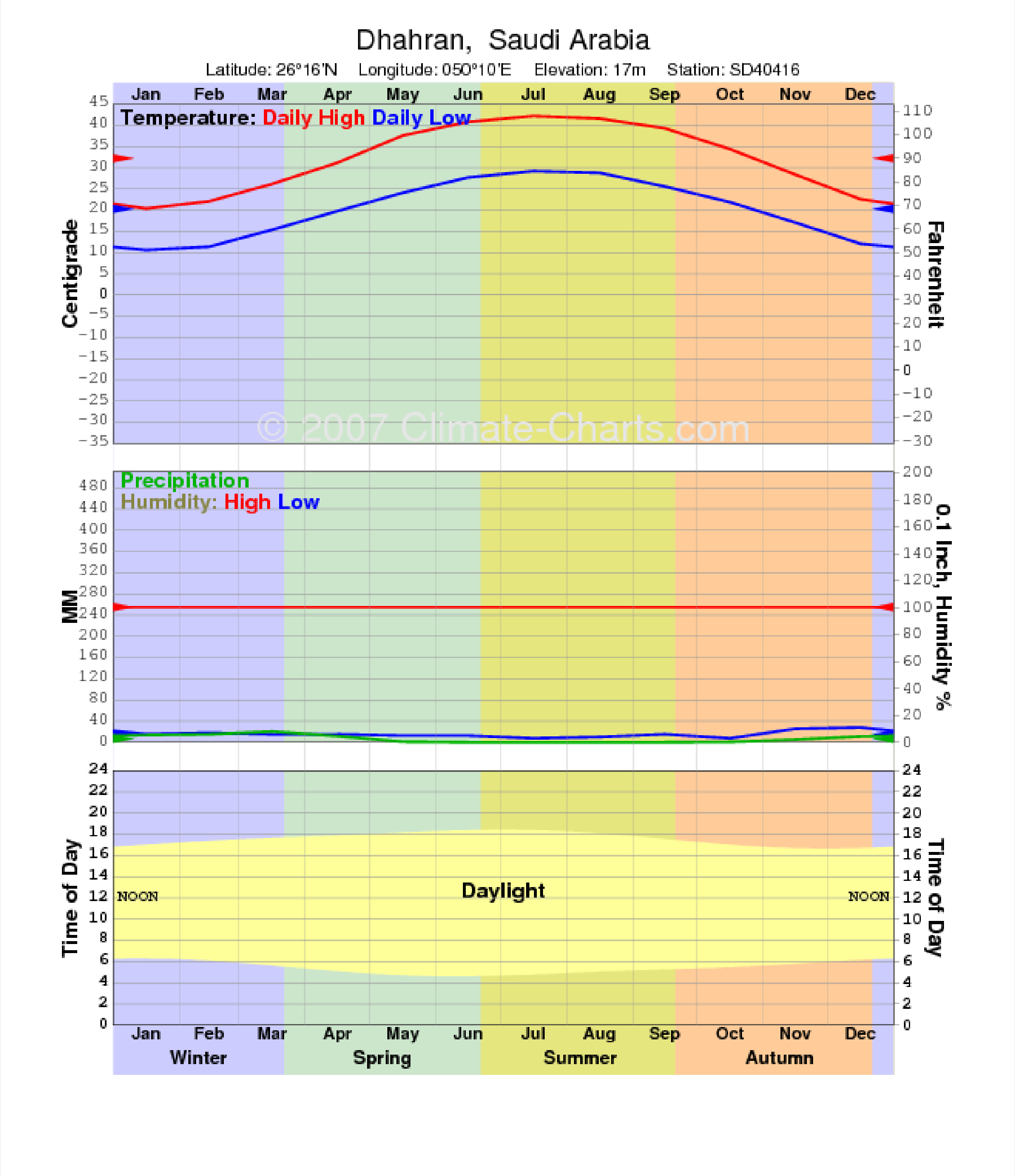


Figure 1: Daily temperature and precipitation of Dhahran City

Methodology

The article methodology is illustrated in Figure 2. The initial steps including identifying impactful elements for the assessment of building envelopes in addition to the practices that are conducted in the Kingdom of Saudi

Arabia. Furthermore, influencing elements are identified, specifically moisture, insulation, and thermal conditions. An assessment of energy conversation is applied to the database based on the identified data and results and conclusions are drawn.

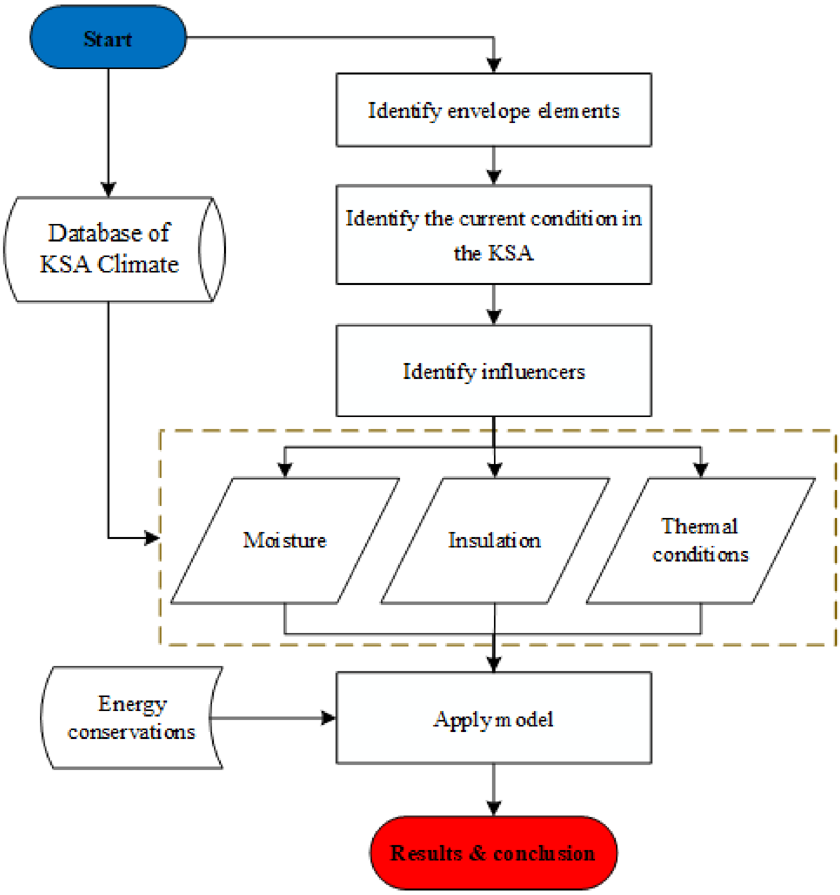


Figure 2: Research framework

Building Envelop

In a building, there are active and passive systems. Active systems refer to those that require mechanical or electrical support to function while passive systems utilize inherent or man-made qualities to function. A building's envelope is categorized as a passive system and it is comprised of the roof, ceiling, walls, windows, doors and floors. It regulates air or vapor flow, heat, light, noise, and moisture penetration between the interior and exterior parts of the building environment [21]. Therefore, it impacts indoor comfort of a building. For the construction of an effective building envelope, the architectural design of a building together with the requirements of the building owner are both necessary [20].

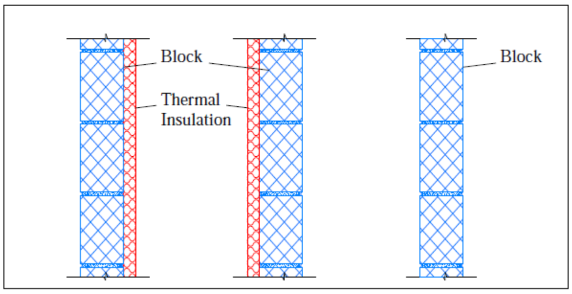
The primary role of building envelope is to act as a as barrier between the controlled indoor environment and outdoor. It also to separates the interior and exterior environments, by managing the air flow, moisture, and heat between them. The main components of building envelope are walls, windows, doors, floor, ceiling and roof. The impact of architectural orientation and styles, future requirements and owner's expectations must be required in order to design successful building envelope. Building is composed of many active and passive systems. Active systems are those which use electronic, mechanical and electrical equipment to achieve the required condition. While passive systems utilize their components natural and artificial made properties to perform their intended function. Building envelope is a passive system that indebted to perform many functions such as controlling air flow, water vapor flow, rain penetration, and light. It has also to control solar and other radiation, noise, and fire, provide strength and rigidity. It also separates the interior of the building from the exterior physically and influences the indoor air temperature and occupants comfort.

The nature of the building enclosure

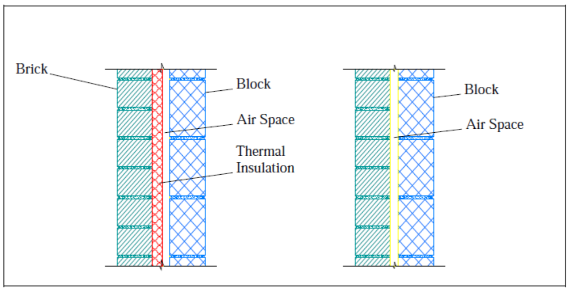
Building envelope mainly consists of three interactive components as the following: 1) exterior environments; 2) enclosure system; and 3) interior environments. Furthermore, there are four main components of building enclosure: The roof systems, the above- grade wall systems including windows (Fenestration) and doors, the below-grade wall systems and the base floor systems.

Exterior wall systems

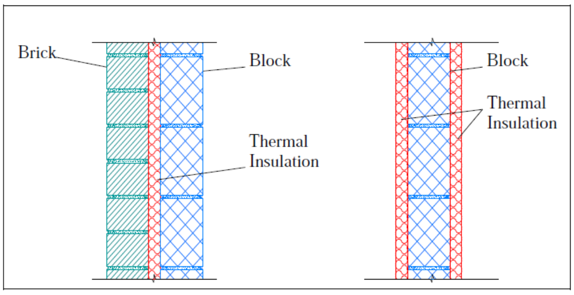
Many of construction materials are used in constructing wall systems to achieve a certain aesthetic, structural, and thermal purposes. Those materials include: include wood, glass, steel, concrete; clay and thermal insulation. wood, concrete and clay are widely used in developing countries. Building materials are assembled in many ways to form different types of building envelope. For constructing wall systems, materials can be arranged to create single-leaf solid walls with or with-out insulation. Insulation material can be placed either inside or outside relevant to the principle material. Cavity walls are constructed with full air space or partially filled with an insulated material or with reflective material such as aluminum paper, and a sandwich or composite wall panel (see Figure 3).



3.a : Single-Leaf solid wall



3.b: Cavity walls



3.c: Sandwich walls

Figure 3: Different types of walls

Factors influencing the thermal performance of exterior wall systems

Moisture Characteristic

Moisture can affect material, physical, and thermal characteristics of a building as well as its durability. Excessive moisture on certain materials can lead to irrevocable damage. Corrosion of metals is also likely for long periods of exposure. Alternating periods of wetting and drying can cause a reduction in length, strength, and modulus of elasticity of the affected materials. For wetted bricks, efflorescence can occur, which results in the appearance of salt on the surface of the material.

Insulation materials

An in-depth understanding of insulation systems is essential for decision making with respect to moisture regulation. The interplay between insulation systems such as vapor retarders and air barrier systems and indoor environmental factors such as temperature and humidity should also be well understood. Table 1 presents a list of insulation materials that are commonly used in Saudi Arabia.

Table 1: Insulation materials in Saudi Arabia

Insulation Material	Density (kg/m^3)	Thermal conductivity W/m °C
Polyurethane	0.025	0.025
Polystyrene	0.032	0.032
Fiber glass	0.035	0.050

Thermal characteristics

Thermal characteristics refer to the ability of a building to retain or lose energy due to the interplay between its structural components and the environment [23].

Thermal conductivity (K)

Thermal Conductivity is the measure of the amount heat that will be transmitted through a one inch (1") thick piece of homogenous material, one square foot (1 ft.2) in size, in one (1) hour, when there is a one degree Fahrenheit (1° F) temperature change. The equation for "k" is:

$$K = \frac{BTU \times inch}{sq.\ ft. \times hour \times {}^{\circ}F} \qquad (1)$$

Total Thermal Resistance RT

The total thermal resistance of a building component, RT is equal to the sum of a number of individual thermal resistances, which are related to material type, internal and external surface air film, and air spaces (CSR, 2001).

Heat transfer

Heat transfer occurs by heat flowing from a hot region to a cool region. Minimizing heat flow is desirable in winter because buildings require internal heating. On the other hand, in summer, it is desirable to minimize the thermal transmission which is flowing inwards through the external building components. Heat flow is a function of three mechanisms; radiation, conduction and convection (CSR, 2001).

Thermal resistance (R-value)

The thermal resistance of a material is the resistance to heat flow between two surfaces at different temperatures. The higher the R-value, the greater the insulation effectiveness. It depends on the type of insulation and includes its material, thickness and density (KSR, 2001).

The energy efficiency of buildings is determined by R-values (resistance to thermal flow) of building segments such as walls, floors , roof and windows (Dalibor, 2002). R-value is measured in m^2K/W and is equal to the thickness of the material (in metres) divided by the conductivity of that material. Surfaces and cavities also provide thermal resistance and there are standard figures for these resistances that must be taken into account when calculating U-values. The resistances of each material within an element are added together to determine the overall resistance of the element. The reciprocal of the overall resistance is the U-value. U is the inverse of R with SI units of W/(M^2K).

$$U = \frac{1}{R} = \frac{Q_A}{\Delta T} \qquad (2)$$

Table 2: Thermal characteristics with their relationship to thermal insulation

Thermal Characteristics	Relationship to thermal resistance
Thermal Conductivity, *K*	The lower the value, the better the thermal insulation
Thermal Resistance (R-value)	*R* The greater the value, the better the thermal insulation
Thermal Resistance of Surface Air Film, Rs	*Rs* The greater the value, the better the thermal insulation.
Thermal Transmittance, *U* = 1/ RT	*U* The lower the value, the better the thermal insulation

Overall heat energy transfer rate : U-values:

The U-Value is the measure of the rate of heat loss through a material. Thus, in all aspects of home design one should strive for the lowest U-Values possible because, the lower the U-value, the less heat that is needlessly escaping. So for example single glazed windows have a typical U-value of 5.6 while double glazed windows have a typical U-value of 2.8. a U-Value is measured as the amount of heat lost through a one square meter of the material for every degree difference in temperature either side of the material. It is indicated in units of Watts per Meter Squared per Degree Kelvin or W/m^2 K (SEI, 2007).

In Figure 4, the U values measures how well a building component (wall, roof or windows) keeps heat inside the building. *The higher the U values the more heat flows*. So a good U value is a lower one as you want to keep heat inside the building or outside depending on the climate you live in. For those living in cold climate the U value is relevant as it is an indicator of how long the inside of the building can be kept cold.

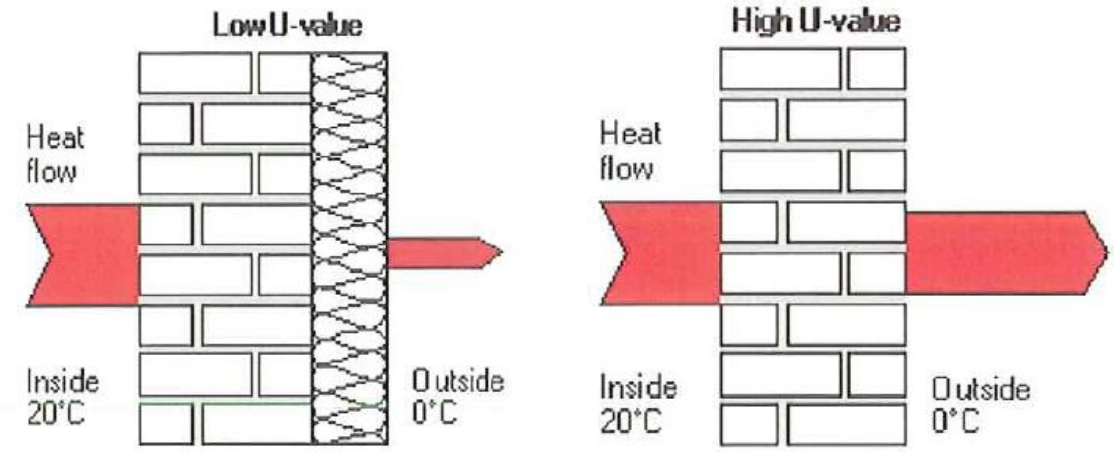


Figure 4: High and low U-value

Building orientation and solar radiation

Orientation of the building is a significant factor that affects a building's thermal characteristics. It can increase the possibility of "passive solar heating". For example, in northern regions of the world, a building that is oriented towards 30o or less of the true south, either to the east or west, will be able to gain up to 90% solar energy. For a rectangular-shaped building, it is recommended that the length of the building should run from east to west in order to reduce the intensity of the sun on the eastern and western walls of the building and to promote "passive solar heating" for the southern areas of the building. In practice, a building's orientation is dependent on the site of the construction and the topography of the surrounding region [24]–[26].

Energy conservation

There is a need for energy conservation in buildings in Saudi Arabia. Ranking third in energy consumption, the building sector consumes about 70% of the country's electrical energy due to high rate of air conditioning in buildings [27]. A typical apartment in Riyadh, Saudi Arabia consumes about 20,000 kWh per year while the same apartment in the US consumes 40% of this value [28]. Buildings are one of the three primary economic sectors consuming energy. Buildings in Saudi Arabia consume the largest portion (about 73%) of the total electric energy. The average electricity consumption of an apartment in Riyadh is 20,000 kWh/yr, while the average consumption of areas of similar climates in the United States is 8000-10,000 kWh/yr. As a result of this, buildings are considered as the largest consumers of energy in Saudi Arabia [27]. Figure 5 shows that air conditioning accounts for about 73% of total electricity consumed in the residential sector.

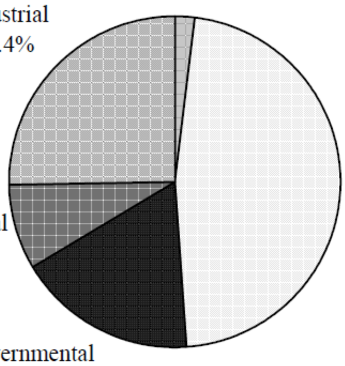


Figure 5: Energy consumption for different sectors in the Kingdom of Saudi Arabia

Construction material

In building construction, several materials have been using to build wall systems to achieve a certain aesthetic, structural, and thermal purposes interims of building performance modeling. In addition, these materials include stone, wood, glass, steel, concrete, mud and thermal insulation. Stone, wood, concrete and mud are widely used in developing countries such as Saudi Arabia. However, building materials are compiled in certain approaches to evaluate different types of building envelope. For constructing wall systems, materials can be arranged to create single-leaf solid walls with or with-out insulation. Thus, insulation material can be placed either inside or outside relevant to the principle material of the buildings. For instant, cavity walls are constructed with full air space or partially filled with an insulated material or with reflective material such as aluminum paper, and a sandwich or composite wall panel [29].

Simulation and analysis

Simulation of alternatives wall system for hot-humid climatic condition (Dhahran City) Introduction to the simulation tool hygIRC-2D: The hygrothermal simulation tool, hygIRC-2D, is a computer aided numerical model that can predict the moisture response of building envelopes and is used mainly to analyze and obtain meaningful results [28]. HygIRC-2D is continuously developed by a group of researchers at the Institute for Research in Construction (IRC) of the National Research Council (NRC), Canada [29]. The reliability of hygIRC-2D outputs has been established through laboratory measurements and benchmarking exercises [28].

Model input data

The structure form is used to build the model wall to be input to the simulation engine. Orientation: A south vertical wall orientation was assumed and the models of four wall systems were built as shown in Table 3.

Table 3: The components of The models of four wall systems

Types of wall	Components (from exterior to interior)
Double Wythe Solid masonry Wall	Brick III - Buff Matt Clay Brick (100mm) Mortar II - Type 1-S (20mm) Brick V - Concrete Brick (100mm) Expanded Polystyrene Insulation (50mm) Gypsum (13mm)
T.T.W. (Through the Wall) Brick Wall	Brick III - Buff Matt Clay Brick (200mm) Mortar II - Type 1-S (12mm) Expanded Polystyrene Insulation (75mm) Gypsum (13mm)
Precast Wall Insulated Directly	Aerated Concrete (50mm). Expanded Polystyrene Insulation (60mm). Gypsum+ Primer (13mm).
Precast Sandwich Panel	Aerated Concrete (50mm). Expanded Polystyrene Insulation (60mm). Aerated Concrete (100mm). Gypsum+ Primer +Later (13mm).

Simulation input data

Simulation of the given wall systems was with the following data:

- From the point view of simultaneous "thermal" and "moisture" transfer under the weather conditions of Dhahran city, (2002).
- Constant value of temperature (21C◦).
- Relative humidity (55%).
- Simulation started from first January 2002 to 31 December 2002.

Temperature and Moisture Content- Wall No.1 (Double Wythe Solid masonry Wall)

It is noted that the temperature decreased through the wall layers. It started from 42 ºC and then decreased to 25 C◦ through the layers of the wall as shown in Figure 8. This reduction in temperature was due to using the Expanded Polystyrene Insulation (50 mm). The moisture content was different in this wall system because of the properties of materials. After staying at the same level for some time, then the moisture content start increased dramatically then decreased and staying at the same level again. But, suddenly, there was a sharp increase and staying at same level through the Gypsum layer. Therefore the maximum amount of moister content was in the Gypsum layer (13 mm) and the minimum amount of moister content was in the Brick III - Buff Matt Clay Brick (100 mm) as shown in Figure 6.

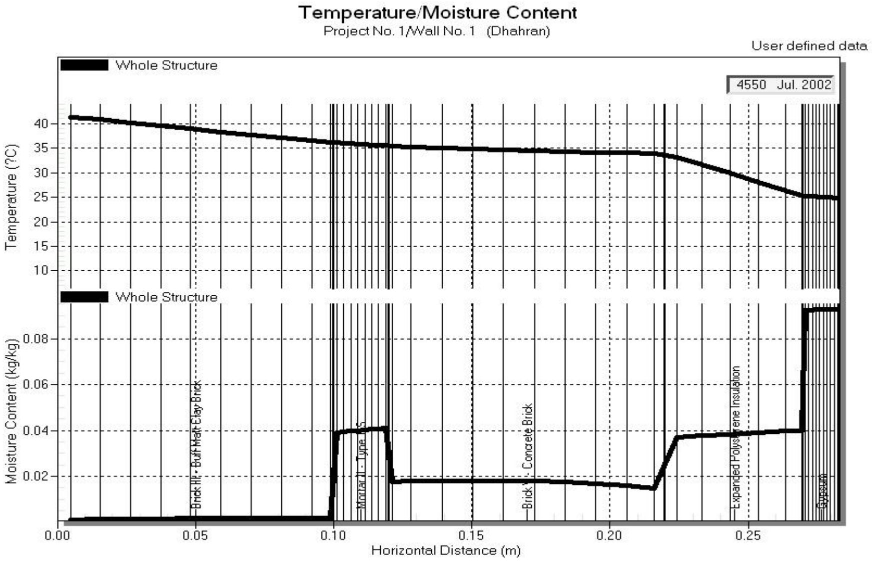


Figure 6: Variation of temperature with moisture content at whole structure at hour 4550 (Case No.1)

Total Moisture Content

Moisture content is the quantity of water contained in a material. It is noted that the total moisture content values for the whole structure fluctuated widely through the year. It started from 6.7 kg/m^2 and then increased gradually to reach the maximum in day 102 and then decreased gradually to reach the minimum in day 240 (1th of August and then increased to reach 7.05 at the end of the year as shown in Figure 7.

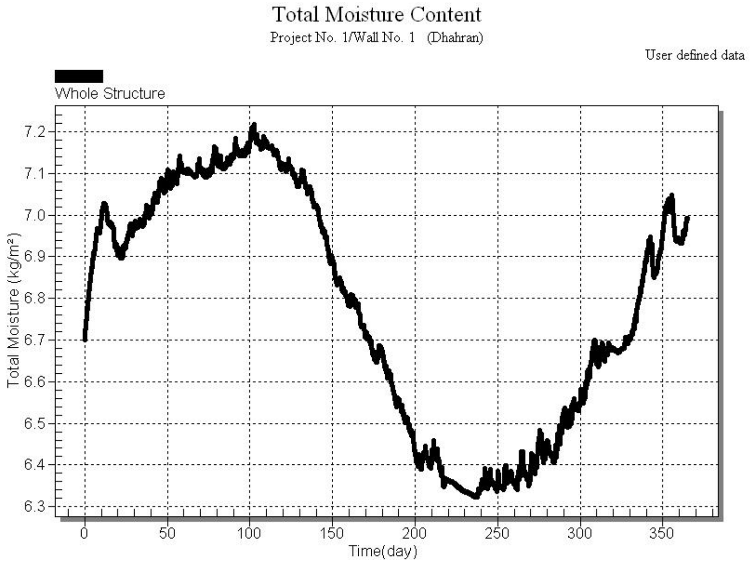


Figure 7: Variation of moisture content by whole structure (Wall No.1)

Transfer Rate of Heat (total)

Transfer rate of heat decreased on first 10 or 15 days and then increased to the maximum which is 8.2 w\m2 at day 200 (July) and then decreased gradually to the same of the beginning of the year as shown in Figure 8. This is due to the climate conditions of Dhahran city.

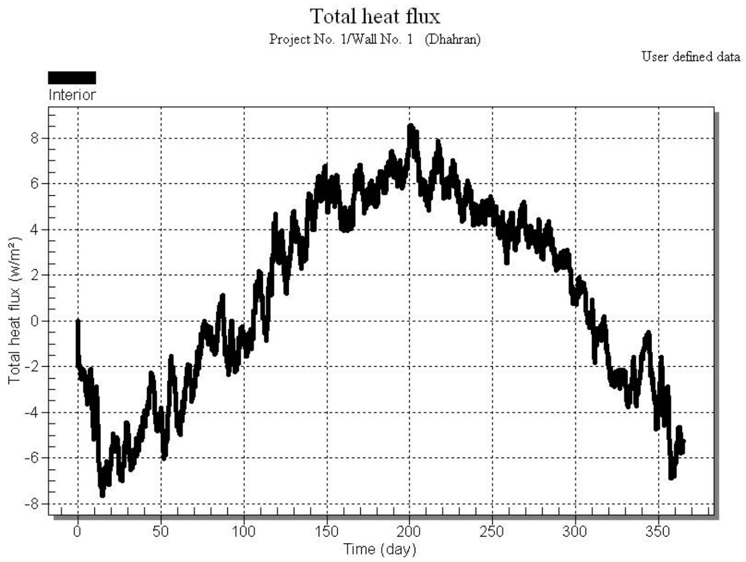


Figure 8: Variation of Transfer Rate of Heat (total) (Wall No.1)

Temperature and Moisture Content- Wall No.2 (T.T.W.) (Through the Wall) Brick Wall)

It is noted that the temperature decreased through the wall layers. It started from 42 ºC and then decreased to 22 C◦ through the layers of the wall as shown in Figure 11. This reduction in temperature was due to using the Expanded Polystyrene Insulation (50 mm). Moisture content is the quantity of water contained in a material. Due to the properties of materials in this wall system, it is noted that the moisture content was minimum in the Brick III - Buff Matt Clay Brick (200 mm) and maximum in Gypsum as shown in Figure 9.

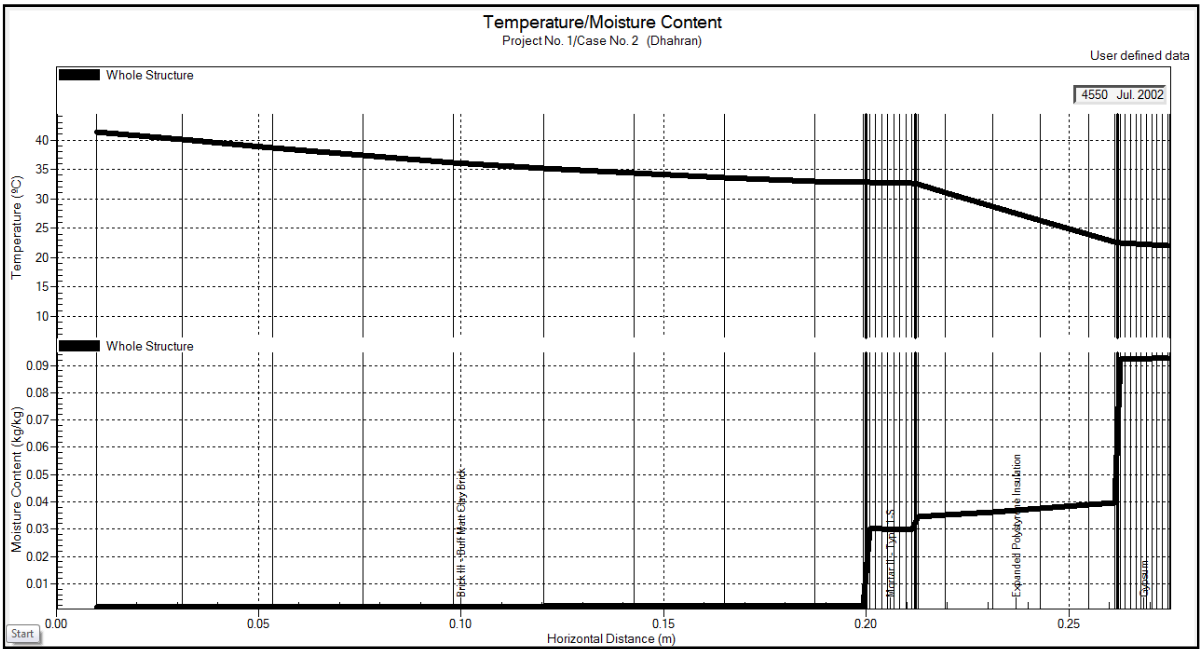


Figure 9: Variation of temperature with moisture content at whole structure at hour 4550 (Case No.2)

Total moisture content

Moisture content is the quantity of water contained in a material. The total moisture content started from 2.35 kg/ m^2 and then increased gradually to reach the maximum value 2.54 kg/ m^3 in day 60.Then it decreased gradually to reach the minimum value 1.00 kg/ m^3 in day 180 and then increased to reach 2.4 kg/ m^3 at the end of the year as shown in Figure 10.

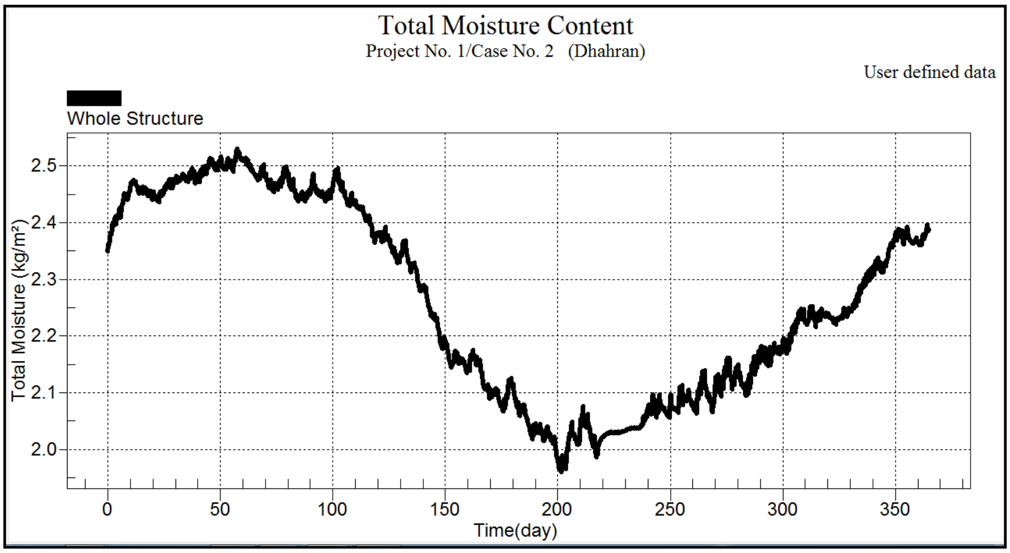


Figure 10: Variation of total moisture content by whole structure (Case No.2)

Transfer Rate of Heat (total)

Transfer rate of heat decreased on first 15 days and reached -5.2 w/m^2. Then it increased gradually to the maximum value 11.00 w/m^2 on about the day 200 and then it decreased gradually and reached -1.00 w/m^2 at the end of the year as shown in Figure 11. This is due to the climate conditions of Dhahran city.

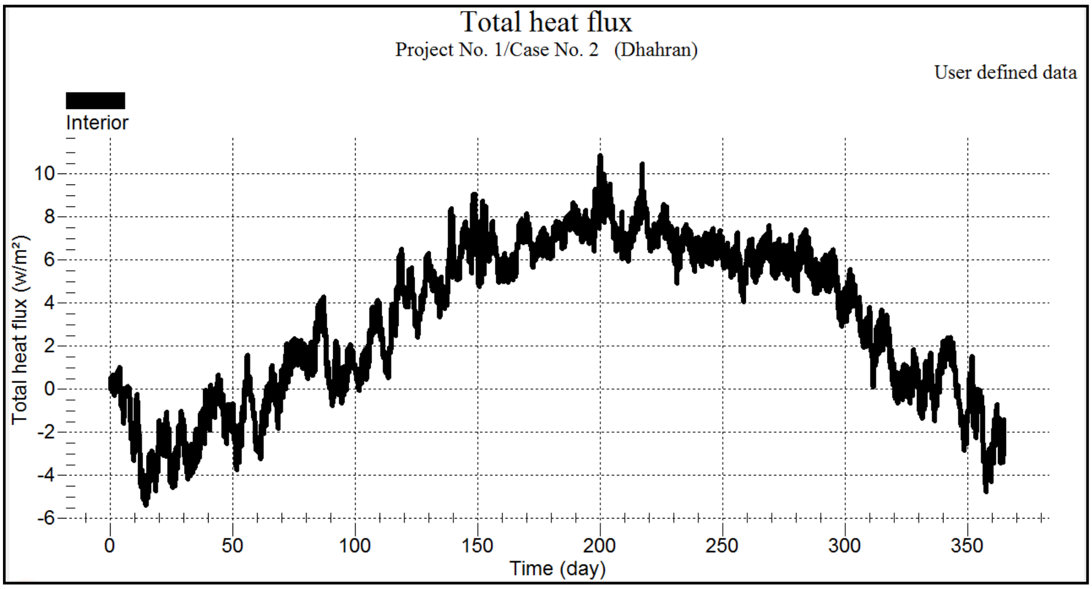


Figure 11: Variation of Transfer Rate of Heat (total) (Case No.2)

Temperature and Moisture Content- Wall No.3 (T.T.W. (Precast Wall Insulated Directly)

It is noted that the temperature decreased through the wall layers. It started from 42 ºC and then decreased to 22 ºC through the layers of the wall as shown in Figure 12. This reduction in temperature was due to using the Expanded Polystyrene Insulation (50 mm). Moisture content is the quantity of water contained in a material. Due to the properties of materials in this wall system, it is noted that the moisture content was minimum in the aerated concrete layer (100 mm) and maximum in Gypsum as shown in Figure 12.

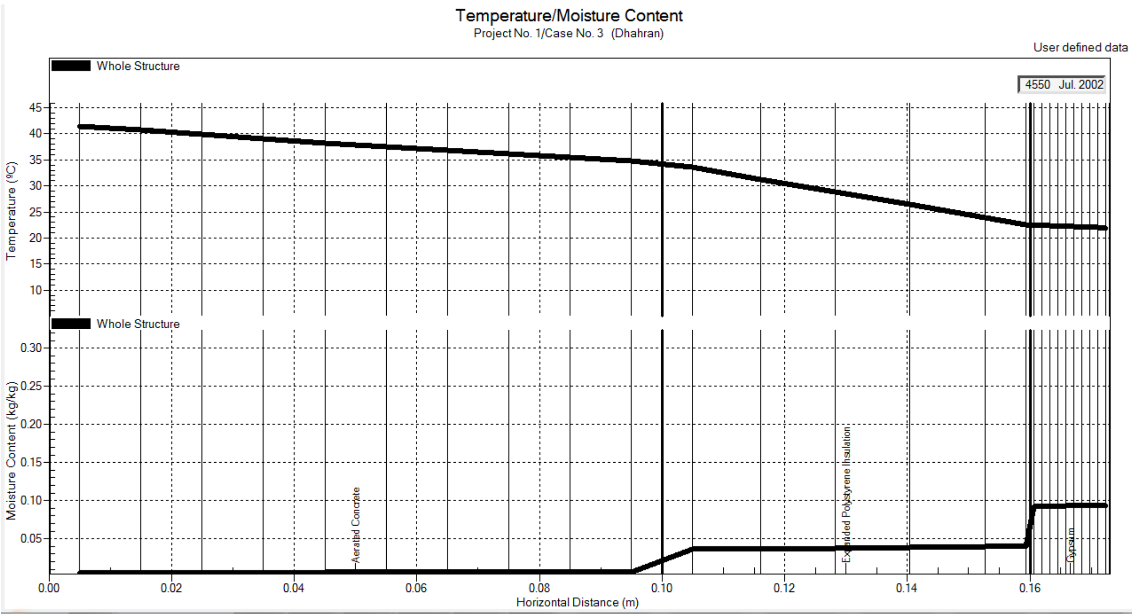


Figure 12: Variation of temperature with moisture content at whole structure at hour 4550 (Case No.3)

Total moisture content

The total moisture content in this wall system started from 1.2 kg/ m^2 and then decreased gradually and reached the minimum value 1.00 kg/ m^2 in day 200.Then it increased sharply and reached the maximum value 8.9 kg/ m^2 in day 350. Lastly, it decreased gradually to reach 7.6 kg/ m^2 at the end of the year as shown in Figure 13.

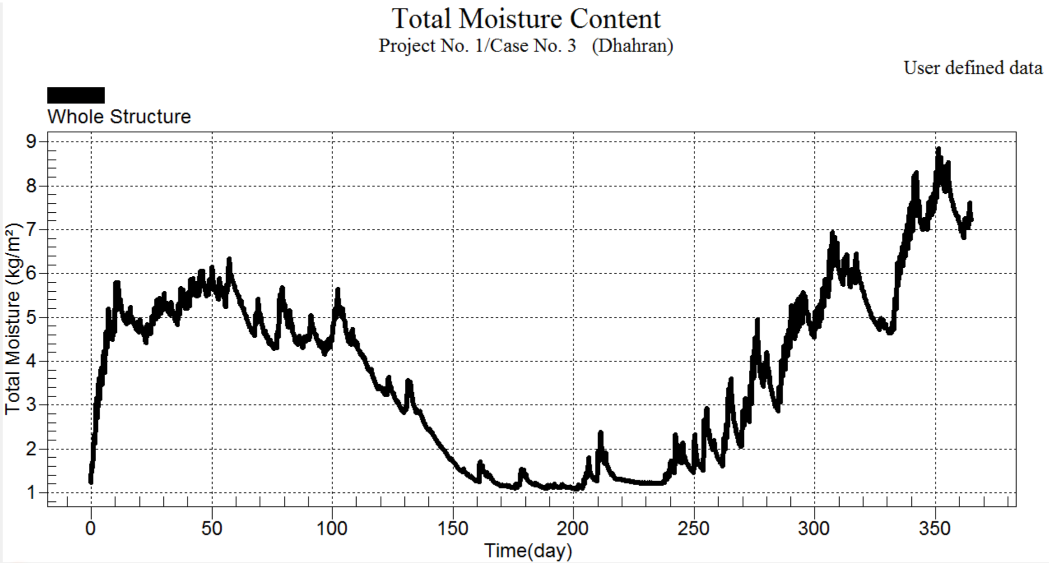


Figure 13: Variation of total moisture content by whole structure (Case No.3)

Transfer Rate of Heat (total)

Transfer rate of heat decreased on the first 20 days and reached -6 w/m^2. Then it increased gradually to reach the maximum value 8.5 w/m^2 on the day 200. Then it decreased gradually and reached -5.8 w/m^2 at the end of the year as shown in Figure 14. This is due to the climate conditions of Dhahran city.

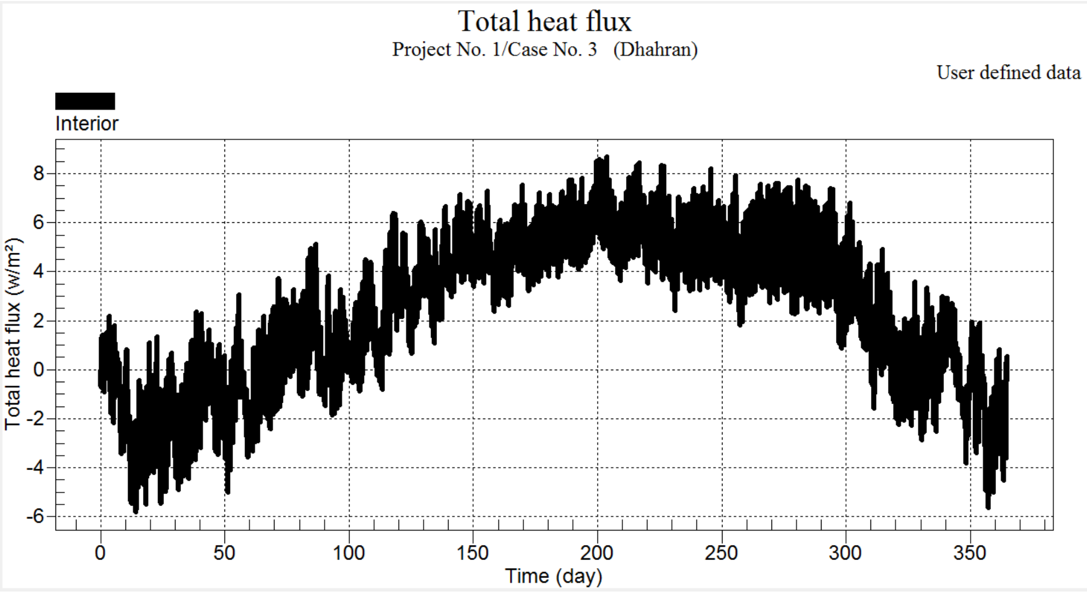


Figure 14: Variation of Transfer Rate of Heat (total) (Case No.3)

Temperature and Moisture Content- Wall No.4 (T.T.W. (Precast Sandwich Panel)

It is noted that there was a slight decrease in the temperature through the wall layers. After staying at the same level through the first two layers. Then It started decreased through Expanded Polystyrene Insulation layer, and staying at same level again. It started from 40C◦ and then decreased to 25 C◦ through the layers of the wall as shown in Figure 15. This reduction in temperature is due to using the Expanded Polystyrene Insulation (50mm). In this wall system, because of the properties of materials, the moisture content staying at the lowest level and here was a sharp increase through the Gypsum layer as shown in Figure 15.

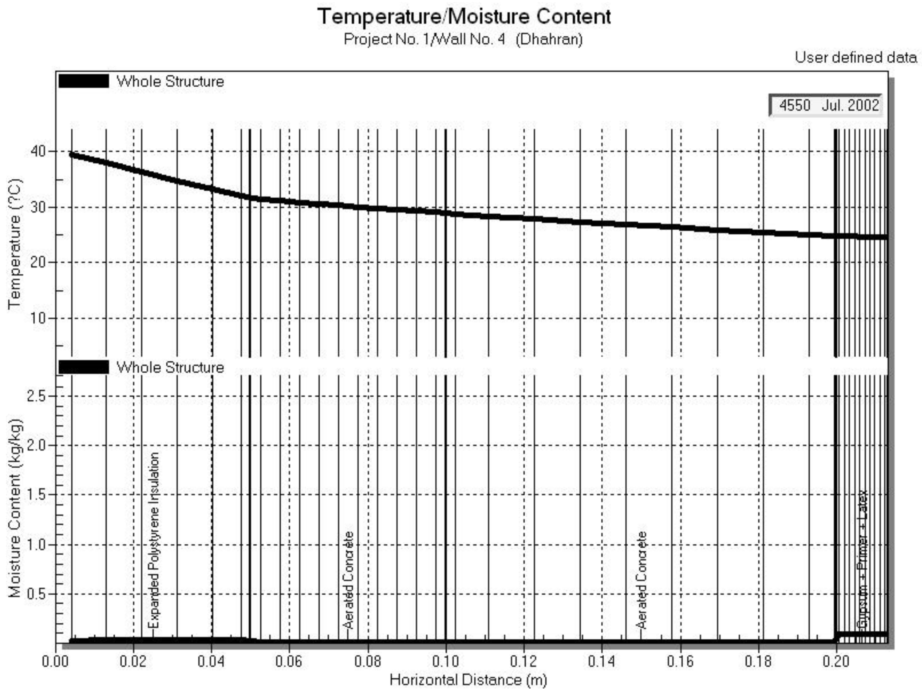


Figure 15: Variation of temperature with moisture content at whole structure at hour 4550 (Case No.4)

Total moisture content

In this wall system, it is noted that also, the total moisture content values for the whole structure fluctuated widely through the year. It started from 1.4 kg/m^2 and then increased dramatically and then decreased gradually to reach the minimum in day 200 (20th of June) and then increased gradually to reach the maximum 1.99 kg/m^2 at the end of the year as shown in Figure 16.

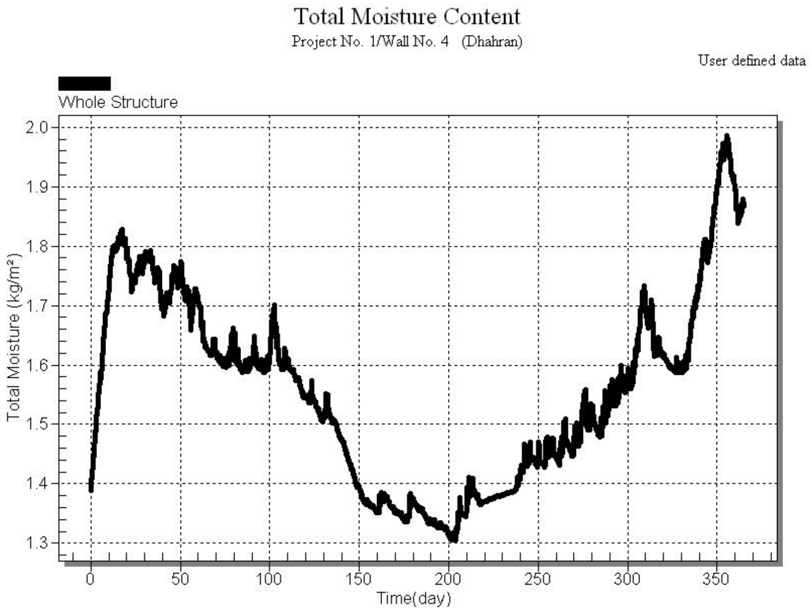


Figure 16: Variation of moisture content by whole structure (Wall No.4)

Transfer Rate of Heat (total)

It is noted that the Transfer rate of heat values for the whole structure fluctuated widely through the year. It started from 0.0 w/m^2 and then increased gradually to reach the maximum in day 200 which is 6 w/m^2 and then decreased gradually to the same of the beginning of the year as shown in Figure 17. This is due to the climate conditions of Dhahran city.

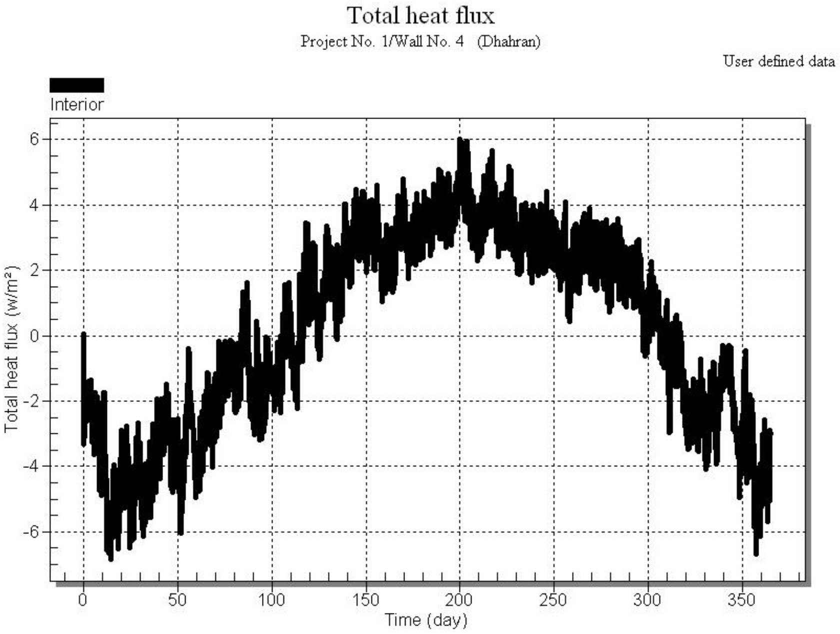


Figure 17: Variation of Transfer Rate of Heat (total) (Wall No.4)

Conclusion

In this study, the moisture management performance of external walls of buildings under the climate of Saudi Arabia was investigated. Literature review points to four other possibilities with respect to external wall systems and their varied moisture attributes. HygIRC software was employed to simulate and study the performance of these walls in a hot climatic condition. The following elements were considered: moisture content, the type of insulating material used, thermal conditions (temperature and total heat transfer), energy conservation, solar radiation, and orientation, amongst others.

Wall assemblies must control the transfer of heat, air, and moisture between outdoor and indoor environments. HygIRC predicts the performance of a given building envelope in a selected location. The case studies were simulated under the climatic condition of Saudi Arabia. The comparison between the cases includes temperature, moisture content, total moisture content, and the transfer rate of heat (total). In this application, the model and simulation of the given four-wall systems were done a) 6.7 kg/m^2, b) 2.24 kg/m^2, c) 2.2 kg/m^2, d) 1.5 kg/m^2. Selection of the best wall system was based on the studying and comparison between the given four-wall systems.

- This study has been carried out to evaluate the moisture performance of alternative exterior wall systems in housing building in Dhahran (hot-humid climate) utilizing HygIRC Software simulation.
- Based on the literature review, many factors affecting moisture performance of external wall systems have been identified. These factors include moisture characteristic, insulation materials, thermal characteristics, air leakage and inter-space air movement, building orientation and solar radiation and energy conservation.
- Based on the literature review, four alternative exterior wall systems were selected to represent the wide variation of moisture characteristics of the generated wall designs.
- Wall assemblies must control the transfer of heat, air, and moisture between outdoor and indoor environments. HygIRC predicts the performance of a given building envelope in a selected location.
- The case studies were simulated under the climatic condition of Dhahran City. The comparison between the cases include temperature, moisture content, total moisture content and transfer rate of heat (total).
- In this application, the model and simulation of the given four wall systems were done. Selection the best wall system was based on the studying and comparison between the given four wall systems.

Acknowledgment

The authors would like to thank the Deanship of Scientific Research at King Saud University and the Research Center at the College of Architecture and Planning for supporting this research.

References

[1]. Al-Sakkaf, A., Zayed, T., & Bagchi, A. (2020). A sustainability based framework for evaluating the heritage buildings. International Journal of Energy Optimization and Engineering (IJEOE), 9(2), 49-73. DOI: 10.4018/IJEOE.2020040105

[2]. Al-Sakkaf, A., Zayed, T., Bagchi, A., Mahmoud, S., & Pickup, D. (2020). Development of a sustainability rating tool for heritage buildings: future implications. Smart and Sustainable Built Environment. https://doi.org/10.1108/SASBE-04-2020-0047

[3]. Chandra, S., Parker, D., Beal, D., Chasar, D., Martin, E., McIlvaine, J., ... & Chasar, D. (2004). Alleviating Moisture Problems in Hot, Humid Climate Housing.

[4]. S. B. Sadineni, S. Madala, and R. F. Boehm, "Passive building energy savings: A review of building envelope components," Renew. Sustain. energy Rev., vol. 15, no. 8, pp. 3617–3631, 2011.DOI: 10.1016/j.rser.2011.07.014

[5]. J. E. Christian and J. Kosny, "Thermal performance and wall ratings," ASHRAE J., vol. 38, no. 3, 1996.

[6]. Aelenei, D., & Henriques, F. M. (2008). Analysis of the condensation risk on exterior surface of building envelopes. Energy and Buildings, 40(10), 1866-1871.DOI: 10.1016/j.enbuild.2008.04.003

[7]. Liu, Z., Wu, D., Li, J., Yu, H., & He, B. (2019). Optimizing building envelope dimensions for passive solar houses in the Qinghai-Tibetan region: window to wall ratio and depth of sunspace. Journal of Thermal Science, 28(6), 1115-1128.DOI: 10.1007/s11630-018-1047-7

[8]. Roberz, F., Loonen, R. C. G. M., Hoes, P., & Hensen, J. L. M. (2017). Ultra-lightweight concrete: Energy and comfort performance evaluation in relation to buildings with low and high thermal mass. Energy and Buildings, 138, 432-442. DOI: 10.1016/j.enbuild.2016.12.049

[9]. Gaillard, L., Giroux-Julien, S., Ménézo, C., & Pabiou, H. (2014). Experimental evaluation of a naturally ventilated PV double-skin building envelope in real operating conditions. Solar Energy, 103, 223-241.DOI: 10.1016/j.solener.2014.02.018

[10]. Zhang, Y., Zhou, G., Lin, K., Zhang, Q., & Di, H. (2007). Application of latent heat thermal energy storage in buildings: State-of-the-art and outlook. Building and environment, 42(6), 2197-2209.DOI: 10.1016/j.buildenv.2006.07.023

[11]. Moretti, E., Belloni, E., Merli, F., Zinzi, M., & Buratti, C. (2019). Laboratory and pilot scale characterization of granular aerogel glazing systems. Energy and Buildings, 202, 109349. DOI: 10.1016/j.enbuild.2019.109349

[12]. Cuce, E., & Riffat, S. B. (2015). Aerogel-assisted support pillars for thermal performance enhancement of vacuum glazing: a CFD research for a commercial product. Arabian Journal for Science and Engineering, 40(8), 2233-2238.DOI: 10.1007/s13369-015-1727-5

[13]. Ghosh, A., & Norton, B. (2018). Advances in switchable and highly insulating autonomous (self-powered) glazing systems for adaptive low energy buildings. Renewable Energy, 126, 1003-1031.DOI: 10.1016/j.renene.2018.04.038

[14]. Hens, H. S. (2006). The vapor diffusion resistance and air permeance of masonry and roofing systems. Building and environment, 41(6), 745-755. DOI: 10.1016/j.buildenv.2005.03.004

[15]. Fantozzi, F., Galbiati, P., Leccese, F., Salvadori, G., & Rocca, M. (2014, November). Thermal analysis of the building envelope of lightweight temporary housing. In Journal of Physics: Conference Series (Vol. 547, No. 1, p. 012011). IOP Publishing. DOI: 10.1088/1742-6596/547/1/012011

[16]. Gagliano, A., Patania, F., Nocera, F., Ferlito, A., & Galesi, A. (2012). Thermal performance of ventilated roofs during summer period. Energy and Buildings, 49, 611-618.DOI: 10.1016/j.enbuild.2012.03.007

[17]. Castleton, H. F., Stovin, V., Beck, S. B., & Davison, J. B. (2010). Green roofs; building energy savings and the potential for retrofit. Energy and buildings, 42(10), 1582-1591.DOI: 10.1016/j.enbuild.2010.05.004

[18]. Berardi, U., & Naldi, M. (2017). The impact of the temperature dependent thermal conductivity of insulating materials on the effective building envelope performance. Energy and buildings, 144, 262-275.DOI: 10.1016/j.enbuild.2017.03.052

[19]. Ng, L. C., Persily, A. K., & Emmerich, S. J. (2015). IAQ and energy impacts of ventilation strategies and building envelope airtightness in a big box retail building. Building and Environment, 92, 627-634.DOI: 10.1016/j.buildenv.2015.05.038

[20]. Košir, M., Gostiša, T., & Kristl, Ž. (2018). Influence of architectural building envelope characteristics on energy performance in Central European climatic conditions. Journal of Building Engineering, 15, 278-288.DOI: 10.1016/j.jobe.2017.11.023

[21]. Charisi, S. (2017). The role of the building envelope in achieving nearly-zero energy buildings (nZEBs). Procedia Environmental Sciences, 38, 115-120.DOI: 10.1016/j.proenv.2017.03.092

[22]. Ahmad, A. (2004). Energy Simulation for A Typical House Built with Different Types of Masonry Building Materials. Arabian Journal for Science & Engineering (Springer Science & Business Media BV), 29.

[23]. Korniyenko, S. (2015). Evaluation of thermal performance of residential building envelope. Procedia Engineering, 117, 191-196.DOI: 10.1016/j.proeng.2015.08.140

[24]. Hachem-Vermette, C. (2018). Multistory building envelope: Creative design and enhanced performance. Solar Energy, 159, 710-721.DOI: 10.1016/j.solener.2017.11.012

[25]. Lam, J. C., Tsang, C. L., Li, D. H., & Cheung, S. O. (2005). Residential building envelope heat gain and cooling energy requirements. Energy, 30(7), 933-951.DOI: 10.1016/j.energy.2004.07.001

[26]. Chwieduk, D. A. (2009). Recommendation on modelling of solar energy incident on a building envelope. Renewable Energy, 34(3), 736-741.DOI: 10.1016/j.renene.2008.04.005

[27]. Robinson, C., Dilkina, B., Hubbs, J., Zhang, W., Guhathakurta, S., Brown, M. A., & Pendyala, R. M. (2017). Machine learning approaches for estimating commercial building energy consumption. Applied energy, 208, 889-904.DOI: 10.1016/j.apenergy.2017.09.060

[28]. Alaidroos, A., & Krarti, M. (2015, June). Impact of passive cooling strategies on energy consumption reduction of residential buildings in the Kingdom of Saudi Arabia. In Energy Sustainability (Vol. 56857, p. V002T17A002). American Society of Mechanical Engineers.DOI: 10.1115/ES2015-49128

[29]. Almusaed, A., Almssad, A., Homod, R. Z., & Yitmen, I. (2020). Environmental profile on building material passports for hot climates. Sustainability, 12(9), 3720.DOI: 10.3390/su12093720