تأثير الفراغ الشمسي على الأداء الحراري للمباني في المناطق الحارة والجافة: مدينة الرياض كحالة دراسية

وليد بن محمد أبانمي

قسم العمارة وعلوم البناء، كلية العمارة والتخطيط، بجامعة الملك سعود، المملكة العربية السعودية

abanomi@ksu.edu.sa

المستخلص. ستهلك المباني في مدينة الرياض، عاصمة المملكة العربية السعودية، كمية كبيرة من الطاقة خلال فترة الشتاء كأحمال كهربائية تستهلك لتدفئة الفراغات الداخلية بهدف الوصول لمستوى الراحة للمستخدمين. وبما أن مدينة الرياض تقع في مناخ حار وجاف، فهي تواجه صيفاً طويلاً وشتاءً قارصاً. وبسبب الصيف الطويل في المنطقة الوسطى، وبالتحديد مدينة الرياض، فإن أغلب البحوث المعمارية تركز على الدراسات والتصاميم البيئية التي تقلل من أحمال التبريد في المباني. وقليل ما نجد أبحاث ودراسات تهتم بترشيد استهلاك الطاقة المستخدمة في تدفئة الفراغات الداخلية. لذلك يقوم هذا البحث بدراسة مدى تأثير الفراغ الشمسي أو كما يعرف بـ (SUNSPACE) الملاصق للمبنى على الأداء الحراري للفراغات الداخلية في فصل الشتاء. ولتحقيق ذلك، تم بناء غرفتين متماثلتين كغرف اختبارية. وبعد ذلك تمت إضافة الفراغ الشمسي على أحد الغرفتين. وبواسطة استخدام أجهزة قياس لدرجات الحرارة والرطوبة النسبية داخل وخارج كلا الغرفتين، تم عمل مقارنة للأداء الحراري في الفراغين. وبعد تحليل النتائج، اتضح أن هناك تأثير فعال للفراغ الشمسي في زيادة الحرارة المكتسبة داخل الفراغ في الغرفة المعدلة خلال الساعات المتأخرة بالليل والصباح الباكر. نتائج هذا البحث سوف تساعد المصممين المعماريين والباحثين في تحسين الأداء الحراري للمباني في فصل الشتاء، ليس فقط في مدينة الرياض، بل في جميع مدن العالم، والتي تقع في مناخ حار وجاف.

الكلمات المفتاحية: التصميم البيئي، الفراغ الشمسي، الإشعاع الشمسي، التدفئة الطبيعية، الأبنية الخضراء.

building would considerably increase the indoor air temperature and relatively would reflect positively on energy efficiency. A comparison between savings and initial cost would depend entirely on the size and materials used in the Sunspace, which could be dealt in future research studies. As a result, Sunspace should be considered while designing new buildings and also can be added on existing buildings to minimize the energy that used to heat indoor spaces of buildings during winter seasons in hot arid regions.

Acknowledgments

This research cannot be done without the support and encouragement of the Department of Architectural and Building Science at King Saud University and Al Yamamah University.

References

- [1] **Shyamal, B.N.** (2004). *Rabindra Causality between energy consumption and economic growth in India: A note on conflicting results* *Energy Econ.* **26** pp: 977-983.
- [2] **Saidi, K. and Hammami, S.** (Nov. 2015). The impact of CO₂ emissions and economic growth on energy consumption in 58 countries (see link): <https://www.sciencedirect.com/science/article/pii/S235248471500013X>.
- [3] **Lean, H.H. and Smith, R.** (2009). CO₂ emissions, energy consumption and output in ASEAN. *Business and Economics, Development Research Unit Discussion Paper DEVDP* 09-13.
- [4] **Al-awaji, Saleh H.** (2002). Seventy per cent of energy consumption in buildings is used for air-conditioning. *Alriyadh (daily Arabic newspaper)*, Issue no. **12439**, 2002.
- [5] **Hashem, A. A. and Bakhsh, A. A.** (10 Mar. 2017). Energy Sources, Part B: Economics, *Planning, and Policy*, **12**(6).
- [6] **Goulding, John R., Owen, Lewis J. and Steemers, Theo C.** (1992). *Energy in Architecture: The European Passive Solar Handbook*. London: Batsford for the Commission of the European Communities.
- [7] **Asdrubali, F., Cotana, F., et al.** (2012). On the Evaluation of Solar Greenhouse Efficiency in Building. Simulation during the Heating Period. *Energies*, **5**: 1864-1880; doi: 10.3390/en5061864.
- [8] **Ulpiani, G., Giuliani, D., Romagnoli, A., et al.** (2017). Experimental monitoring of a sunspace applied to a NZEB mock-up: Assessing and comparing the energy benefits of different configurations, *Energy and Buildings*. (DIISM), 60131, Italy.
- [9] **AlHashlamun, Rifqa M.** (2017). Building envelope thermal upgrade: developing an approach to envelope retrofitting for government school buildings in Jordan. *M. Sc. thesis*, Jordan University of Sciences and Technology.
- [10] **Wood, B. and Muncaster, M.** (2012). Adapting from glorious past to uncertain future. *Structural Survey*, **30** (3): 2019-231.
- [11] **Anderson, B.** (1990). *Solar Building Architecture*. The MIT Press.
- [12] **Chalfoun, N.** (2000). Computer energy analysis 2. *House Energy Doctor Program*. University of Arizona. USA.
- [13] **Department of Energy Office of Energy Efficiency and Renewable Energy U.S. Sunrooms and Sunspaces**; November, (1994). DOE/CH10093-350 FS 124. (See link) <https://www.energy.gov/energysaver/sunrooms-and-sunspaces>.
- [14] **Givoni, B.** (1994). *Passive and Low Energy Cooling of Buildings*. New York: John Wiley.
- [15] **Yannas, S.** (1994). *Design of Educational Buildings-Primer*. London: Environment and Energy Studies Programme, Architectural Association Graduate School on behalf of the Commission of the European Communities, Directorate General XII for Science, Research and Development, Renewable Energies Unit.
- [16] **Steven, W. A.** (1998). *The Passive Solar Design and Construction Handbook*, in Crosbie, Michael J. (ed.) New York: Wiley.
- [17] **Abdel-Ghany, A. M., Al-Helal, I. M. and Shady, M. R.** (2014). Evaluation of human thermal comfort and heat stress in an outdoor urban setting in summer under arid climatic conditions, Vol. 40 No.3 DOI: 10.5277/EPE140311. (See link): https://www.researchgate.net/publication/286216179_Evaluation_of_human_thermal_comfort_and_heat_stress_in_an_outdoor_urban_setting_in_summer_under_arid_climatic_conditions.
- [18] **Konya, A.** (1980). *Design Primer for Hot Climates*. London: Architectural Press. Lechner,
- [19] **The Energy and Resources Institute (TERI)** (2018). https://www.livemint.com/Money/VOU7s47bJreraISic_a0J/Running-your-AC-at-27C-vs-18C-can-cut-your-electricity-bil.html. New Delhi India.

Fig. 11. Comparison in Air Temperature between Base Case and Modified Case.

Fig. 12. Comparison in Relative Humidity between Base Case and Modified Case.

10. Conclusion

Sunspace is a passive solar design strategy that improves the thermal performance of indoor spaces. This research conducted field experiments to assess the effectiveness of using sunspace to improve the indoor environment during winter time. Two identical rooms were built to conduct this research. The sunspace was installed on the southern window of room No. 2 which was called the modified case. Data loggers were placed inside and outside the experimental

rooms. The findings of the research show that there is a potential for installing sunspace attached to the southern window of the modified case. The air temperature inside the modified case which has the sunspace was higher than the base case when the outside air temperature dropped. The difference reached 1°C during night and early morning hours. There is significantly up to 6% of energy savings produced for every 1°C decrease change in temperature^[19]. Relative to this, the more area that sunspace would be used in a

increase the indoor air temperature in the modified case during night and early morning.

The results also, show that the relative humidity (RH) was slightly increased inside the modified space. The average RH inside the room with the Sunspace is higher by 1 to 7% during the day. However, the RH inside the base case was slightly higher by 1 to 4% during night and early morning, (Fig. 12).

The Energy and Resources Institute (TERI) ^[19] states that there are saving up to 6% from the energy for every 1°C. However,

care should be given to the design of the Sunspace in order to maximize the benefits of using it. The glazed area of the Sunspace should be covered by insulators such as shutters that can be closed manually or mechanically to protect the Sunspace from the cold air by night and early morning hours in winter seasons. In addition, the Sunspace should be opened during summer for air circulation, because the Sunspace traps the heat summer if it is closed which will increase the cooling load inside the building.

Fig. 9. Calibration in Air Temperature among Base Case, Modified Case and Outdoor.

Fig. 10. Calibration in Relative Humidity between Base Case and Modified Case.

which could lead to sick building syndrome symptoms ^[17]. Asdrubali and other ^[7] conducted an experimental research by doing simulation to a flat with an attached Sunspace. Their results show that the average reduction of the winter energy demand due to the greenhouse are about 20%.

However, Yannas ^[15] argues that Sunspace design needs considerable effort. Sunspace can have a negative effect on the building during overheated periods of the year, if it is not protected from direct solar radiation. Thus, the glazed area of the Sunspace should be protected and opened with natural ventilation during summer time. Using movable shading devices, such as plastic roller shades attached directly to the outside of the collector, or placing vegetation, such as deciduous trees near the Sunspace, can protect the collector from intense solar heat gain during summer ^[18]. In summer, glazed doors should be opened all the time with natural ventilation in order to use the space as a semi-outdoor space. In addition, the glazed areas of the sunspace should be protected by the shelters during the night and early morning hours during winter time to save the warm air inside the sunspace in order to maximize the potential of its performance. These shelters can be opened and closed mechanically or manually.

8. Field Experiment

To achieve the main goals of this research field experiments were conducted. Two identical experimental rooms were built by the researcher to fulfill the research requirements. All of them have identical design, orientation, construction methods and materials. Air temperature, globe temperatures and relative humidity measurement devices will be used inside and outside the case studies to assess their thermal performance while windows were closed. The experiment will go through two stages; First stage is monitoring

the thermal behavior of the two rooms without modification for 30 hours to ensure the similarity in their conditions. Stage two is monitoring the two case studies while sunspace is added on one of them while windows were closed. Both rooms will be monitored for eighteen days, (from 29th of December to 15th of January); when the air temperature reach almost the minimum in the region of Riyadh, Saudi Arabia.

The calibration results show that the thermal performance of both rooms were very close. The differences in the measured air temperature ranged about 0.05°C to 0.6°C. The maximum difference reached 0.6 °C at 5pm. The air temperature inside the base case room at 5pm was higher than the modified case room by 0.6°C, and the air temperature inside the base case room at 7am was higher than the modified case room by 0.05°C at 7am (Fig. 9). The differences in the relative humidity inside the experimental rooms were also low. The differences in RH between the base case and the modified case ranged between -2.6 % to 4.4 %, (Fig. 10). These differences in thermal performance between the two experimental rooms will be considered in the analysis of the collected data onto the Sunspace.

9. Findings

The comparison of the thermal performance between base case and the modified space shows that the indoor air temperature was increased from the room with the Sunspace during night and early morning by 1°C, if the results of the calibration are considered, (Fig. 11). In addition there is no significant difference in the air temperature between the two rooms during afternoon. Because the Sunspace works as an insulator, it reduces the direct solar radiation. However, the Sunspace traps the warm air inside it and gradually transferred into the spaces which

Fig. 8. Gemini Tinytag Ultra used to measure the external temperature. Photo by the Author.

7. Literature Review

Sunspaces is a valuable tool that acts as passive solar heating elements, which is one of the sustainable and energy-efficient constructive and/or retrofitting strategies [8]. Passive solar design strategies became essential in the built environment design due to the huge energy consumption used to heat and to cold buildings. AlHashlamun [9], Wood and Muncaster [10], state that a huge number of buildings in developed countries do not meet the standards for today and tomorrow, and the number of these buildings is higher in developing countries. As a result environmental design strategies should be involved in new buildings design and in existing buildings if possible. These design strategies are integrated and there are no rule-of-thumb for all buildings. The design parameters should be chosen based on the location and the type of building usage [11].

Air Exchange Subsystem which can be achieved by Sunspace is a combined concept between direct and indirect heat gain [6]. Ulpiani, *et al.* [8] state that “Sunspaces are conceived for the heating season as they capture the maximum sunlight coming in through the glazed surface, which is transparent to the visible wavelengths and opaque to the NIR's, causing the internal air and wall surfaces to increase their temperatures”. It can provide warmth, light, aesthetics, and a healthy environment for

plants and people [12]. A Sunspace or conservatory is an enclosed glazed space attached to one of the building's external walls and windows to trap direct and indirect solar radiation.

Department of Energy Office of Energy Efficiency and Renewable Energy [13] claims that “Conservatories, (Sunspaces), provide a useful physical thermal and visual buffer space between the internal and the external environment”. Sunspaces are commonly located on the south façade of buildings and connected to the main activity rooms. Because southern windows are ideal to gain heat during winter season and easily can be protected during summer season [14]. For orientation and glazing, ideally, Sunspace should face 30 degrees east or west of due south as it will deliver about 90% of the maximum fixed solar collection potential [13].

Yannas [15], believes that “The possible architectural functions of a conservatory in educational buildings are as a circulation space, entrance hall or as seasonal extension of classroom space”. To optimize the effectiveness of the Sunspace, there should be a thermal mass wall as a partition between the Sunspace and the adjacent interior space of the building [16]. The thermal mass wall inside the Sunspace can absorb and store heat during the day and re-emit it during the night. Installing a small fan could also advance the air circulation from the Sunspace to the adjacent room.

Sunspaces can be an effective design strategy in building design during both summer and winter to achieve the thermal comfort for users. Human thermal comfort is defined as the condition of mind which expresses satisfaction with the surrounding environment, and because of the harsh winter season in Saudi Arabia, people tends to feel the discomfort sensations and usually cold stress which reduces productivity of a person

Fig. 3. The two identical rooms are ready to be monitored for comparison. Photo by the Author.

Fig. 4. Data logger inside room1. Photo by Author.

Fig. 5. Data logger inside room 2. Photo by Author.

Fig. 6. The data logger placed outside between the two experimental rooms. Photo by Author.

Fig. 7. The sunspace was attached to the room No. 2 as a modified case. Photo by Author.

design as one of the environmental design strategies.

2- Field experiments: Two identical experimental rooms will be built by the researcher to fulfill the research requirements. All the case studies will have identical design, orientation, construction methods and materials as shown in Fig. 1, 2 and 3. Both rooms were built by concrete blocks of 20cms.thick with reinforced concrete columns and slabs. They were also finished with 2cm thick plaster to match the real construction materials and methods used in Saudi Arabia. Each room has a southern 1 m^2 window. Air temperature, globe temperatures and relative humidity measurement devices will be used inside and outside the case studies to assess their thermal performance (Fig. 4, 5 and 6).

The experiment will go through two stages; First stage is monitoring the thermal behavior of the two rooms without modification for 30 hours to ensure the similarity in their conditions. Stage two is monitoring the two case studies while sunspace is added on one of them (Fig. 7). The sunspace performance was monitored during winter season which was from the end of December until the middle of January, when the air temperature almost reached the minimum in the region of Riyadh, Saudi Arabia.

6. Equipment

A number of Gemini tiny data loggers called Tinytag Ultra loggers were used for the experiment. They were used to assess outdoor air temperature, indoor air temperature and humidity. Gemini Tinytag Ultra logger is a small, lightweight, self-contained device with memory of 1800 readings which has a logging rate of 1 sec to 10 days with min, max and actual readings and up to 5 years battery life. They all are also battery powered (Fig. 8).

The Gemini Tinytag Ultra loggers were launched on a personal computer using Gemini Logger Manager (GLM) software. Gemini

Logger Manager (GLM) Software was also used to set the loggers up to start logging and to download data from them after they were collected from the experiment. The downloaded data was viewed, saved, printed, copied to the clipboard and exported to Excel software to translate it into tables and charts.

Fig. 1. Plans, sections and elevations of the test rooms. By the Author.

Fig. 2. The two experimental rooms during the construction. Photo by the Author.

This research addressing the Sunspace as one of the passive solar design strategies, that can be installed to enhance the indoor environment during winter time. Sunspace is an air exchange subsystem, which is a combined concept between direct and indirect heat gain ^[6]. Sunspace traps the heat and stores it in a glazed enclosure in order to transfer the heat on indoor spaces through mass walls and windows especially during night and early morning hours. The investigation into this research will assess the thermal performance of the Sunspace during winter time in Riyadh city, the capital city of the Kingdom of Saudi Arabia. Field experimental works followed by data analysis were conducted to achieve the main goals of this research. The finding of this research will demonstrate design guidelines and recommendations that can be used during the early stages of buildings' designs or can be applied on existing buildings in order to improve their thermal performance.

2. Research Problem

Energy is consumed to warm indoor spaces in buildings that are located in Riyadh city. Due its long summer season most of the architectural research in Saudi Arabia focuses on cooling design strategies. Little effort has been done in research studies that are addressing the heating load conservation in buildings. As a result, the field of architecture in Saudi Arabia needed to implement design guidelines and recommendation to save energy that is used to increase indoor air temperature during winter time. This research will show some of the recommendations and design guidelines for designers to improve the thermal performance of buildings during winter season.

4. Research Objectives

1- To evaluate the thermal performance of the Sunspace during winter time in Riyadh, Saudi Arabia.

2- To demonstrate design guidelines and recommendations in order to reduce heating loads inside buildings, that are located in hot, arid climates in general and for the Riyadh region in particular.

3. Research Significance

During the rapid economic improvements in Saudi Arabia after the large-scale production of oil in the early 1960s, environmental design principles and saving energy were not on the buildings' design agenda. Nowadays, adopting environmental design strategies in the buildings' design is mandatory. However, attention was given to the environmental design research for cooling, as Riyadh experiences long summer weather. This research intends to fill the gap between researches because little effort was made to address the environmental design strategy that conserves heating loads in buildings located in Riyadh.

Sunspace is one of the passive solar design strategies that could increase indoor air temperature and therefore, can reduce the heating loads. A Sunspace is a closed, southbound volume, built by transparent surfaces, adjacent to a building, which reduces winter energy demand by utilizing the solar heat ^[7]. This research attempts to contribute to the knowledge of environmental design of buildings in hot, arid regions in general and in the Riyadh region in particular.

5. Research Methodology

The investigation into the research problem, justification, conclusions and findings has been achieved by two methods, which are: Literature review and field experiments.

1- Literature review: The theoretical foundation for this research has been obtained by a literature review related to Sunspace

The Effect of Sunspace on Thermal Performance of Buildings in Hot and Dry Regions, Riyadh City as a Case Study

Waleed M. Abanomi

Department of Architecture and Building Sciences, College of Architecture and Planning, King Saud University, Riyadh, Saudi Arabia

abanomi@ksu.edu.sa

Abstract. Due to the long summer season in Riyadh, most of the research activities in Saudi Arabia were dedicated to environmental design strategies for cooling. Little efforts have been done in research studies that are addressing the heating load design conservation in buildings. The Sunspace is one of the environmental design strategies that can be used to increase the indoor air temperature of the attached spaces during winter season. This research will evaluate the effectiveness of the Sunspace on the thermal performance of the indoor spaces in buildings located in Riyadh City. Two identical experimental rooms were built to achieve a comparison between base case room and the modified room that had an attached Sunspaces. Thermal assessment devices had been used to record the air temperature and relative humidity inside the two rooms and outside environment during winter time. The Sunspace was able to increase the indoor air temperature and early morning hours. The findings of this research illustrate the effectiveness of Sunspace to increase the indoor air temperature inside the buildings. The results of this research can be applied to all buildings in Riyadh City and in all buildings located in hot arid region.

Keywords: Environmental design, Sunspace, Solar radiation, Passive solar, Green buildings.

1. Introduction

Energy conservation became a worldwide concern especially nowadays due the huge negative impact on carbon dioxide emissions. A decomposition method used by Shyamal and Rabindra ^[1] shows that emissions of CO₂ in the industrial sector shows a decreasing trend due to an improved energy efficiency ^[2]. Research study by Lean and Smith ^[3] indicates a statistically significant positive association between energy consumption and emissions. Grounded by a dynamic panel data from 1990 to 2012, result shows that the effect of economic growth on energy use is positive and statistically significant worldwide. It implies that economic growth, CO₂ emissions and

energy consumption corresponds with each other.

Buildings in Saudi Arabia are consuming about seventy percent (70%) of the generated energy ^[4]. As a result care should be given to buildings' design to minimize the energy consumption that is used to heat and cold interior spaces. Winter season in an arid climate place like Saudi Arabia consumes up to 35%, which is used for Heating Systems. Prolonged use of Heating Systems during winter season particularly could cause a noticeable rise in the energy bill. The use of Sunspace however becomes an energy efficient solution as one of its function is a source of auxiliary heat which classifies the importance of the subject ^[5].