The Effect of Atrium on the Thermal Comfort in Buildings in Hot Arid Zones

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Abstract

The atrium is an open interior space that may be linked to the external environment; it is becoming more and more popular and a key element in the architectural design of many buildings, due to its attractive and symbolic aesthetic characteristics for the public. It is a filter against unwanted external environmental phenomena such as rain, snow and wind. A well-designed atrium can contribute towards having a significant effect on the indoor environment, affecting the comfort of the occupants. However, in certain hot and arid regions such as the city of Laghouat in the south of Algeria characterized by a scalding and dry summer, and cold winter, these fully enclosed atrium spaces with their untouched typological and architectural diversity, and due to lack of a good renewal of the indoor air, can cause considerable thermal discomfort to the occupants of space, and thermal stratification inside, especially in summer. The present work studies the impact of the atrium configuration on the inside thermal environment, for summers and winter periods, and to provide a sufficient air renewal within the atrium to ensure good air quality. As a result, a rectangular, fully enclosed, unventilated central atrium building was examined with its adjacent spaces, by a series of field measurements to study two geometric factors that have a considerable impact on the interior thermal comfort, the height width ratio (SAR Index) and the glazed coverage ratio. The impact of SAR index and glazed area ratio on thermal comfort and stratification of the air in summer and winter period were also examined.

Keywords: Atrium configuration; Thermal comfort; Air stratification; SAR index; Hot and arid climate

1 Introduction

The basic requirement for a building is to provide shelter from the environment and the weather. Although buildings are not just structures, they house occupants who must be comfortable and healthy in the intended environment. The architectural solutions adopted in modern buildings were the integration of the atrium, especially in regions with a temperate climate; this architectural form is generally defined as a large open glazed space in a multi-tiered building. Large glassed surfaces can lead to excessive solar heat gain in summer, heat loss in winter, and air stratification, especially in summer, which can affect the building user's comfort and energy performance. Many recent studies that deal with the role of atrium geometry in energy consumption were done by a group of researchers (Wang, Huang, Zhang, Xu, & Yuen, 2017; Shafqat, 2012; Moosavi, Mahyuddin, Ghafar, & Ismail, 2014; Pichatwatana & Wang, 2013). The studies aim to investigate how the geometry of the atrium affects the indoor thermal, lighting and natural ventilation. The present work studies the impact of atrium configuration on the internal thermal environment, for summers and winter periods by field measurements of the indoor temperature distributions, in order to study two geometric factors, which have a considerable impact on the interior thermal comfort namely: the height/width ratio (SAR Index) and the glazed coverage ratio.

2 Presentation of the Study Case

In order to better concretize the expected objective of this research, a building with an atrium, was taken as a case study in our investigation, the studied building located in the western part of Laghouat city with an average altitude of 750 meters, latitude 33°46'N and longitude 2°56'E; it has a hot dry climate. Figure 1 presents the annual minimum-maximum temperature and Figure 2 presents the mean monthly insolation hours recorded from 2006-2015.

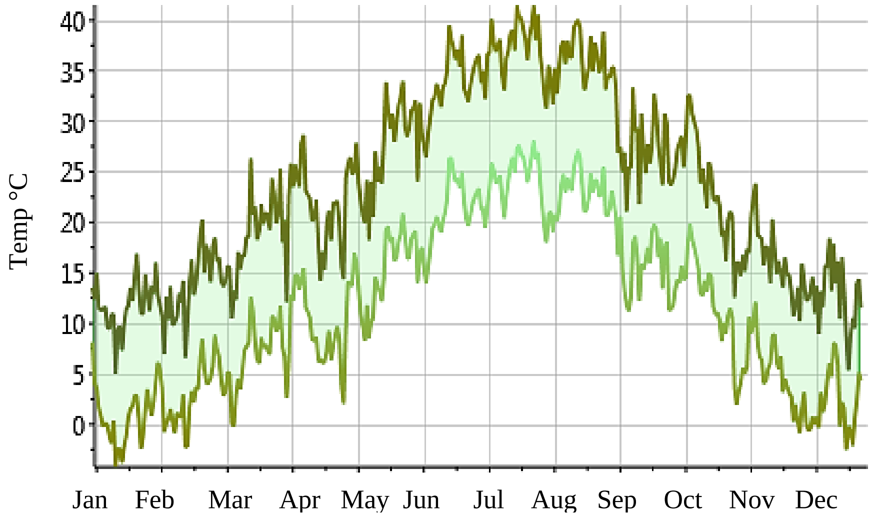


Fig. 1: Annual min and max temperature

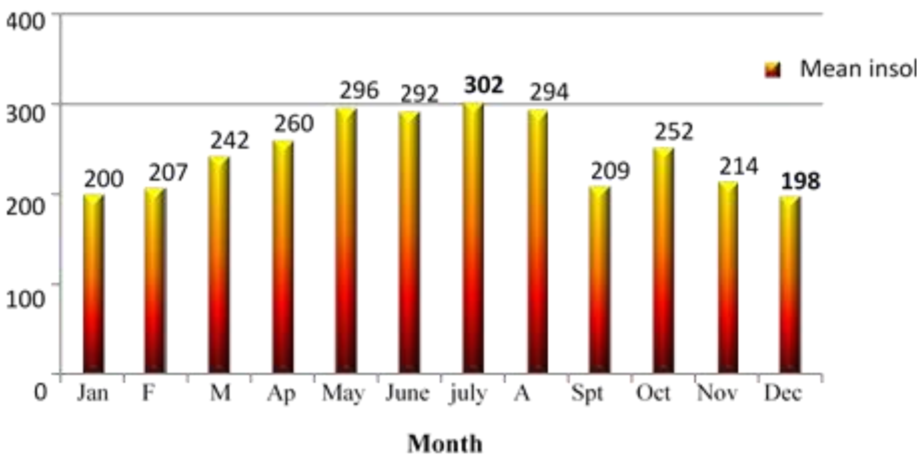


Fig. 2: Mean monthly insolation hours (2006-2015)

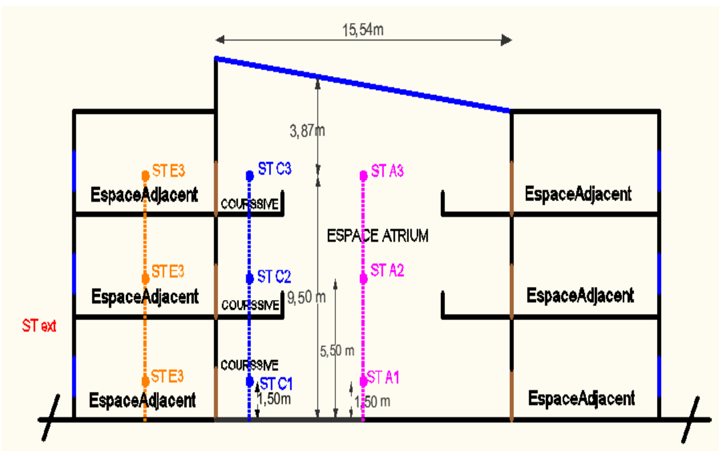
The studied building has two interior patios and a central atrium preceded by an entrance hall. The atrium represents a multifunctional, unifying, important gathering space, and can be used even as an exhibition and display space. It is rectangular in shape, naturally lit only from above by a huge canopy inclined at 10° to the south, covers the atrium roof without any solar protection, or openings. Rising along the levels of the building, this atrium is surrounded by corridors serving the adjacent spaces (classrooms), which are designed to receive natural light from the atrium through non-opening glazed transoms in their adjacent walls. The atrium space has an area of 141.96 m^2 and a volume of 1868.19

m^3; see Figure 3 shows plan Vue, the atrium and the atrium glazed cover.

Fig. 3: View of atrium space

3 Results and Discussions

The first measurement campaign was carried out during the winter period, February for four days separately (the 12, 13, 19, and 26), in weekend days in order to eliminate the heating, and the users heat gain, which help in estimating the level of the passive heating by atrium. The second measurement campaign was carried out during the summer period in July for a duration of 4 successive days (10, 11, 12, and 13), knowing that the building was also not occupied. The measurements were taken at 13 points, 12 distributed vertically over the three levels of the building and the 13th point was outside the building; see Figure 4, the measurements were limited to the period of occupation by users, from 8.00 a.m. to 5.00 p.m. at a height of 1.50m.



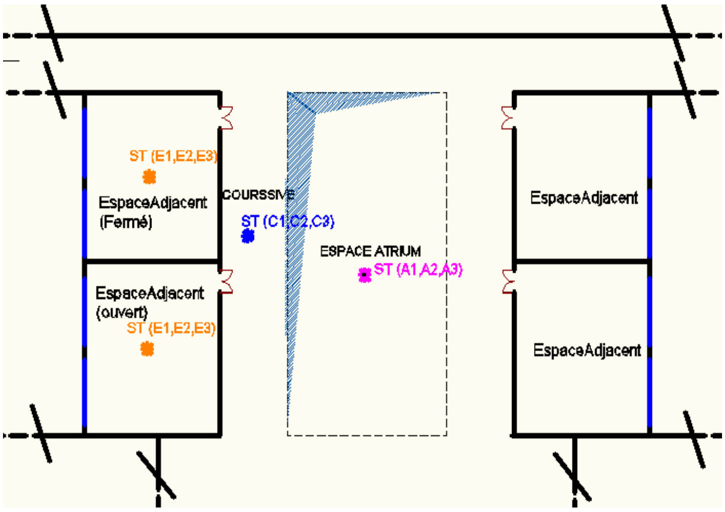


Fig. 4: Measurements points

3.1 Summer Period

The day of 11th July was a hot summer day, sunny with clear skies, characterized by an average wind speed of 2.5m/s, and an average temperature equal to 33°C, with a maximum of 41°C and a minimum temperature of 30°C. As previously mentioned, this measurement campaign was carried out in the raw internal conditions of the building (without internal gains) in order to better experience the almost raw thermal behaviour of the atrium.

Indoor air temperatures in the atrium space, in global reading and the results given by the graphs in Figure 5 show that the profiles of the air temperatures measured inside the atrium take the same shape with the outside air temperatures. Similarly, we can see a gradual evolution of the interior temperatures for the first hours of the morning (sunrise) to reach its maximum during the afternoon time slot, and falling slightly for the last hours of the afternoon (towards sunset), obviously this variation in temperature corresponds to the degree of intensity of the solar radiation received by the atrium glass roof. We can thus see that the temperature always exceeds those recorded in the various points of the measurements in the atrium, by recording a heat peak equal to 42.1°C at 3:00 p.m. for the outdoor temperature measured on-site. Similarly, a peak of 33.6°C is recorded at the same time in the ground floor with the lowest thermal zone, while the other peaks (1st and 2nd floor) are recorded after one hour, respectively, 34.8°C and 37°C. This phase shift is strongly influenced by the thermal capacity of the building envelope. A temperature difference of 4°C at 4:00 p.m., between the lower and the upper level confirms that the upper zone which is exposed to the higher solar intensity gets the higher air temperature, and that in the total absence of natural ventilation, in the roof, the warm air will not be able to escape to the outside and will remain trapped in the upper part creating this amplification. According to Figure 5, which illustrates the indoor temperatures measured in the atrium in relation to the thermal comfort zone calculated for the month of July by the Humphrey formula, hence, according to (Humphreys & Fergus, 2002), temperature of 28.4°C is higher than the limits of the comfort zone particularly for the 2nd floor during all the hours of occupation. On the other hand, the air temperatures on the ground floor are located within the limits of the comfort zone, only for the 8:00 to 12:00 a.m. time slot, in a temperature range of 26.6°C and 30.4°C, and for the first floor in a range of 29.9°C and 30.4°C from 8:00 to 9:00 a.m. It expresses a situation of discomfort generally felt inside the atrium.

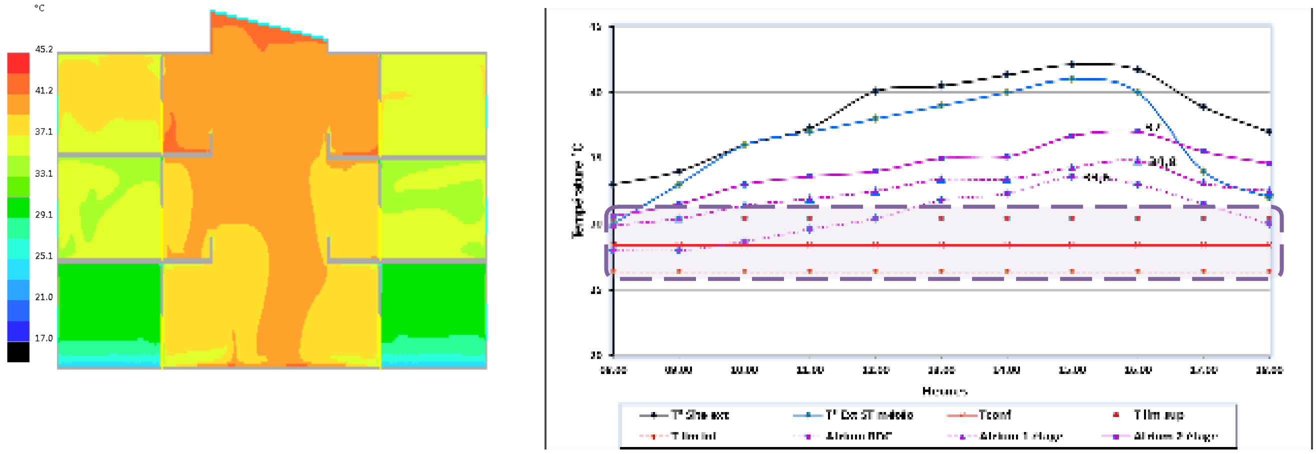


Fig. 5: Summer: The indoor temperatures compared to the adaptive thermal comfort

Analysis of thermal stratification in the middle of the atrium, the graphs shown in Figure 6 present the vertical thermal profiles of the air temperatures recorded in the middle of the atrium for the different hours of the day corresponding to the different intensities of solar radiation during the building occupancy schedule. From the profiles in Figure 6, we can see that there are three types of profiles in accordance with the profiles cited by Heller:

1. Non-linear profile for the first hours of the morning, where the temperature decreases slightly at the upper level. The low intensity of solar radiation and the low temperature levels during the morning are the factors responsible for the cooling of the area under the glass roof.

2. Non-linear profile, increasing in the upper level for the afternoon hours, especially at 3:00 p.m. This is the frequent case of a stratification produced at a high level inside the atrium, where the heat sources are distributed only in the upper part (Miray Gemi, 2006). This is strongly influenced by the high intensity of solar radiation.

3. Profile of a linear increase, from 1:00 p.m. to 2:00 p.m., when the sun is at its zenith, and at the last hours of occupation (4:00, 5:00 and 6:00 p.m.). This is the typical case in atriums where the heat sources are uniformly distributed in the space and its surfaces (Gemi, 2006).

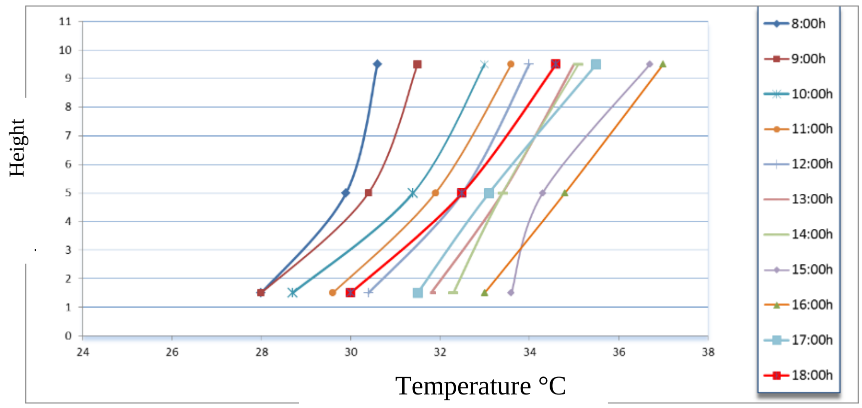


Fig. 6: The vertical thermal profiles of air temperatures recorded in center of the atrium for different hours of the day

3.2 Winter Period

A second measurement campaign was carried out in winter period, in order to complete the atrium thermal behaviour evaluation. A representative day was taken for the analysis; this day takes a drop in air temperature of an average of 12°C, and a wind speed of 5 m/s. A partly cloudy sky during the morning hours before noon and from the afternoon onwards the scenario changes and the sky becomes clear and uncluttered.

From the curves in Figure 7, the temperatures measured at the different points in different levels of the atrium maintain the same profile and follow the same pattern as the outside air temperatures, with very small differences between them. It can also be seen that the temperatures recorded indoors are generally higher than those outside, revealing the strong influence of the weather conditions outside in terms of sky coverage, so that the highest values are recorded during the afternoon time slot, which coincides with the clearing of the sky after being cloudy, recording almost equal peaks on the ground, first and second floors, i.e. 15.8°C, 16.1°C and 16.5°C at 5:00 p.m., respectively. This rise in temperature is close to the lower limit of the comfort temperature “15.7°C,” only in the afternoon hours from 02:00 to 04:00 p.m., and finally in the comfort zone during the peak heat hour (05:00 p.m.), recording temperatures equal to: 15.8°C, 16.10°C and 16.5°C on the ground floor, first floor and top floor, respectively. Therefore, we can say that the comfort situation during the winter period is strongly influenced by the state of the sky and the solar radiation.

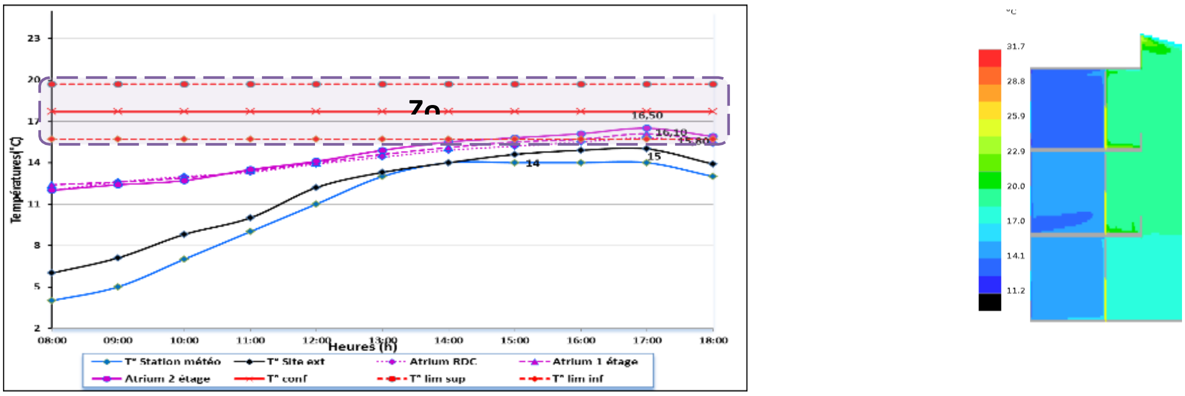


Fig. 7: Winter: The temperatures measured at different points on the different level

Analysis of thermal stratification in the middle of the atrium, from the vertical thermal gradient profiles that show the vertical interior temperature distributions in the atrium (Figure 8), here the space is weakly stratified, with moderate temperature gradients. Although there are profiles that conform to the three types of Heller profiles.

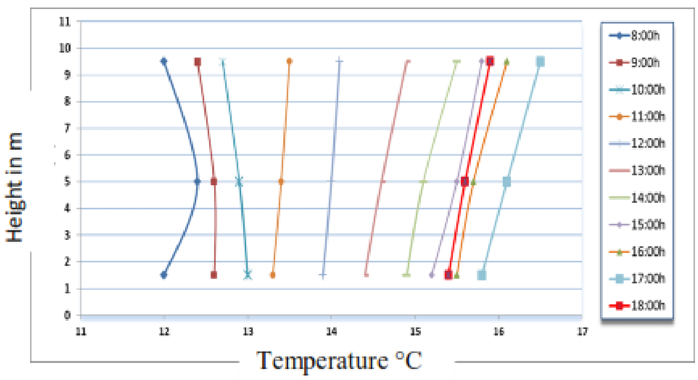


Fig. 8: The vertical thermal profiles of air temperatures recorded in center of the atrium for different hours of the day

4 Conclusion

The analysis of the results obtained from the investigation shows that the measured temperatures in the atrium type in question remained outside the comfort zone for the summer period in the presence of a well-illustrated stratification. As it has considerably influenced the corridors surrounding it. On the other hand, the temperatures in the adjacent spaces showed a more or less destabilizing influence due to many of the factors already mentioned, the most influential ones in our case being: the exchange of ventilation between the atrium and the adjacent space, the wall glazing separating the atrium from its adjacent space and its opening, which did not exist in our case, as well as the presence of the adjacent walls exposed to the external conditions.

For the thermal behavior of the atrium and its adjacent spaces, we were able to observe that in winter, the atrium in question can be heated passively by freely admitting solar rays to the interior through the glazed cover, while depending on the external climatic conditions (mainly cloudiness of the sky), and on surface area of the atrium in relation to the total surface of the building. Nevertheless, the indoor temperature of the adjacent spaces will be influenced by several parameters, mainly by the direct gains absorbed through the external walls (opening or closing of external windows, spaces located on the top floor), the type of the atrium itself, such as the characteristics of the adjacent wall of the atrium, its glazed surface and its degree of opening. Therefore, we can say that the atrium can be considered as a passive strategy in winter, achieving relative comfort, but its influence on the adjacent spaces will remain conditioned by several parameters mentioned above.

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