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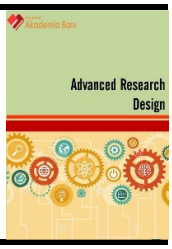

Microclimatic performance of courtyard residential buildings in Kafanchan-Nigeria

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ABSTRACT

The Climatic performance of courtyard residential buildings needs to be investigated if the assertion that courtyard is a microclimate modifier is to be accepted. Therefore, this study seeks to examine the microclimatic performance of two existing courtyard residential buildings with similar characteristics in Kafanchan-Kaduna Nigeria, -the fully enclosed courtyard residential building and the semi-enclosed courtyard residential building. The purpose of this research is to investigate their microclimatic performances in other to establish the best courtyard house. This study uses measurement to achieve its aim. The tool employed for data collection is the Hobo Weather Data Loggers (HWDL). Three HWDL were used to collect data in the two case-study, and the third one was placed in the outside area as a benchmark. Only air temperature and relative humidity were measured. This study revealed a tangible difference in the microclimatic performance of the two case-study. The fully enclosed courtyard residential building is seen to have air temperature difference of 1 oC to 3 oC, and the relative humidity difference of 4 % to 8 %. In conclusion, the fully enclosed courtyard house demonstrated a more favorable microclimatic performance than the semi-enclosed, and further simulation studies towards its optimization are required.

1. Introduction

The architectural design of buildings that ensure the thermal comfort of occupants could be attained through a proper awareness of the climate, built environment, and the human response to physiological conditions [1]. For example, in the northerly portion of the Nigerian states, the climate is made up of a long dry period accompanying with the cold and dry wind, high air temperature and high radiation. The climatic conditions demand architectural design schemes that depend on passive rather than active strategies for climate-responsive buildings.

Of course, Passive Architectural Design Strategies (PADS) may be one of the approaches towards the attainment of buildings with favorable microclimatic conditions in this generation where

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modernism and civilization seem to be making more emphasis on the actives means [2]. According to Olutoa [3], energy-efficient architectural design approaches towards achieving sustainable residential housing in Nigeria is very paramount.

Studies in PADS have stressed that the courtyard is an excellent architectural design element, and its microclimatic impact on the building microclimatic behavior should be explored [4-6]. Also stressing that the courtyard has a lot of advantages and that it is passive [7-11]. Correspondingly, studies have also shown that the courtyard microclimatic adapting ability should be understood explicitly.

Consequently, for the courtyard to do its microclimatic modifying task, that is, enhancing cooling in buildings, additional examination effort in the direction of understanding its microclimatic influence on the indoor thermal performance is required. Even though investigational studies on the microclimatic performance of the fully enclosed courtyard residential building and the semi-enclosed courtyard residential building seems to be scarce, the reality that the Courtyard is a passive design component need to be proved. As a result, this research is to explore the microclimate performance of a fully enclosed courtyard residential building and a semi-enclosed courtyard residential building. The prime objective is to make a contrast between their performances and make conclusions on the utmost favorable case study. This research used the measurement approach. Three (3) Hobo Weather Data Loggers (HWDL) were employed. The distinctiveness of this study lies in the examination of air temperature and relative humidity as the studied variables which have not been considered before in a courtyard study in Nigeria.

2. Literature Review

A good knowledge of the procedures and forces that conclusively impact the microclimatic performance of the courtyard residential buildings is very important. Despite the research efforts by academics to deeply investigate on the courtyard house, most have acknowledged the religion of Islam as the main cause behind the conception of the courtyard form [12-16]. It is obvious that privacy is supposed to have been the main influence on the formation of the courtyard in residential buildings in the Arab World. The courtyard became one of the most important spaces [17].

The fact that the courtyard evolved due to other factors is overlooked by many opinions which place a strong accent on just the sole concept of attaining religious requirements. Even though the use of courtyard in residential building has been assign to Islamic architecture, according to Rapoport [18], "Courtyard houses, and separation of domains in general, are used in cultures which are both crowded and hierarchy." Also, Rapoport [19] stated that the courtyard has been used all through the olden times of architecture and is established as a common design component in several places around the sphere of human existence, including civilizations, for instance, the Indus Valley (5,000 B.P.), ancient Greece and Rome, and Mesopotamia. The palace at Mari is a most prominent instance where the courtyard is celebrated in the Mesopotamian architecture.

In Nigeria however, Adeyemi [20] stressed that the courtyard is an ancient element that has numerous benefits such as; sleeping, children playing area, area for keeping animals, cooking area, and family meeting area. He continued that the courtyard is a symbol of African traditional Architecture, and concluded that the courtyard can be a climatic component of the house. In this view, therefore, the climatic aspect of the courtyard should be taken into consideration. Just as Fathy [21] rightly stated, "Dwellings are built to serve a variety of functions, but one of the most important is to create living conditions that are acceptable to their occupiers, particularly in relation to the prevailing climates." Consequently, indigenous architectural design component such as the courtyard cropped up as a result of unfavorable climatic situations that forced architects of olden days to

proffer solutions for thermal requirements [22]. It can then be easily concluded that climate was foremost in the conceptualization of the courtyard in residential buildings and its microclimatic benefits in buildings cannot be overemphasized [8-11, 23].

2.2 The Study Area

The city of Kafanchan consists of a settlement of people with basically two religion –Christianity and Islam. The inhabitants have accepted the courtyard house due to their cultural, religious and climatic needs. Kafanchan is located in the Southern region of North Central Nigeria. It is in latitude. 9° 35'N and long. 8° 17'E, a land area of 32 km^2. Its population is 30,407 [24]. The area has a tropical winter and summer seasons which are common of a tropical climate. The winter season commences from the month of April and ends in October, whereas the summer season commences in November and ends in the month of April. The quantity of yearly rainfall collected is between 1140 mm to 1204 mm. Kafanchan has the annual average air temperatures of 36.4°C [24]. The city is well-known for its huge amounts of fuelwood [25].

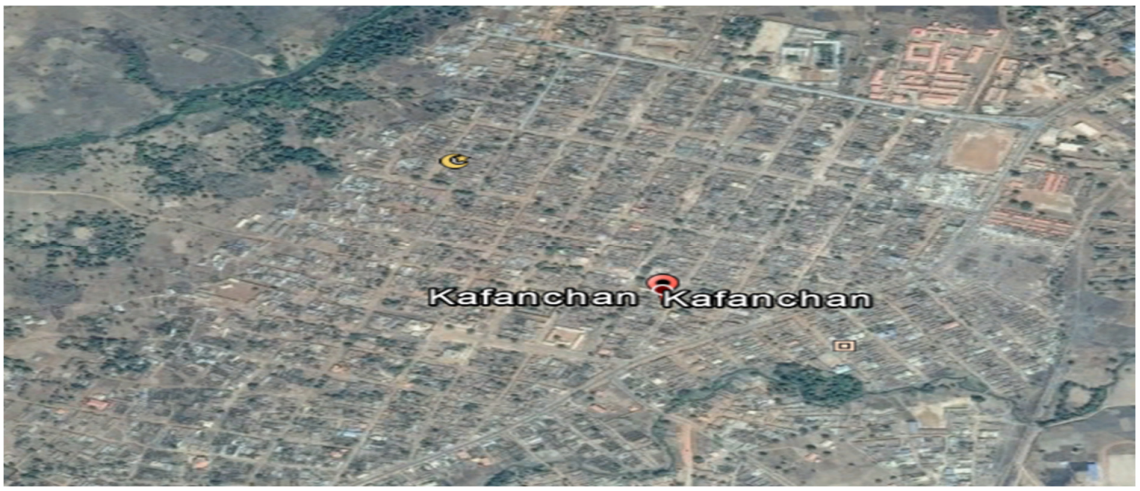

Fig. 1. Image of Kafanchan showing the Physical Planning

3.1 Methodology

The research approach of this study adopted [26] methodology with some few adjustment such as calibration of the tools used in the experimental. Figure 2 explains the research processes.

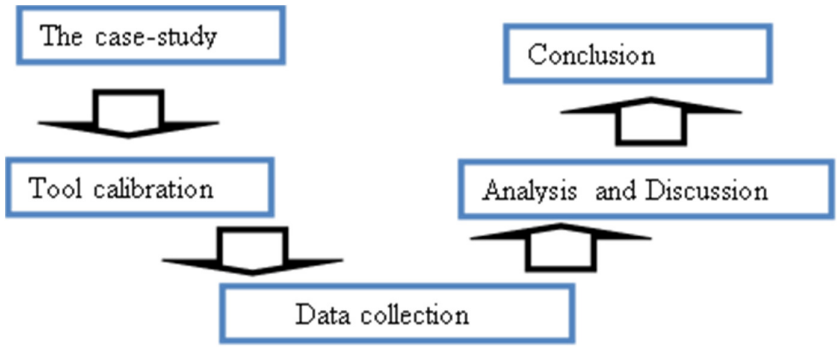

Fig. 2. The Research Processes

3.2 The Case-Study

The choice of case-study buildings for this study was a big task as we have to select residential courtyard residential buildings that have analogous features so as to have the general background for assessment. From the numerous courtyard residential buildings in Kafanchan, one each from the fully enclosed courtyard residential building category and the semi-enclosed courtyard residential building type was chosen. The buildings were chosen and examined concomitantly from 6:00 am hours in the morning to 6:00 pm hours in the evening, along with the outside door as a benchmark. The buildings were chosen based on some basic factors for instance; the building orientation have to be the same layout such that the lengthiest side to face the North/South direction, the two case-study should be of identical sizes and scopes, the material composition of the vertical walls, floors, ceiling, and roof should be of equal type. Even the doors and windows should be of the same typology, their locations should also be the same. The configuration and features of the buildings are shown in Figure 3 and 4, and Table 1.

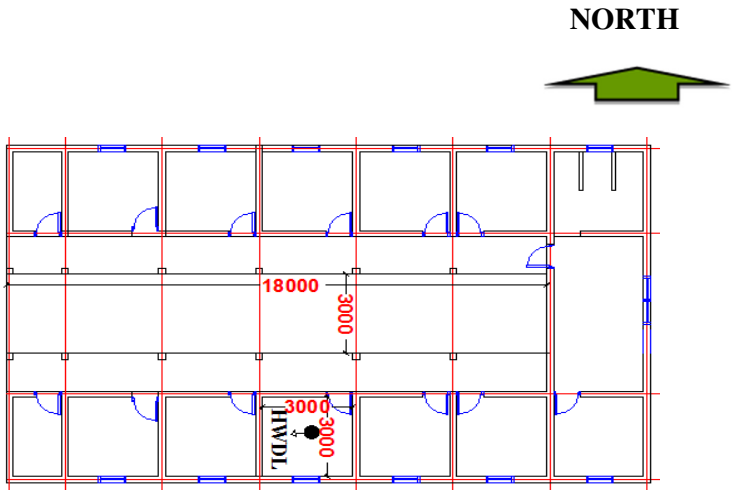

Fig. 3. Floor Plan of the Semi-Enclosed Courtyard House (case-study 1)

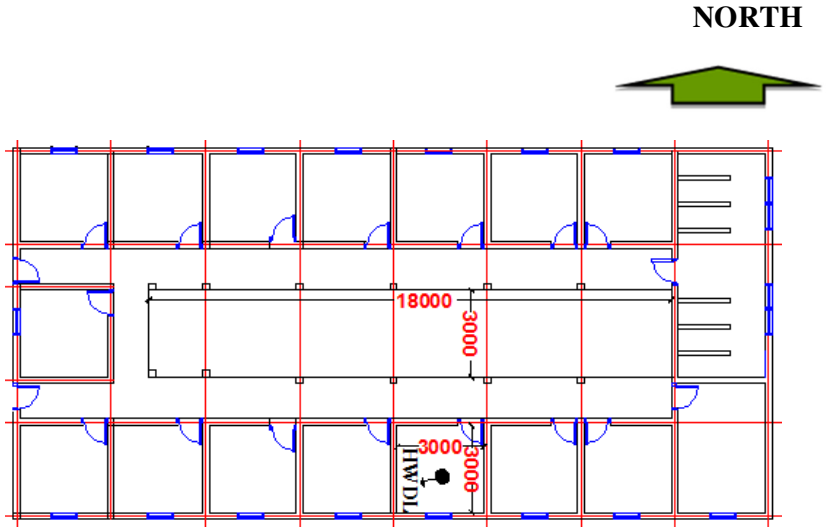

Fig. 4. Floor Plan of the fully enclosed Courtyard House (case-study 2)

Table 1
Characteristic of the two Case-Study

House-Type	Area of Room and Courtyard	Orientation, Door, and Windows locations	Building Materials Finishes
Fully enclosed Courtyard House	Room, 3 x 3 = 9 m^2 Courtyard, 3 x 18 = 54 m^2	North/South, Doors facing North, and windows facing south	-Iron Corrugated roofing sheets -Steel Frame Doors and Windows -PVC Ceiling Sheets -Sand/Cement Plastered Wall -Sand/Cement Screed Floor Finish
Semi-Enclosed Courtyard House	Room, 3 x 3 = 9 m^2 Courtyard, 3 x 18 = 54 m^2	North/South, Doors facing North, and windows facing south	-Iron Corrugated roofing sheets -Steel Frame Doors and Windows -PVC Ceiling Sheets -Sand/Cement Plastered Wall -Sand/Cement Screed Floor Finish

3.3 Tool Calibration

Tool calibration is basically the testing of tools by subjecting them to run measurement concurrently in other to check the readings for any disparity. Two hours before the beginning of the site measurement, the examination was conducted. The three Hobo Weather Data Loggers (HWDL) were allowed to run at the same time. The examination was carried out for the purpose of testing for precision in other to approve their degree of accurateness. Leng [26] stressed that for a research of this nature to be valid, the calibration procedure is required. Therefore, the variables used are; the air temperature and relative humidity. Figure 5 illustrates the three HWDL used in the experiment.

Fig. 5. A View of the Hobo Weather Data Loggers (HWDL)

3.4 Data Collection

The purpose of this investigational study was to observe and to investigate the microclimatic conditions of two existing courtyard residential buildings with the same characteristics and conditions but different layout. The carefully chosen case-study buildings are located in Kafanchan-Kaduna North Central of Nigeria. The measurement tool is the Hobo Weather Data Loggers (HWDL). Three HWDL were deployed in collecting data in the two case-study, and the third one was used as a benchmark. The calibrated procedure was conducted just two hours before the commencement of

the measurement in order to confirm the accuracy of the HWDL. The measurement took place simultaneously at one room each of the selected case-study between the hours of 6.00am and 6.00pm on Wednesday, 29th day of April 2017. The HWDL were positioned at the center of each room as demonstrated in Figure 6, and the air temperature and the relative humidity were taken at 30 minutes time intervals and documented at a space distance of 1.2 m (meter) above the floor level. Then, the attained data was read out with the instrumentality of the HoboPro software and then transferred to Origin7.0 for analysis. Figure 6 and 7 are the view of the HWDL during the entire exercise and the two case-study buildings.

Fig. 6. A View of HWDL in the Room

4. Results and Discussion

Two different categories of courtyard buildings have been measured to investigate their microclimate performances. The studied climatic variables are; air temperature and relative humidity. These variables were studied in the buildings, with the outdoor as a benchmark. Previous to the commencement of the measurement, the three measuring tools were calibrated to check their degree of precision. The following sections contain the findings and discussion of the study.

4.1 Calibration of Tools HWDL

The calibration study of the Hobo Weather Data Loggers (HWDL) was done for all the three tools. The result indicates that there is a consistent difference in the air temperature and relative humidity values. For the air temperature and relative humidity, a difference of 0.01 ^{o}C to 0.02 ^{o}C, and 0.01 % to 0.03 % was observed respectively (see figure 8 and 9 for illustration). According to Aldawoud [27] and Leng [26], the difference readings observed are very small and can be considered as negligible. As a result, these findings have certified the reliability of the Hobo Weather Data Loggers and should be used for future experimental studies.

4.2 The Site Measurements (Air Temperature and Relative Humidity)

Figure 10 shows the microclimatic performance of the two case-study as compared to the benchmark. The difference in the air temperature and relative humidity in the two case-study were seen to be much better in the courtyard buildings than in the outdoor (benchmark). A difference of 3 ^{o}C to 8 ^{o}C and 6 % to 11 % is revealed. Therefore, the outdoor is seen to be the worse.

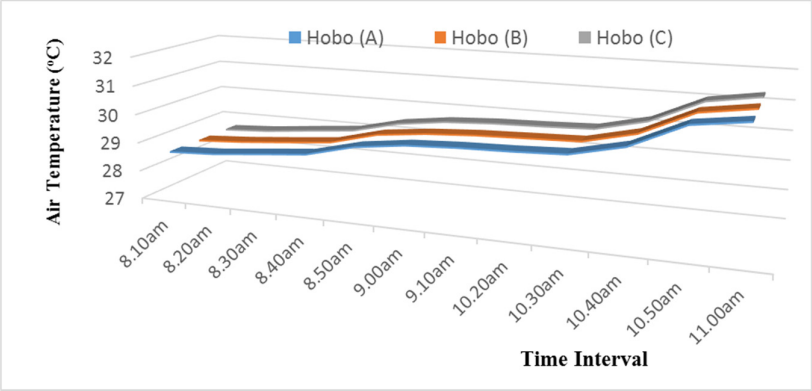

Fig. 8. Air Temperature of the three HWDL

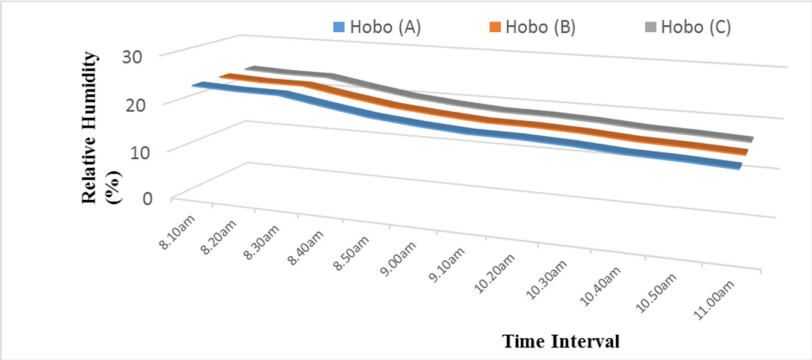

Fig. 9. Relative Humidity of the three HWDL

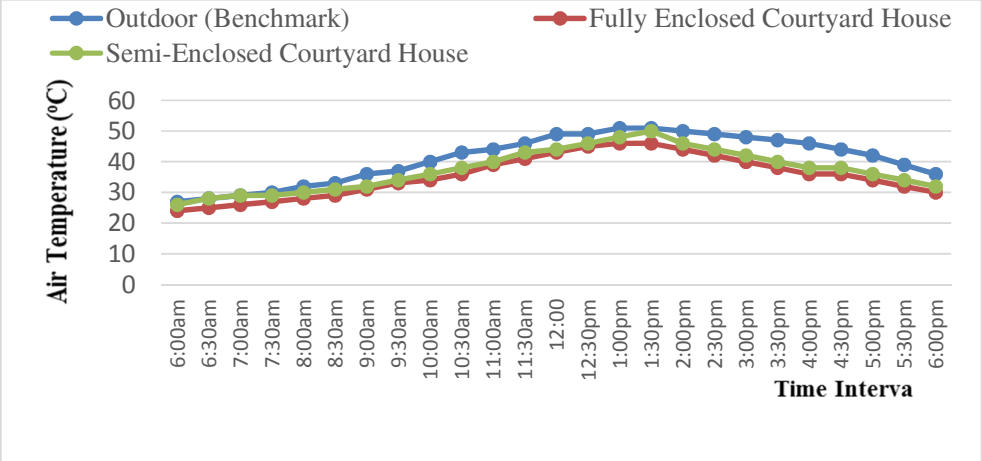

Fig. 10. Air Temperature

Besides, the fully enclosed courtyard residential building has a better microclimatic performance than the semi-enclosed courtyard residential building. The highest variance of air temperature between the two courtyards residential buildings was 3ºC recorded at 1:30 pm. While the lowest variance of air temperature was 1 ºC recorded almost consistently in the time intervals.

The fully enclosed case-study is fully confined all around and has the benefit of meaningfully modifying its own microclimate, but the semi-enclosed case-study is not fully confined but opened totally towards the western direction and exposed to the hot air temperature which has a tendency not to favor microclimate adaptation [27]. Therefore, according to Markus [28], the courtyard configuration in the two case-study may have affected the indoor microclimatic performances of the buildings as illustrated in figure 10 and 11.

But then again, the relative humidity had a unique relationship with the air temperature, as the air temperature rises the relative humidity declines. As explained in Figure 11, the relative humidity was higher in the outdoor benchmark (environment). The fully enclosed case-study has revealed a much better relative humidity than the semi-enclosed case-study. The highest discrepancy of relative humidity between the two case-study were 8 % recorded at 7:30 to 11:30 am.

Whereas, the lowest discrepancy of the relative humidity was 4 % recorded at 4:30 pm to 5:30 pm. The semi-enclosed case-study has a greater sky-view factor, it has a direct contact with the environment than the fully enclosed. The amount of the sky-view factor of the courtyard building is proportional to the amount of relative humidity obtained [11]. Hence, the greater the exposure to the environment the greater the amount of relative humidity. Conclusively, the high amount of relative humidity observed in the semi-enclosed courtyard residential building is in accordance with the Bekovic conclusion.

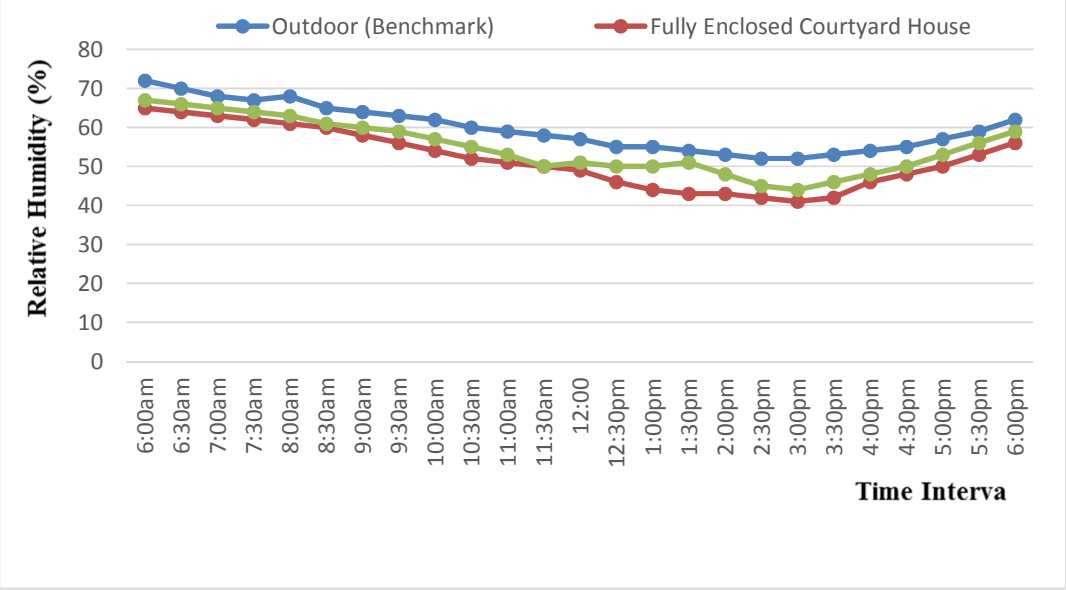

Fig. 11. Relative Humidity

5. Conclusion and Recommendation

The fully enclosed courtyard residential building have shown a more conducive indoor microclimatic performance than the semi-enclosed courtyard residential building and for that reason, this study can be concluded as follows:

(1) The case-study 1 -the fully enclosed courtyard residential building is preferable than the case-study 2 –the semi-enclosed courtyard residential building with a difference range of 1^{o}C to 3^{o}C, and 4% to 8% for air temperature and relative humidity respectively. And therefore, a further simulation study on its optimum ratio for a better indoor environmental performance should be examined.

(2) The benchmark is the poorest situation, then case-study 2 –the semi-enclosed courtyard house, and then case-study 1 -the fully enclosed courtyard house. The air temperature and relative humidity difference are between 3 ^{O}C to 8 ^{O}C, and 6 % to 11 % respectively. Consequently, it can be concluded that the courtyard is a good passive architectural design element in the hot-dry climate of Nigeria.

Finally, the fully enclosed courtyard residential house has an improved microclimatic performance over the semi-enclosed courtyard residential house, and further simulation investigational effort towards its enhancement for a more favorable microclimatic performance is highly required.

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