ASSESSMENT OF INDOOR THERMAL CONDITION OF A LOW-COST SINGLE STORY DETACHED HOUSE: A CASE STUDY IN MALAYSIA

Ashrifa Amir[1*], Mohd. Farid Mohamed[1], Mohd Khairul Azhar Mat Sulaiman[1] and Wardah Fatimah Mohammad Yusoff[1]

[1]Department of Architecture, Faculty of Engineering and Built Environment, Universiti Kebangsaan Malaysia, Bangi.

* Corresponding author:
ashrifaamir@gmail.com

ABSTRACT

Thermal comfort is an important factor to ensure good thermal condition of a house. To understand the current indoor thermal situation of a typical low-cost single story detached house in Malaysia, several parameters of thermal comfort need to be measured. The main objective of this study is to analyse the indoor thermal condition of a low-cost single story detached house through measurement of the indoor air temperature. The methodology applied in this study was field measurement to validate the IESVE simulation model of a low-cost single story detached house of a rural area, located in Kuala Pilah. Field measurement was done under two different conditions: (i) windows and door closed and (ii) windows and door opened. Air temperature, air velocity, and relative humidity data were collected using thermal comfort meters and a weather station. The data were used to validate the model generated by IES<VE> simulation software. Therefore, the objectives of this paper are to find out the statistical significance between the variables and to initiate passive design strategies using IES<VE> software to make indoor thermal condition more comfortable. Statistical analysis revealed that indoor air temperature (Ta) is statistically significant with time but not with the conditions. In opposition, air velocity (Va) is correlated with the conditions but not with indoor air temperature and time. Afterward, the window sizes were enlarged, and roof insulation was added to the simulation-based models to observe the temperature changes. Results show that in both cases, the temperature reduced to some extent but was not satisfactory nor in the recommended indoor air temperature range. Therefore, more careful deliberation is needed to design the layouts for the low-cost detached houses. Using roof insulation material is also important to improve the indoor thermal condition of the low-cost single story detached houses in Malaysia.

Keywords: *Indoor air temperature, low-cost single story detached house, thermal condition, IES<VE> simulation.*

1. INTRODUCTION

Low-cost housing had been a minor category of housing for both government and private sectors of housing in the early period of Malaysia. However, during the 7th Malaysian plan (Economic Planning Unit, 1996), 8th Malaysian plan (E. M. Plan, 2001; Unit, 2001) and 9th Malaysia plan (Bakhtyar et al., 2013; N. M. Plan, 2008; Zaid and Graham, 2010), the government paid attention towards low-cost and low-medium-cost houses under the affordable housing category (Cagamas Holdings Berhad, 2013). In recent days, housing rules are being executed for masses of people and their development. The Malaysian government is trying to create an easy pathway to provide affordable housing for its people.

Besides, the climatic condition of Malaysia has a direct impact on the indoor thermal condition of a house. According to the Malaysian Meteorological Department, the daytime minimum and maximum temperature ranges are 23 °C to 27 °C and 30 °C to 34 °C respectively. The windows, walls and roof surfaces of a house gain direct heat from solar radiation (Al-tamimi, Fairuz, and Fadzil, 2011; Al-Tamimi and Syed Fadzil, 2011; Datta, 2001). The relative humidity also remains very high which is nearly 75% with heavy rainfall (Tinker, Ibrahim, and Ghisi, 2004).

Thermal comfort issues have always been one of the most discussed topics for architects and academicians of tropical countries. As stated in MS 1525:2007, 23 °C to 26 °C is the recommended indoor air temperature range for the Malaysian climate (Department of Standards Malaysia, 2007; Jamaludin and Izma, 2015). Additionally, many researchers indicated the range of 25 °C to 28 °C as the recommended indoor air temperature for Malaysia (Hanafi, 2014; Heating, Refrigerating, Engineers, and Institute, 2004; Ibrahim, 2004; Madros, 1998; Zain-Ahmed, Sayigh, and Othman, 1997).

Henceforth, different experiments and studies were done for different categories of housing to determine the recommended indoor air temperature. An experiment by Jamaludin and Izma (2015) revealed that under Kuala Lumpur climatic condition, the highest indoor temperature of master bedroom was 32.6 °C. But in Kuching and Bayan Lepas, 31.10 °C and 31.60 °C were recorded respectively (Jamaludin & Izma, 2015). For terrace houses, many researchers found that 23 °C to 28 °C could be the comfort range under the Malaysian climate (Jamaludin & Izma, 2015; Zain, Taib, & Baki, 2007).

1.1 The recent scenario of low-cost houses in Malaysia

In Malaysia, the quality of low-cost housing has not been upgraded as compared to other categories of housing. One of the reasons for introducing affordable housing in Malaysia was dissatisfaction of the residents with the quality of low-cost housing (Musa et al., 2015). Despite the government's endeavour, the quality of low-cost housing is still not satisfactory. The causes include the building standards, planning layouts, materials' quality and thermal comfort (Hanafi 2014; Isnin et al. 2012). However, in most cases, thermal comfort issues have always been neglected in low-cost housing design. As a result, the thermal condition of these houses lead to higher indoor air temperature during the daytime (Tinker et al., 2004). Liang (2010) also enlightened that the indoor environmental quality of a low-cost house is always an overlooked issue (Isnin et al., 2012; Liang, 2010). There was always a matter of costing in choosing the materials for constructing the low-cost houses.

Furthermore, the indoor air temperature of low-cost houses is much higher than the recommended indoor air temperature for tropical climate (Hanafi, 2014). Incompetent thermal designs have affected the thermal comfort of low-cost houses as well as the residents of the houses (Hanafi 2014; Madros 1998; Ibrahim and Baharun 2014).

A comparative study was conducted by Ibrahim et al. (Hanafi 2014; Madros 1998; Ibrahim and Baharun 2014) on two different houses in Betong and Saratok. The indoor air temperature readings under different conditions were 34.2 °C and 34.5 °C for Betong and Saratok houses respectively, which were far from the recommended indoor air temperature in Malaysia. However, after opening the windows and doors, the air movement had increased but the indoor environmental condition was not comfortable at all.

The Malaysian government still puts the effort to improve the environmental quality of the low-cost houses (Musa et al. 2015). Typical layouts of single-story detached houses are shown in Figure 1 and 2. A standard guideline is available for low-cost housing, which is noted as the Construction Industry Standard (CIS 1: 1998). The guideline is for one- to two-story buildings, compiled by the Construction Industry Development Board Standard (Ismail, 2003; Suzaini Zaid and Peter Graham, 2010). The guide by the Construction Industry Standard (CIS 1: 1998) (Mohit, Ibrahim, & Rashid, 2010; Roadmap & Roadmap, 2003) is as follows:

- A minimum floor area of 63 square meter
- Three (3) bedrooms
- A kitchen
- A living and dining area
- A storeroom
- A bathroom, and
- A toilet

2. METHODS

The field measurement was chosen as a method for this study. A typical low-cost single-story detached house was selected to measure the thermal condition of the house which is built by the Rubber Industry Smallholders Development Authority (RISDA). As air temperature is one of the most important variables to determine human comfort (Kordjamshidi & Energy, 2011), this paper specifically focuses on the indoor air temperature measurement to find out the indoor thermal condition of the house.

Figure 1: Typical low-cost single-story detached house

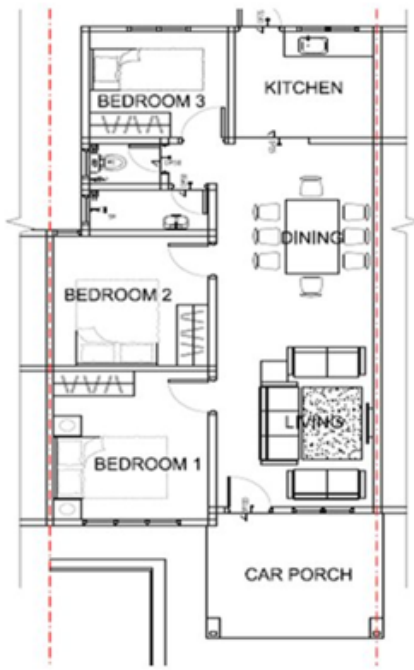

Figure 2 : Typical layout of a low-cost house

2.1 Equipment calibration

All the equipment was calibrated within a controlled environment before taking the on-site measurements to find out the error values. The list of the equipment used in the calibration is shown in Table 1 and Figure 3.

Table 1 : Equipment calibration

No.	Instruments	Units
1	Delta Ohm HD32.3 WBGT-PMV	02
2	Weather station	01

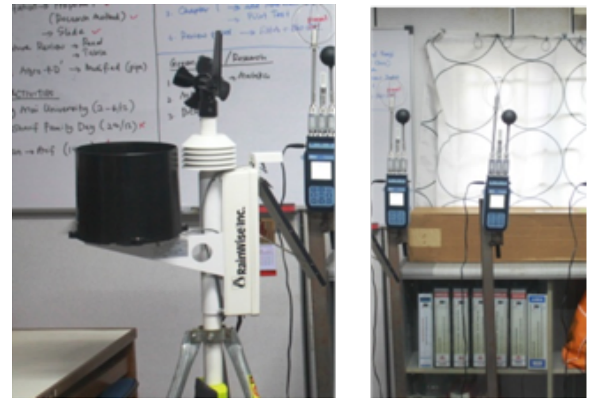

Figure 3: Calibration of all instruments in the indoor controlled environment

2.2 Field measurement

The field measurement was conducted on a low-cost single-story detached house located at 'Kampung Parit Seberang', 'Kuala Pilah', Negeri Sembilan (Latitude: 2°45'9.72" Longitude: 102°13'47.27"). The house had three bedrooms, one bathroom, one toilet, kitchen, dining and living room area of 57.88 square meter (623 square feet), as shown in Figure 4 and Figure 5. The measurement was conducted for three days from morning to evening for each condition (08:15 am to 19:15 pm). The first three days were under the setup where the door and windows were closed. The last three days, the door and windows were opened. During field measurement, a weather station was set outside the house to measure the outside meteorological conditions and two thermal comfort meters were set in different rooms of the house (labelled F2 and J1 in Figure 5).

Figure 4: Surroundings of the low-cost location single story detached house used for field measurement.

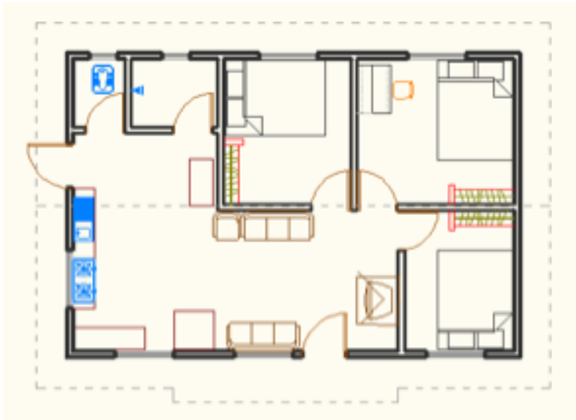

Figure 5: Layout plan of the house and thermal comfort meters

Figure 5 shows the location of both thermal comfort meters. The thermal comfort meters labelled as F2 was located in between the living and dining rooms and J1 was set to 1.1 meter above the floor level based on a similar study of Nguyen (Anh Tuan Nguyen 2012).

Figure 6: The position of J1 and F2 thermal comfort meters

2.3 Data collection

After completing the field measurement, the measured data were transferred and analysed. Thermal condition assessment were carried out under two different conditions (Ibrahim and Baharun 2014; Tinker et al. 2004):

Condition 1: Windows and door closed
Condition 2: Windows and door opened

The air temperature, wind speed, relative humidity and PMV data were collected for both conditions. However, in this paper only discusses the air temperature data. All data were statistically analysed using Microsoft Excel and SPSS.

2.4 Integrated environmental solutions <virtual environment> simulation

Integrated environmental solutions <virtual environment> (IES<VE>) is one of the efficient simulation software that can perform a detailed analysis of thermal performance (Doyle 2008; Nikpour et al. 2013). Three different models were developed to run three different simulations to attain a sound thermal condition of the house. Afterwards, changes were made to the base model to see the results. The window sizes were enlarged and different insulation materials like bubble foil and glass wool were used in the roof for the simulation model.

3. RESULTS AND DISCUSSIONS

The main emphasis was on the changes in the indoor air temperature under different conditions of the selected low-cost single-story detached house. At first, the obtained data from the field measurement were validated. Afterward, the validated data were analysed to see the relations between the variables. The indoor air temperature from both conditions was compared with the recommended temperature for Malaysia. Then, the base models of the IES<VE> simulation for two different conditions were improved to give further passive design suggestions.

3.1 Validation of IES<VE> model

Validation is very important for any kind of thermal simulation program. After comparing different simulation models, Hensen disclosed that IES<VE> validation is one of the best (Hensen 2004). Other than that, IES Apache simulation is also a trustable simulation tool for getting high accuracy (Ahmad et al. 2012; Attia 2010; Nikpour et al. 2013; Saleem et al.). However, the data from the field measurement and IES<VE> model simulation were compared for validation purpose (Saleem et al.).

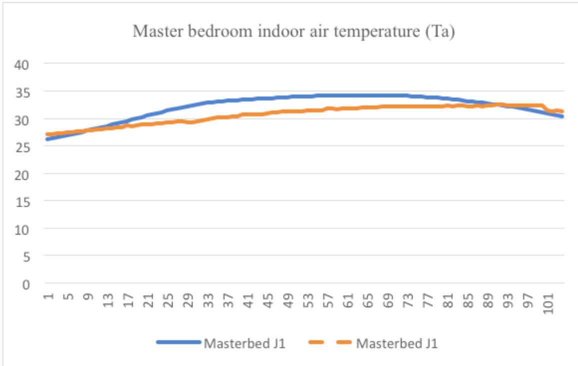

Figure 7: Indoor air temperature (°C) at the simulated and field measured data (Condition 1)

At first, the simulated data of two different conditions were validated with the field-measured data. Table 2 represents the difference in the indoor air temperature and the deviation percentage for two thermal comfort meters set in the master bedroom and living room area in condition 1.

Table 2 : Uncertainty estimation of the indoor air temperature (°C) sensors as calibrated:

Condition 1	Master bedroom (F2)	Living room (J1)
Diff of temp (°C)	0.5	1.5
Deviation (%)	1.9	2.3

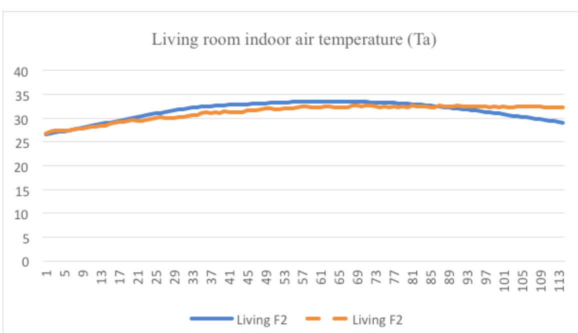

Figure 8: Indoor air temperature (°C) at the simulated and field measured data (Condition 1)

For condition 1, the maximum uncertainty in calibrated data found in the living room area was ± 1.5 (°C) with the standard deviation at ± 2.3% (Table 2 and Figure 9). Under the setup of condition 2, the maximum uncertainty in calibrated data found in the living room area was ± 0.9 (°C) with ± 3.2% standard deviation (Table 3 and Figure 10). The weather station was excluded from uncertainty estimation (Muhsin, Fatimah, Yusoff, and Farid, 2017).

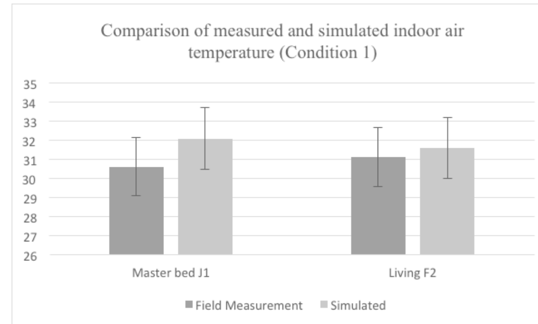

Figure 9: The comparison of air temperature (°C) between IESVE model and field measurement data (Condition 1)

Table 3 : Uncertainty estimation of the indoor air temperature (°C) sensors as calibrated:

Condition 2	Master bedroom (F2)	Living room (J1)
Diff of temp (°C)	0.7	0.9
Deviation (%)	2.6	3.2

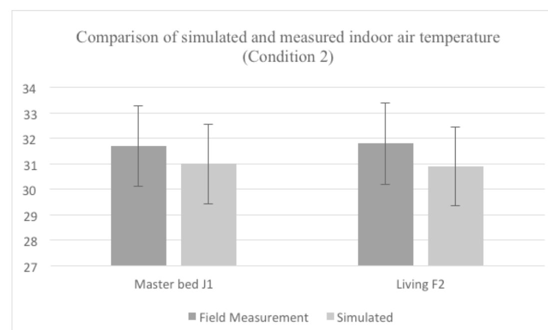

Figure 10: The comparison of air temperature (°C) between IESVE model and field measurement data (Condition 2)

The results revealed that for both conditions, the deviation (%) between IES<VE> model and field measurement was less than 5% for indoor air temperature data which indicates that IES has the validity to calculate the thermal analysis (Ahmad et al., 2012; Nikpour et al., 2013).

3.2 Pearson's correlation test

The Pearson's correlation test was conducted to see the impact of time and condition on indoor air temperature. The test results in Table 4 show that the indoor air temperature increased throughout the day and highly correlated with time.

Table 4 : Pearson Correlation test for different variables with time and conditions

		Time	Conditions	Indoor air temp.	Air velocity
Indoor air temperature	Pearson Correlation	.705**	-.118	1	-.068
	Sig. (2-tailed)	.000	.324		.571
	N	72	72	72	72

**. Correlation is significant at the 0.01 level (2-tailed)

3.3 Comparison between indoor air temperature and recommended temperature

According to the guidelines of Department of Standard Malaysia, the recommended temperature range for Malaysian climate is between 23 °C and 26 °C that indicates an average temperature of 24.5 °C. The measured indoor air temperature of the house was listed to compare with the recommended temperature under condition 1 and 2, for three different times of day (Table 5 and Table 6).

Table 5 : Condition 1: Indoor air temperature and recommended air temperature (°C):

Condition 1: (Windows/door closed)	**Temperature**	
	Indoor air temperature (°C)	Indoor recommended temperature (°C)
Morning 0900	29.2	24.5
Noon 1200	31.2	24.5
Evening 1700	33.0	24.5

Table 6 : Condition 2: Indoor temperature and recommended air temperature (°C):

Condition:2 Windows/door opened	**Temperature**	
	Indoor air temperature (°C)	Indoor recommended temperature (°C)
Morning 0900	29.7	24.5
Noon 1200	33.1	24.5
Evening 1700	31.4	24.5

In the morning (9.00 am), for Condition 1 and 2, 29.2 °C and 29.7 °C are the lowest indoor air temperature. Even being the lowest temperature recorded, both values were still higher than the recommended indoor air temperature.
3.4Comparison between indoor air temperature and outdoor air temperature
The average indoor air temperature was compared with the monitored average outdoor temperature at 9.00 am under the windows and door closed condition. The results show that the average indoor air temperature is higher than the average outdoor air temperature (Table 7).

Table 7 : Condition 1: Indoor temperature and outdoor temperature (°C):

Condition 1: (Windows/door closed)	**Temperature**	
	Indoor air temperature (°C)	Outdoor air temperature (°C)
Morning 0900	28	25.2

3.5 IES<VE> simulation with different design strategies

IES<VE> simulation was used to initiate further passive design strategies for this study. After doing different statistical analyses, the indoor air temperature was observed by developing different simulation models by making changes on the base models for both conditions. The selected typical low-cost single-story house was modelled in the IES<VE> simulation to provide further recommendations for the betterment of the indoor thermal comfort of the house using selective passive design strategies. The base model obtained from the IES<VE> software was improved to run different simulations with different passive strategies for the betterment of the indoor environmental condition of the selected house (Figures 11 and 12).

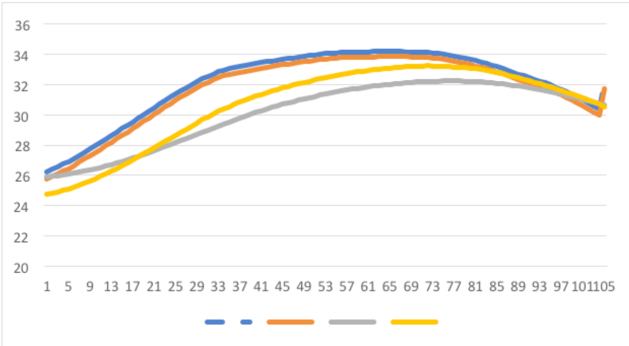

Figure 11: Changes in indoor air temperature of master bedroom in different simulations (Condition 1)

Figure 12:. Changes in indoor air temperature of master bed in different simulations (Condition 2)

In the first model, the openings sizes were increased to 4.5% from the original size. In the second and third models, roof insulation materials were replaced with bubble foil and glass wool insulation. The indoor air temperature of master bedroom dropped to 26.4 °C in the morning (9.00 am) when the window sizes were enlarged. The temperature dropped to 28.3 °C and 26.7 °C when using the glass wool and bubble foil insulation material respectively. It means the maximum indoor air temperature was decreased by 2.3 °C when the windows were larger.

The indoor air temperature was compared for three different times of day: Morning (0900), noon (1200) and afternoon (1700). The results of condition 1 are illustrated in Table 8.

Table 8 : Master bedroom and living room indoor air temperature analysis with three different IES<VE> simulation models: Condition 1

	Condition 1				
Master bedroom	**Time**	**Base model**	**Glass wool**	**Bubble insulation**	**Larger window**
	9:00	28.7	28.3	26.7	26.4
	12:00	33.6	33.2	30.5	31.6
	17:00	32.1	31.7	31.6	32.0
Living and dining area	9:00	28.7	28.3	26.7	26.4
	12:00	33.6	33.2	30.5	31.6
	17:00	32.1	31.7	31.6	32.0

On the other side, for condition 2, while bubble foil insulation used in the simulation, the maximum temperature dropped to 25.5 °C indicating 2.4 °C reduction in the indoor air temperature. Using glass wool insulation did not result in much lower temperature, with 0.3 °C drop in the minimum temperature, as shown in Table 9.

Table 9 : Master bedroom and living room indoor air temperature analysis with three different IES<VE> simulation models: Condition 2

	Condition 2				
Master bedroom	**Time**	**Base model**	**Glass wool**	**Bubble foil insulation**	**Larger window**
	9:00	27.9	27.6	25.5	26.6
	12:00	31.8	31.7	31.0	31.3
	17:00	32.2	32.1	32.4	32.1
Living and dining area	9:00	27.6	27.4	27.1	27.0
	12:00	31.5	31.4	31.2	31.2
	17:00	32.3	32.2	32.1	32.3

3.5.1 Analysing different passive design strategies

For all cases, simulation results were not highly satisfactory. But the measured indoor air temperature values were higher than the simulated model obtained values of the study house. With larger windows, the temperature decreased the most at 2.4 °C and 1.3 °C for both tested conditions. Windows can be enlarged easily to reduce the indoor air temperature. However, the installation of the roof insulation materials went well for condition 1 as all the windows were closed and the heat could not enter directly through the windows. But interestingly for condition 2, the temperature increased in the evening. For both conditions, the roof indoor temperature reduction is much higher in the model using bubble foil insulation than in the model using glass wool insulation. The roof insulation materials can be assessed under conventional metal deck roof by adding some extra cost. Applying different strategies can reduce the temperature to some extent but these strategies need to be improved or combined with other strategies to achieve a comfortable thermal environment inside the house.

4. CONCLUSION

The results from statistical analysis and IES<VE> simulation model analysis showed that the indoor air temperature was not in the range of the recommended air temperature. For improvement of the indoor thermal condition of a low-cost house, indoor air temperature should be reduced for more conductive thermal environment for the occupants. Although the indoor air temperature was dropped after the windows and door being opened, the results were neither satisfying nor falling in the suggested indoor air temperature range. Hence, there is a need for an alteration in the windows and roof materials and an implementation of the low-cost design strategies to make the indoor thermal environment of these houses more liveable. The results showed that the passive design strategies have made positive impacts on the indoor thermal condition of the houses. The objectives have been fulfilled by initiating different low-cost passive design strategies from the methodology in reducing the indoor air temperature. Using bubble foil roof insulation materials could be one of the suitable strategies by spending a bit more to reduce the indoor air temperature of the low-cost single-story detached houses significantly. The findings of this study offer potential guidelines for the developers and builders to make the decision in building new low-cost houses more efficiently. This study only focused on the indoor air temperature issue of single-story detached low-cost houses in Malaysia. Therefore, further studies involving different types of low-cost houses should be carried out in the near future to improve the indoor thermal quality of the low-cost houses in Malaysia.

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