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STUDY OF THE HEAT VENTILATION WITH INCLINED CHIMNEY IN THE ATTIC

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ABSTRACT: This paper proposes the design of inclined chimney with horizontal outlets that integrated with a triangular roof. Utilize solar radiation to heat and induce air through natural ventilation in the interior of the house. For achieving this goal, Solidworks Flow Simulation software is used to visualize and simulate the 3-D flow plane performance of the chimney, by modeling using Navier-Stokes (RANS) for numerical investigations. The effect of depth the channel of solar chimney investigated in six configurations under the roof with a slope of 45°. The simulation is performed on steady-state, to predict the dynamics of heat transfer, velocity distribution, and mass flow rate. The results showed that the greater the depth of the chimney, the higher the airflow and quite effective in reducing the temperature of the interior space, but would result in a decrease in heat in the solar chimney channel. Solar chimney airflow is mainly caused by buoyancy due to differences between ambient temperature and in the channel. They confirmed that the more significant the difference in temperature inside and the environment, the more efficient the performance of ventilation. However, the triangle channel output is still a place to collect hot air and high airflow. Natural ventilation using a solar chimney in the roof cavity seems to be effectively applicable to solar incidence discharges in traditional homes in the Indonesian climate.

Keywords: Attics, CFD simulation, Natural ventilation, Solar collector, Thermal comfort

1. INTRODUCTION

Increased indoor temperature compared to outdoor temperatures in residential buildings that have triangular roofs have been a concern in designing buildings in a hot and humid tropical climate. Residents experience uncomfortable conditions because of the high temperature of the room [1]. Daytime sun radiation causes trapped accumulation of heat, which raises the temperature of interior space mainly from the upper part, which includes the attic area and roof [2]. To maintain the room temperature at the comfort level, generally, the use of mechanical devices such as fans becomes an option or air conditioning system [3]. Failure to design passive cooling systems and reliance on mechanical ventilation systems can result in additional costs for building installation, operation, and maintenance [4, 5].

Several studies to address the problem of heat in buildings in humid tropical climates have been carried out. Field studies of thermal comfort in office buildings [6]. Research on the thermal comfort of schools in Indonesia's climate [5, 7-10], natural ventilation system various strategies [11, 12].

Some researchers see the potential the difference in the height of the attic temperature compared to the heat of the ambient environment in hot and humid tropical climates can support the stack effect on the solar chimney to purpose cool the room free [1, 2, 13, 14]. Natural airflow through a triangular loft using a solar chimney as a reliable renewable energy system has shown encouraging results [15, 16]. Tan and Wong [17], has investigated the geometry of solar chimneys with sloping outlets in Singapore. Yew *et al*. [18], propose a strategy of air flowing in the gap between the roof and the ceiling of a residence in the Malaysian climate. According to Shi *et al*. [19], the solar chimney has an excellent optimal performance at the lowest cost. Four main groups influence chimney performance, environmental conditions, installation conditions, material use, and including configuration. Improve performance, the solar chimney recommended with a gap of 0.2 to 0.3 m, the same inlet and outlet, a high/depth ratio of about 10, a slope angle of 45° to 60°. However, this condition certainly does not apply to some cases that have different characters, for example, as the case of horizontal chimney outlet geometry [16].

In this article, a solar chimney study buried under the roof of the Buginese traditional house, in the climate of South Sulawesi Indonesia has been carried out. This case bears a resemblance to what was done by DeBlois *et al*. [13], the difference is mainly due to the climate in the United States, and it only allows one roof area to receive sunlight, while in Indonesia almost all sides of the roof exposed to daylight all year long [20]. The Buginese houses have a stage construction character with a typical simple triangular roof, so installing solar chimneys under the roof with vertical outlets ruins the characteristic appearance of traditional houses, so it proposed that innovative solar chimney outlets. This recommendation can be a new strategy to apply to conventional homes in hot and humid tropical climates while maintaining the original form of the architecture.

2. MATERIALS AND METHODS

2.1 Geometry

Figure 1a presents the 3-D model of a traditional Buginese stage house in full. There are two bedrooms with facing positions that enter in dotted lines, then form an interior space model that integrated with the attics and solar chimneys.

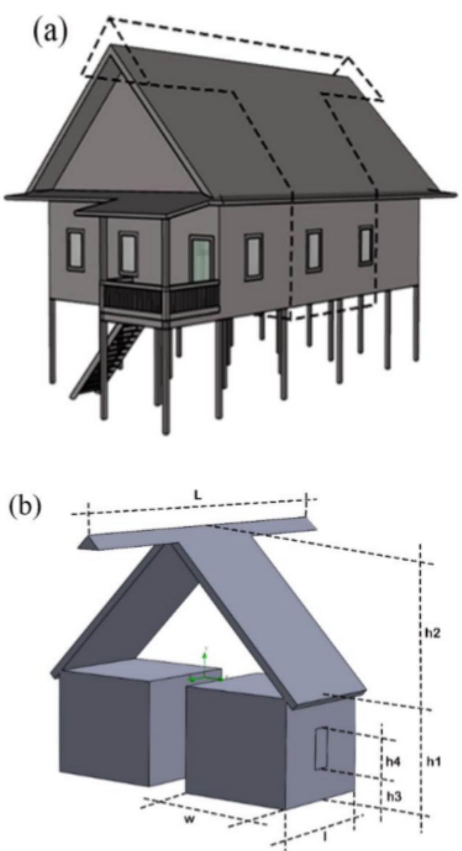


Fig.1 3D view of the building and detail of the model simulation

Figure 1b shows a cross-section of a 3-D simulation model with length (l) and width (w) of 3 m each, height (h) 0.3 m, and the length of the outlet channel (L) 9 m. There are two bedrooms separated by a hallway. Each room has a window with a position of 0.8 m (h3) from the surface of the floor. The measuring 0.5 m x 1 m (h4) high, and a connection with the solar chimney tilted 45^o through a hole in the corner of the ceiling with a gap of 0.1 x 3 m size. There are six models of solar chimney depths, namely; case-1 0.10 m, case-2 0.15 m, case-3 0.20 m, case-4 0.25 m, case-5 0.30 m, and case-6 0.35 m. These chimney depths were adopted from Bassiouny and Korah [21].

At the top of the roof, meet the two inclined chimneys on a horizontal channel that extends in the same direction of the roof ridge that functions as an outlet. The horizontal channel is a triangular space which has a cross-section of 0.036 m^2, 0.068 m^2, 0.011 m^2, 0.162 m^2, 0.223 m^2, and 0.294 m^2.

2.2 Numerical Model

The geometry model and dimensions made the same as the original building 1:1 scale using Solidworks CAD. Combining solar chimneys attached to the interior of the bedroom and additional outlets for horizontal triangle tubes on the roof. The methodology used to simulate collector array operations is examined and presented using the simulation tool used in this work is Solidworks Flow Simulation, combining high-level functionality and accuracy with ease of use where thermal dynamics analysis, fluid flow distribution can carry out simultaneously. This software has also been used in previous research to simulate various solar heat collector [13, 22]. This code based on solving Navier-Stokes equations with a finite volume discretization method. The mathematical description of this model, which is a law that refers to the conservation of mass, momentum, and energy conservation [23], which given as follows:

$$\frac{\partial \rho}{\partial t}+\frac{\partial u}{\partial x}+\frac{\partial v}{\partial y}+\frac{\partial w}{\partial z}=0 \quad (1)$$

$$\frac{\partial u}{\partial t}+\frac{\partial uu}{\partial x}+\frac{\partial uv}{\partial y}+\frac{\partial uw}{\partial z}=-\frac{1}{\rho}\frac{\partial p}{\partial x}+\frac{1}{\rho}\frac{\partial \tau_{xx}}{\partial x}+\frac{1}{\rho}\frac{\partial \tau_{yx}}{\partial y}+\frac{1}{\rho}\frac{\partial \tau_{zx}}{\partial z}+g_x \quad (2)$$

$$\frac{\partial v}{\partial t}+\frac{\partial vu}{\partial x}+\frac{\partial vv}{\partial y}+\frac{\partial vw}{\partial z}=-\frac{1}{\rho}\frac{\partial p}{\partial y}+\frac{1}{\rho}\frac{\partial \tau_{xy}}{\partial x}+\frac{1}{\rho}\frac{\partial \tau_{yy}}{\partial y}+\frac{1}{\rho}\frac{\partial \tau_{zy}}{\partial z}+g_y \quad (3)$$

$$\frac{\partial w}{\partial t}+\frac{\partial wu}{\partial x}+\frac{\partial wv}{\partial y}+\frac{\partial ww}{\partial z}=-\frac{1}{\rho}\frac{\partial p}{\partial z}+\frac{1}{\rho}\frac{\partial \tau_{xz}}{\partial x}+\frac{1}{\rho}\frac{\partial \tau_{yz}}{\partial y}+\frac{1}{\rho}\frac{\partial \tau_{zz}}{\partial z}+g_z \quad (4)$$

$$\frac{\partial(E_T)}{\partial t}+\frac{\partial(uE_T)}{\partial x}+\frac{\partial(vE_T)}{\partial y}+\frac{\partial(wE_T)}{\partial z}=-\frac{\partial(up)}{\partial x}-\frac{\partial(vp)}{\partial y}-\frac{\partial(wp)}{\partial z}-\frac{1}{\rho}\left[\frac{\partial q_x}{\partial x}+\frac{\partial q_y}{\partial y}+\frac{\partial q_z}{\partial z}\right]+\frac{1}{\rho}\left[\frac{\partial}{\partial x}(u\tau_{xx}+v\tau_{xy}+w\tau_{xz})+\frac{\partial}{\partial y}(u\tau_{xy}+v\tau_{yy}+w\tau_{yz})+\frac{\partial}{\partial z}(u\tau_{xz}+v\tau_{yz}+w\tau_{zz})\right] \quad (5)$$

There are four independent variables, namely the spatial coordinates of x, y, and z of several spheres, and time t. There are six dependent variables, mainly; pressure p, density r, and temperature T (contained in the energy equation through total energy E_t) and the three components of the velocity vector; the part u is in the x-direction, component v is in the y-direction, and the w component is in the z-direction, entirely dependent variables are functions of all four sovereign variables [24].

According to Guha *et al*. [25], The results of heat transfer in natural convection studies adjacent to flat plates are generally presented as Nusselt Nu figures or convective heat transfer coefficient h. Local heat flux along with the plate L, and k is the thermal conductivity of the fluid, calculated using the following expression:

$$Nu = \frac{hL}{k} \quad (6)$$

Based on previous research, there are several equations for defining the parameters of dimensionless numbers in the following natural convective flow:

Grashof number:

$$Gr_L = \frac{\rho_\infty^2\, g\, cos\theta\, \beta(T_w - T_\infty)\delta^3}{\mu^2} \quad (7)$$

Grashof number is the ratio between buoyancy force and viscosity force. Where ρ is the density of air (kg/m^3), β is volumetric expansion coefficient, g is acceleration due to gravity (m/s^2), δ is the depth of collector (m), μ is dynamic viscosity (m^2/s).

Prandtl number:

$$Pr = \frac{\mu C_p}{k} \quad (8)$$

Where μ is dynamic viscosity (m^2/s), C_p is specific heat capacity (J/kgK), k is thermal conductivity (W/mK).

Rayleigh number:

$$Ra = Gr_L Pr \quad (9)$$

2.3 Boundary conditions

Table 1 describes the boundary conditions of the simulation, considering the heat flow to the bedroom through the window the same as the weather outside. So that the environmental pressure mode is chosen to show that the inlet and outlet are in direct contact with the surrounding climate - recorded air temperature 30.7 °C, air pressure 101325 Pa. The wall is considered not to transfer heat (adiabatic); the heat source only comes from the roof surface 64.3 °C. The heat transfer coefficient is between 3.7 to 5.3 W/(m^{2}K), the calculation based on the natural convection heat transfer coefficient [25], for easy application available online [26]. In this simulation also consider the gravitational effect of -9.8 m/s for convection analysis. The airflow is evacuated from the bedroom space to the area of static atmospheric pressure, through the solar chimney. The prototype models in the computational domain are roofs, building surfaces, and walls which, are considered the wall boundary conditions. The summary of boundary conditions given in fig. 2.

Table 1. Boundary conditions in the simulations

Component	Parameter
Wall conditions	Adiabatic
Inlet/outlet	Environment pressure 101325 Pa
Roof temperature	64.3 °C
Heat transfer coefficient:	Case-1 = 5.3 W/(m^{2}K)
	Case-2 = 4.7 W/(m^{2}K)
	Case-3 = 4.3 W/(m^{2}K)
	Case-4 = 4.1 W/(m^{2}K)
	Case-5 = 3.9 W/(m^{2}K)
	Case-6 = 3.7 W/(m^{2}K)
Gravity	-9.8 m/s
Ambient and sky temperatures	30.7 °C

The boundary conditions are determined based on field measurement data to determine the heat transfer coefficient value using equations or easy calculation applications [25, 26].

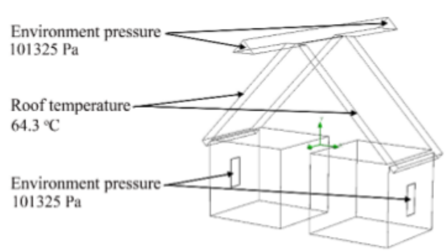


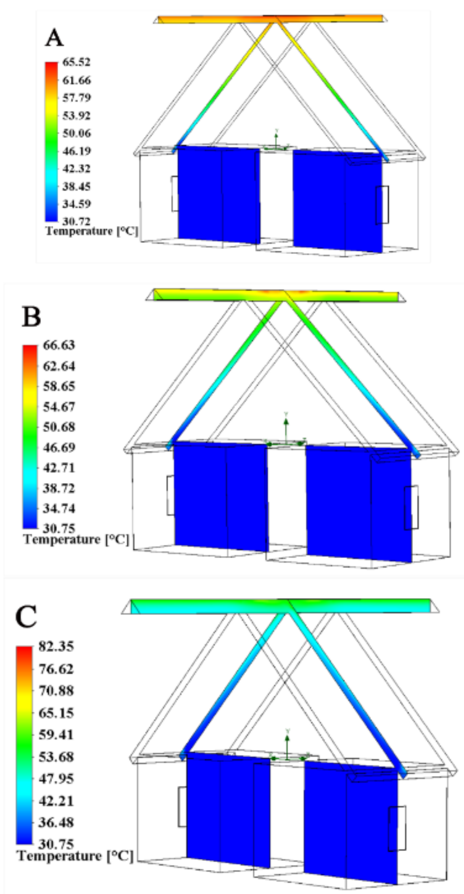
Fig. 2 Boundary Conditions

3. RESULTS AND DISCUSSION

The results of this study are enclosed in two forms, namely in the form of a 3-D image to visualize the distribution of temperature and air velocity in the interior space of the house, the solar chimney channel to the outlet at the rooftop. In this condition, the flow is a steady-state because the air not compressed. Furthermore, the second is to present a graph of the mass flow rate and the volume of the flow rate to describe the quantity of airflow.

3.1 Temperature

Figure 3 shows the temperature field distribution in the interior of the bedroom and solar chimney. Figure 3A to 3F shows the simulation results of the chimney model temperature distribution, which divided into 6 cases of channel depth, ranging from 0.1 to 0.35 m. The average temperature between 31.9 °C to 32.1 °C, with a maximum temperature of 73.9 °C at the case-3 (Figure 3C), the minimum temperature occurs at the case-6 which is 60.6 °C (Figure 3F).



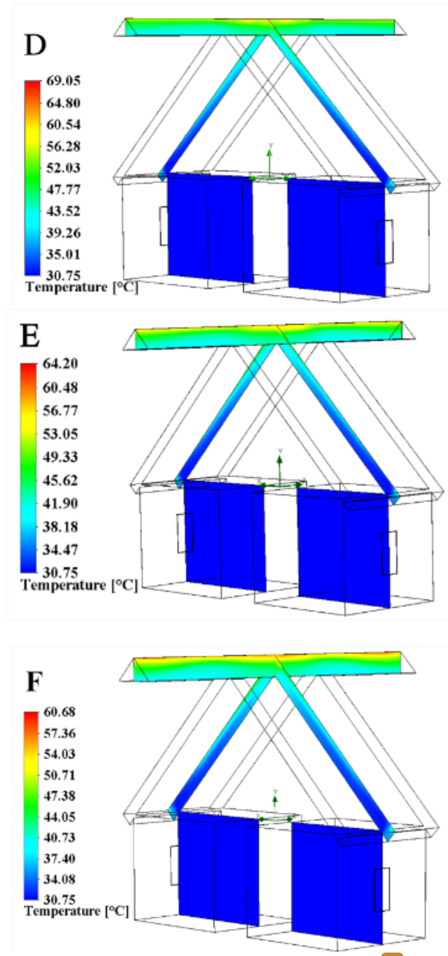


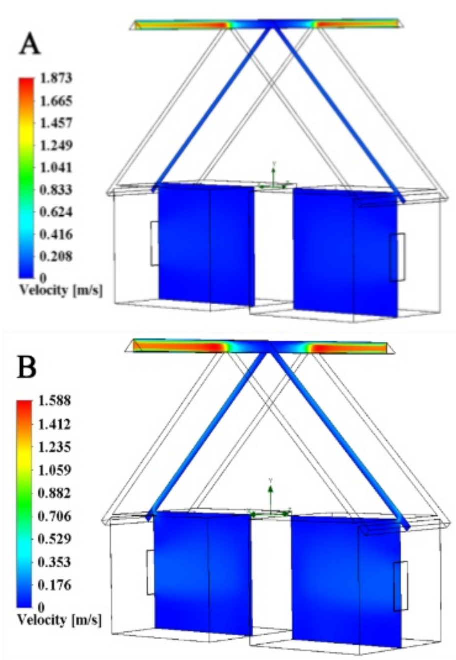
Fig. 3 Distribution of temperature field (A) depth 0.10 m; (B) depth 0.15 m; (C) depth 0.20 m; (D) depth 0.25 m; (E) depth 0.30 m; (F) depth 0.35 m.

The higher the depth of the solar chimney channel has the effect of lowering the temperature of the heat collector. Areas that experience heat build-up occur around the outlet channel at the top of the horizontal triangle tube roof, especially in case models where the chimney depth is small. Overall, all models are quite effective in reducing temperatures. The surface temperature of the roof then begins to decrease due to heat is transported out by the airflow from below, which is colder temperature.

These results reinforce the Solar Chimney design reference from Ahmed and Hussein [14]. According to Bassiouny and Korah [21], ventilation can be achieved naturally based on the principle of solar chimney. The driving force in the solar chimney is buoyant style. Solar energy absorbed by the chimney causes the layer of air that is between two parallel vertical or sloping plates, heating up and inducing air to move upward. As a result, air starts flowing from the interior space to move upwards, then out towards the collector outlet. Thus, a gentle breeze is created indoors, which allows fresh outside air to enter the room through an open window or door.

3.2 Velocity

Figure 4 describes the velocity field distribution of airflow in the interior of the bedroom and solar chimney. Figure 4A to 4F shows the simulation results of the chimney airflow distribution model, which are distinguished by channel depths ranging from 0.1 to 0.35 m. The average airflow velocity tends to rise based on the increase in channel depth, namely 0.039 to 0.1 m/s, with a maximum speed between 1.8 m/s. However, the maximum velocity of each model shows a declining trend as the chimney depth increases. That justifies the reason for the performance of very low air solar collectors with horizontal orientation [15, 16]. The part of the area that experiences high speed occurs around the outlet channel on the top of the flat triangle roof, especially in the small depth chimney models. Overall, all models are quite effective at cooling interior spaces, and these results confirm the opinion of Bassiouny and Koura [27]. Airflow distribution in the interior of the bedroom can reach above 0.25 m/s so that it included in the thermal comfort standard [5, 11].



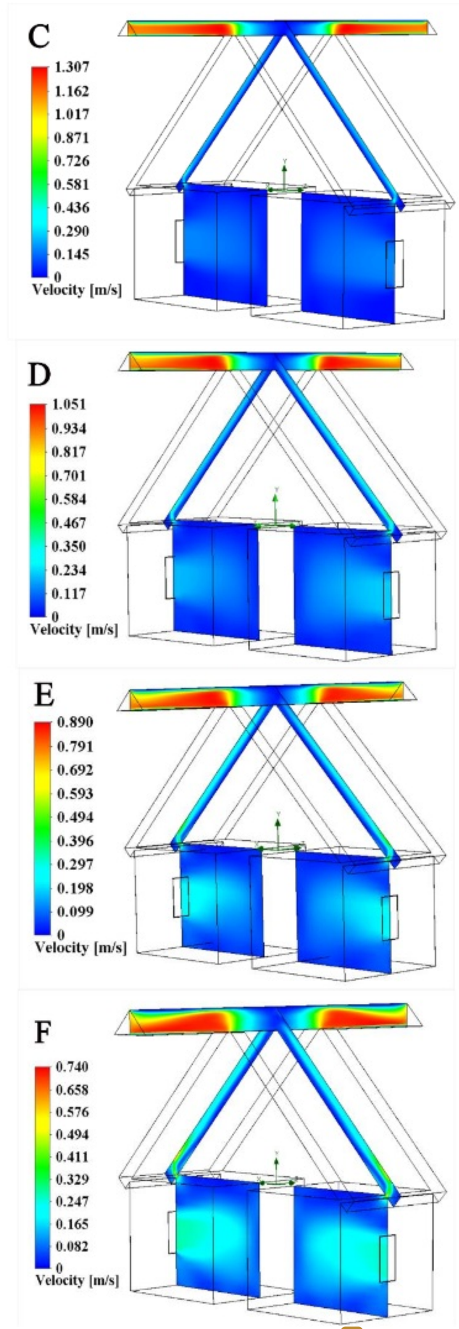


Fig. 4 Distribution of velocity field (A) depth 0.10 m; (B) depth 0.15 m; (C) depth 0.20 m; (D) depth 0.25 m; (E) depth 0.30 m; (F) depth 0.35 m.

This study found a correlation between the gab of the inclined chimney with the temperature and air velocity in the heat channel. The higher the gap of the solar chimney channel has the effect of lowering the temperature of the heat collector. The airflow is smoother because the induction occurs properly carrying heat trapped in the circuit, including the bedroom interior space. However, the solar collector with a small gap, a buildup of heat occurs in the upper channel near the outlet. Although theoretically, the availability of heat provides an advantage in the process of stack effects. However, simulations by increasing the gab to 0.35 m still gave the excellent performance to the heat balance tested in this study.

3.3 Mass Flow Rate

Figure 5 shows the performance of a solar collector, which is determined by the mass flow rate to assess how effectively the collector flows air. The results show that the higher the depth of the solar chimney, the better the air flows. On average, 0.1 to 0.3 kg/s based on the increase in chimney depth.

These results reveal that the higher the depth of the collector, the better the total mass flow rate through the solar chimney with slope of 45°. According to Shi *et al*. [19], the optimum airflow rate can be obtained under a cavity gap of 0.2 to 0.3 m and a height/gap ratio of about 10. However, test results found that depths 0.35 m with an aspect ratio of 14.2, still show excellent flow performance. Perhaps because of changes in the flow direction at the horizontal collector output. This incident supports opinions from previous researchers [16].

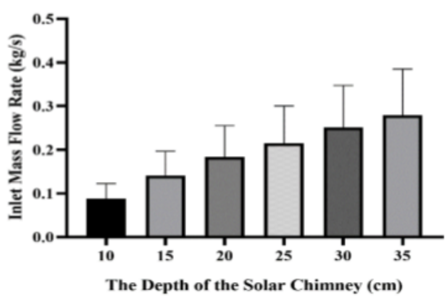


Fig. 5 Mass Flow Rate Performance

4. CONCLUSION

Computational studies using Solidworks Flow Simulation software from heat vents in the attics of traditional Buginese houses in hot and humid tropical climates have been carried out. This research has proposed inclined chimney 45° with horizontal output, to cool the bedroom air for free. The triangular roof of Buginese houses can store large hot stock all day long throughout the year. This solution can improve weather conditions in the attic by modifying how to increase the airflow in it by utilizing the stack effect that occurs due to differences in attic temperature and the environment. In this study, the air intake area is thought to originate from the bedroom window. This flow creates two circulation zones on the inner surface of the roof, which then empties into horizontal channels at the top of the attic. The airflow increases as it passes through the horizontal triangular tube located at the top of the attic. These results present an interesting idea for building thermal energy using a solar chimney system with horizontal field outlets. In the future, we propose to work on a method that saves energy to assume continuous heating with zero energy. The study found that the best of modeling results are the chimney depth was 0.35 m because the balance of heat and induction flow was still perfect.

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