DIMENSI: Journal of Architecture and Built Environment, Vol. 50, No. 1, July 2023 DOI: https://doi.org/10.9744/dimensi.50.1.43-52
ISSN 0126-219X (print) / ISSN 2338-7858 (online)

Additional Roof Ventilation to Produce A Stack Effect in *Ume Kbubu*, The Traditional House of The *Atoni* Tribe

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Article Info:
Submitted: March. 25, 2023,
Reviewed: June. 06, 2023,
Accepted: July 10, 2023,

Keywords:
roof ventilation;
stack effect;
ume kbubu.

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Abstract

Indoor air quality affects the health of building users so that every building needs ventilation. The ume kbubu building was built without using ventilation to get warm temperatures in the building but the air quality inside is highly contaminated with carbon dioxide. The addition of roof ventilation is expected to produce a stack effect phenomenon in ume kbubu. The purpose of this research is to measure the level of carbon dioxide in ume kbubu and the speed at which smoke moves out of the building. The method used in this research is computer simulation using CFD software to determine the effectiveness of adding roof ventilation in reducing carbon dioxide levels and simulation without a computer using mock-ups to see the movement of smoke in ume kbubu. The results of this study indicate that the effectiveness of roof ventilation reaches 60% so that the air quality in the ume kbubu room is safer for its users.

INTRODUCTION

The Atoni tribe is spread across the island of Timor which is administratively in the districts of North Central Timor, South Central Timor District, parts of the Kupang district and parts of the Oecusse-Ambeno region (the territory of the state of Timor Leste). The traditional houses of the *Atoni* people consist of two types, namely *lopo* (men's houses) and ume kbubu or round houses (women's houses). *Lopo* serves as a place to receive guests, a place for discussions, a place to weave cloth, is located in front of and ume kbubu. *Ume kbubu* serves as a place to cook and a place to rest at night. Both of these buildings have the same geometric shape, namely a round plan with 4 main pillars that support the attic above. The shape of the roof is both conical but has a difference in size where the *ume kbubu* roof covers almost the entire body of the building while the *lopo* roof does not cover the building body. Another difference is that *lopo* has no walls and is public, while *ume kbubu* has walls and is private.

The conical shape of the roof makes these two buildings very aerodynamic and can adapt to the climate conditions on the island of Timor, where strong winds often pass through. The closed *ume kbubu* building is a place to rest and shelter from the colder outside temperatures. Two beds are placed on the left and right with a fireplace in the middle which is used for cooking and heating the room (Lapenangga et al, 2020). Foodstuffs from garden produce in the form of corn and beans are stored in the attic in the *ume kbubu* where there is a fireplace below which functions to produce smoke as a natural preservative for stored food. The smoke from the fireplace also serves to drive away rats so they don't damage the stored food. Traditional houses with dual functions as a residence and kitchen that are not ventilated produce a lot of smoke which has an impact on the health of the occupants (Bebhe & Purwanto, 2023)

The indoor fireplace is an important part of an *ume kbubu*, where this fireplace functions as a medium for cooking daily food and drink needs, generates heat to warm the air at night and produces smoke for preserving food ingredients stored in the attic. The floor of the *ume kbubu* is directly above the ground so that the fireplace is made in the form of a traditional stove consisting of 3 stone stoves and using wood as fuel. It is this firewood that produces smoke in the room so that it affects the air quality in this ume kbubu. This building serves as a place to rest at night, a place to cook, a place to store food ingredients as well as a place for giving birth and caring for babies and women after giving birth to keep a warm temperature (Boli et al, 2021).

Temperatures that are too high or low in the room result in uncomfortable conditions and can affect health (Kencasari et al, 2020). Good air quality in the room affects the health of the occupants of the building, as well as the air quality inside the ume kbubu is also important for the occupants in it because its function is not only as a place to cook but also as a place to rest at night and as a place to warm the body from the cold air that occurs almost all year round because most of the Atoni tribe's territory is located in the highlands between 65-1007 meters above sea level for the South Central Timor region (BPS, 2021), Besides that, the function of ume kbubu is also related to the *sei* (grilled) tradition for postpartum mothers which is believed to remove residual blood after the birth process. Thus the air quality in this *ume kbubu* needs to be seriously considered so that the occupants can still feel comfortable in it.

One of the solutions to create a comfortable *ume kbubu* interior with good air quality is that good airflow is needed so that carbon dioxide from firewood smoke can quickly flow outside. A poor ventilation system will result in the accumulation of indoor pollutants from human activities and the equipment used (Aurora, 2021). Passive ventilation in an enclosed space is created by the difference in pressure between inside and outside the building caused by wind and differences in air temperature (Boonyaputthipong & Elnimeiri, 2018). The study of passive ventilation aims to study the heat dissipation process that occurs naturally (Laurini et al, 2017). Good air ventilation keeps the airflow moving to remove smoke but does not allow cold air to enter. A ventilation system like this can be presented with stack effect engineering by adding outlets (ventilation holes) to expel warm air in the room and smoke by taking advantage of the lower indoor air pressure difference which will move out through the outlet. Naturally, the principle of ventilation with a stack effect system is more due to the "suction" factor from the top which can occur due to the large difference in air pressure between the top and bottom (Ishak, 2013). The stack effect performance test uses CFD (Computational Fluid Dynamics) software simulation and miniature hardware. Testing with the software is based on the movement speed of the concentration of carbon dioxide particles coming out through the outlet (ventilation on the roof) which is affected by the temperature difference between the fireplace and the temperature at the outlet (Cahyani, 2017). Testing with hardware is based on the speed of movement of smoke coming out through the outlet (ventilation on the roof).

UME KBUBU

Ume kbubu, also often called round house, is the traditional house of the *Atoni* tribe. This tribe uses *ume kbubu* to shelter from cold weather and at the same time become a food storage barn for one year. The relatively cold weather influenced the community to provide a fireplace in the middle of *ume kbubu*. The smoke from the fireplace functions as a preservative for food in the attic as well as a preservative for wood and bamboo materials in this building (Lapenangga et al, 2020). *Ume kbubu* is able to maintain a stable temperature to keep it warm, so it is an option compared to *ume naek*. In addition, it needs a good design so that air circulation, especially smoke exhaust does not cause problems for the occupants, especially for babies who follow the *neno boha* tradition (Puspita et al, 2016). Round houses have long been suspected of being a contributor to health problems for their inhabitants, because they were built without windows and only have one main door. In general, a round house has a dual function, namely as a place to live, a kitchen and food storage, but from a health point of view, a round house is still far from being a healthy house. This is caused by the round shape of the house without ventilation so that light cannot penetrate into the house (Christiana et al, 2018). For 40 days the mother and her baby have to sit/sleep over the coals of fire that come from burning biomass (wood) inside the round house (*ume kbubu*). Emissions from burning biomass fuel can pollute the home environment and cause health problems for both mother and baby (Athena & Rachmalina, 2014).

INDOOR AIR QUALITY

Indoor Air Quality (IAQ) in rural households, particularly in single cell homes (SCH), is a critical issue while the population is cooking solid fuels (Parajuli, Lee, 2017). Increased attention to indoor air quality (IAQ) issues is also driven by the fact that indoor air pollution is more difficult to spread and dilute than outdoor air pollution (Camelia, 2011). The World Health Organization (WHO) has always emphasized the importance of indoor air quality (IAQ) and the potential hazard of pollutants emitted from indoor sources; thus, it has become one of the major determinants of health (Settimo et al, 2020). Indoor Air Quality (IAQ) is influenced by physical factors in the form of temperature, air humidity and air velocity and chemical factors in the form of substances in the air. Providing proper ventilation and exhaust systems for fireplaces in traditional homes is essential to creating better indoor air quality (Suryabrata, et al, 2007). The fireplaces in traditional houses use firewood which is a regenerative material. Firewood for rural communities is the only source of energy to meet their cooking needs because it is cheaper and easier to obtain (Dwiprabowo, 2010). In traditional houses in areas with cold temperatures, firewood is used to warm the body, but residents will continue to inhale sulfur dioxide (SO_2) and nitrogen dioxide (NO_2) which are contaminated in the air (Rantetampan et al, 2013). In traditional society, women are responsible for cooking and children often spend time with their mothers so that women and young children are more exposed to pollutants (Duflo et al, 2008). The chemical requirements for indoor air quality according to the Regulation of the Minister of Health of the Republic of Indonesia Number 1077/MENKES/Per/V/2011 states that the maximum carbon content required in the house is 1000 ppm for 8 hours.

Table 1. Chemical requirements for indoor air quality

No.	Parameter type	Unit	The maximum level required	Information
1.	Sulfur dioxide (SO_2)	ppm	0,1	24 hours
2.	Nitrogen dioxide (NO_2)	ppm	0,04	24 hours
3.	Carbon monoxide (CO)	ppm	9,00	8 hours
4.	Carbon dioxide (CO_2)	ppm	1000	8 hours
5.	Lead (Pb)	$\mu g/m^3$	1,5	15 minutes

Source: Menteri Kesehatan Republik Indonesia, 2011

Buildings without window openings limit the movement of indoor air and one way to control indoor air quality is to add ventilation to the walls or roof of the building. Ventilation on the roof can present a stack effect phenomenon in buildings. The stack effect is the result of differences in air pressure between environments, tall buildings and has a major impact on the functionality of these buildings, even in parts that will not be in direct contact with the outer walls (Simmonds and Zhu, 2013). The stack effect of air in buildings is generally the same as the effect of air pressure that occurs in building chimneys in cold climates, where low air pressure with high temperatures will move up and out through the outlet. This stack is useful for flowing air from indoors to outside, so that the heat in the room can escape and the room can be comfortable (Yohana & Novariawan, 2013). The pressure stack effect is generated by the difference and density of air with temperature, namely hot air rises and cold air descends. The stack effect is the result of reduced air density when there is an increase in temperature. The greater the temperature difference between the two airs in contact, the greater the buoyancy temperature. The difference in buoyancy is the driving force behind the circulation stack effect, depending on the temperature difference and the difference in height (Febrita, 2021). The drawback of the stack effect that causes stack ventilation flow to be stochastic is that stack ventilation may be difficult to control and predict as well as analyze and design (Jarzabska et al, 2021).

The temperature difference that is shown to increase vertically indicates the movement of the air flow upward with the magnitude of the velocity increasing vertically. Thus, the stack effect phenomenon in the humid tropics can be said to be successful (because it is able to pull airflow upwards, not backwards), although the results are quite low for indoor air velocity (Cahyani, 2017). The design character relates to the stairwell which continues to the roof, indicating a tendency to apply the "chimney ventilation" system (Sangkertadi & Rumagit, 2019). The shape of a high roof with roof ventilation will expel hot air trapped on the roof of the building (Sukawi et al., 2016). Chimneys and ventilation systems perform the basic function of exhausting smoke, spent air and moisture (Bajno et al, 2021). Community adaptation to smoke conditions in traditional buildings by increasing the distance between the walls and the roof of the house as an air gap for smoke to escape so it does not interfere with the health of the occupants (Prabaswara et al, 2021). The purpose of this study was to measure the levels of carbon dioxide in ume kbubu and the speed at which smoke moves out of the building during cooking activities so that indoor air quality is safe for residents.

METHODOLOGY

The method used in this study is a simulation method which is carried out in two ways namely; computer simulation and simulation without a computer. Computer simulation is carried out by modeling objects using applications on a computer to be simulated with data that is the same as the actual situation. The software used in this simulation is Auto CAD to create a 3-dimensional model which can then be used in CFD (Computational Fluid Dynamics) to process data (simulation) of air movement and indoor air concentration. Simulation with CFD to measure the concentration of carbon trapped in *ume kbubu* under existing conditions and conditions with stack effects. The use of CFD is carried out in two stages, namely the solvers (core solution search program) CFD calculates the conditions to be applied and the preprocessing stage is the final step in CFD analysis. The thing to do in this step is to organize and interpret the CFD simulation data in the form of images, curves, or animations (Maulana, 2016). The data used for modeling is obtained by measuring the physical form of objects supported by documentation. The data used to carry out the simulation is the carbon content in ume kbubu which is measured using a measuring device. The simulation without a computer uses an object mockup that is modeled at a scale of 1:10 to measure the speed of moving air. Simulation of a physical object is handled by using actual objects or materials on a scale that the material will be used in actual conditions (Groat & Wang, 2013).

RESULTS AND DISCUSSION

Carbon Measurement

This house is used as a residence with a fireplace in it producing carbon emissions that are harmful to health. Air quality is measured during cooking activities so that the measuring instrument used can easily record the carbon content produced from the fireplace. The measurement was carried out at 09.36 – 10.42 am, the measurement data is recorded in table 1 and figure 1. The room temperature was recorded at 26.5 0C and at the end of the measurement the temperature was recorded at 30.7 0C, the highest temperature was recorded at 34.0 0C with the highest carbon content up to 1004 ppm.

Table 2. *Ume Kbubu* carbon and interior temperature measurements

	Time	Temp (°C)	Humi (%RH)	DP (°C)	CO2 (PPM)
Beginning	09:36	26,5	72,6	44,3	543
Highest carbon	10:01	32,6	59,1	36,9	1004
Highest temperature	10:05	34,0	59,0	37,6	915
End	10:42	30,7	59,8	36,4	673

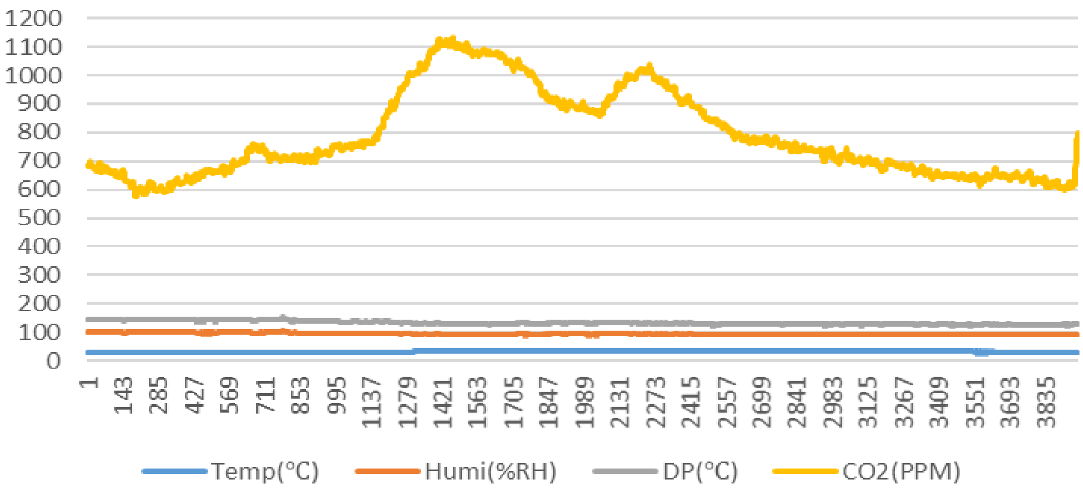


Fig. 1. *Ume Kbubu* interior CO2 measurement

In addition to carbon measurements, object measurements were also carried out to be modeled in software for simulation needs. For the need to simulate carbon levels in buildings, the software used is CFD using a 3D model from AutoCAD software. *Ume kbubu* has a circular plan with a diameter of 4.2 m with a cooking stove in the middle of the room. The walls are made of 1 m high bamboo slats and the conical roof is made of reed grass. The construction of the house consists of 4 main pillars that support 2 main beams and several joists and the attic floor above it. The conical shape of the ume kbubu without ventilation causes the smoke from burning firewood to be trapped for a long time and slowly escape through the pores of the walls and roof. Figure 2 shows the shape of ume kbubu which is the object of research.

CFD Simulation

The purpose of the simulation carried out with CFD software is done for two things;

1. Comparing the existing conditions with the results of previous carbon measurements
2. Test the recommended stack effect

CFD simulation consists of three stages of the process:

1. *Preprocessing stage*
   This stage is the stage of making a model that has been carried out using the AutoCAD application. The object model to be simulated is a fireplace room with a diameter of 4.4 m and a building height of 4.0 m and a cutting effect system is applied as a design recommendation. After that, the data and object models are ready to be input into the CFD software.

2. *Solution stage*
   This stage is the most important stage in the simulation process, where all data obtained related to carbon dioxide is then input starting from the type of material on the object, boundary conditions are points where carbon dioxide is generated with its concentration value, Meshing is the application of grids or cells "to object to simulate. After input data_data will then be completed iteratively until it reaches a convergent condition. Data Measurement of the condition of air contaminated by smoke (carbon dioxide) on average is 1,100 ppm. This data will be input into the CFD to find out what the spread of air conditions in a room contaminated with CO2 is like.

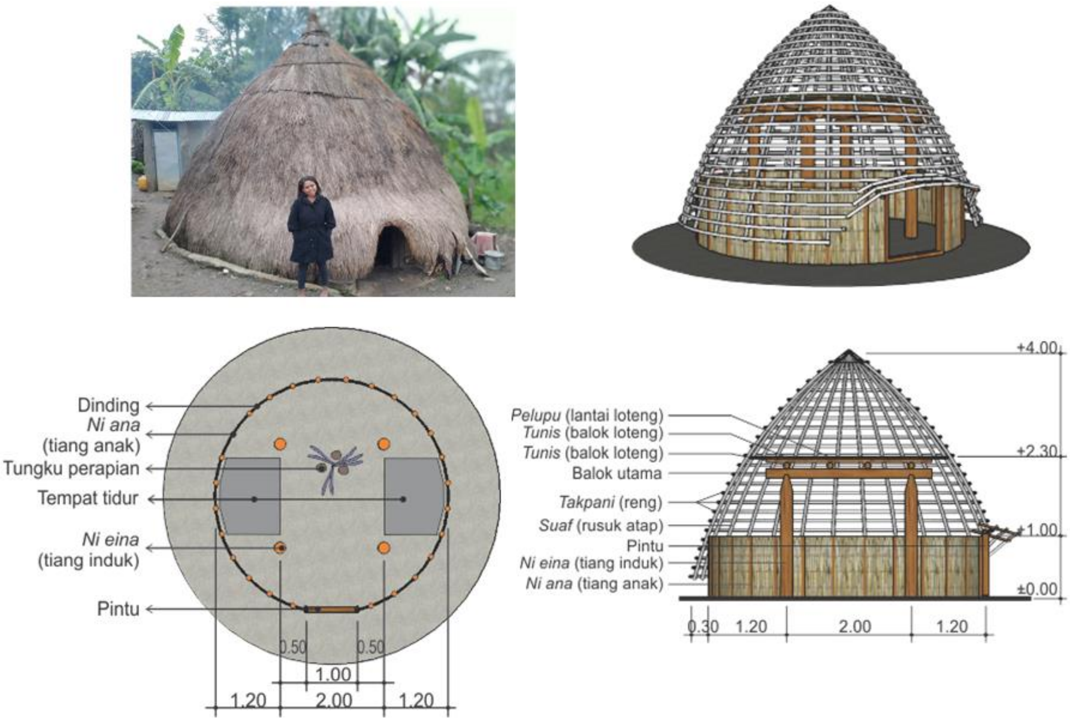


Fig. 2. The existing form of *ume kbubu*

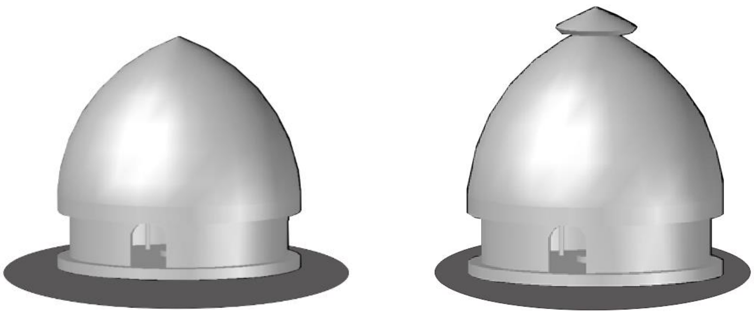


Fig. 3. *Ume kbubu* 3D model

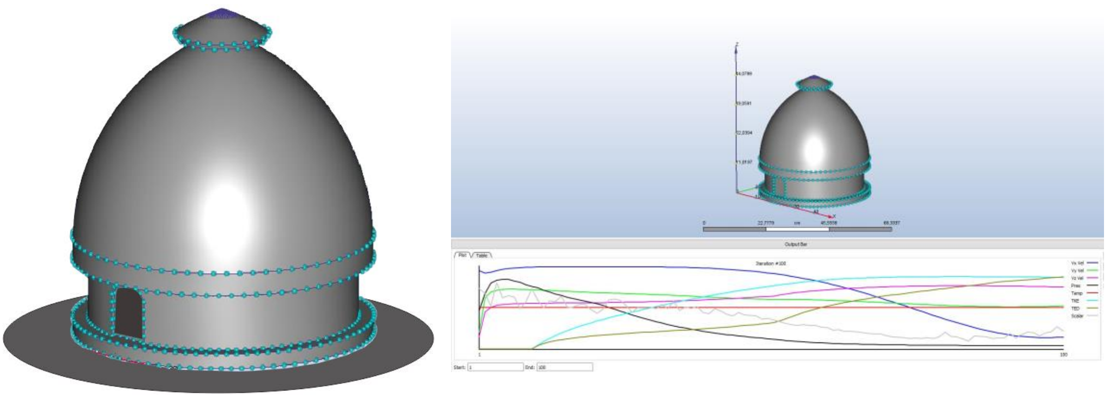


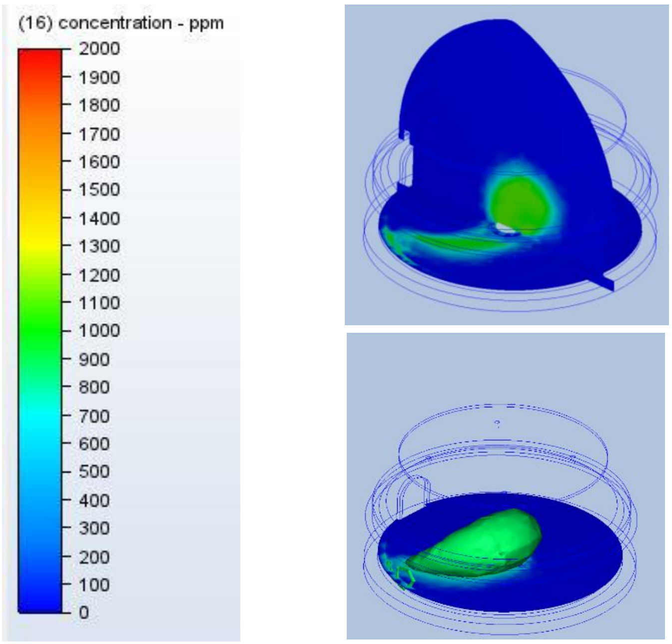
Fig. 4. *Ume kbubu* simulation process

3. *Postprocessing stage*

   At this stage is the result stage of the CFD simulation that has been carried out. The results of this CFD simulation can be in the form of velocity vector plots, pressure distribution contours, and the magnitude of aerodynamic forces. The results of this stage can be a reference for drawing research conclusions. Simulations were carried out on the existing model and the recommendation model.

   a. Existing

   The first simulation for the existing model with input data from initial measurements. The simulation results for the existing conditions show that air is exposed or contaminated with carbon dioxide of 1100 ppm and is trapped in the room and takes quite a long time to be dissolved by clean air.

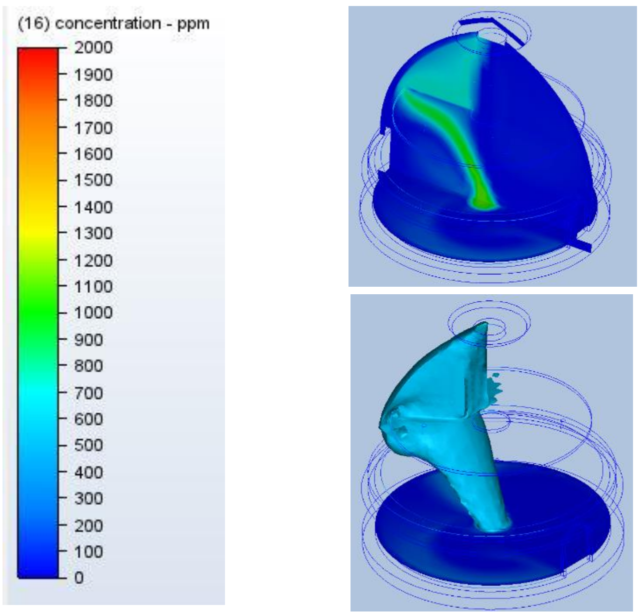


PARAMETER EXISTING SIMULATION

Fig. 5. The results of the existing Ume kbubu simulation

   b. Recommendation

   The results show that the air condition in the fireplace room will be contaminated by carbon dioxide in the room of 700 ppm, so the effect steck system applied is classified as effective because it is able to control the smoke produced in the fireplace room.



PARAMETER RECOMMENDED SIMULATION

Fig. 6. Simulation results of *Ume kbubu* recommendations

Mockup Simulation

The purpose of the simulation carried out with mock models is done for two reasons;
1. Demonstrate a real stack effect work system that supports the CFD simulation results
2. Test and compare the speed of movement of smoke coming out of the existing ume kbubu and ume kbubu using the stack effect

The mock model simulation consists of three stages of the process:
1. Modeling stage
   a. Mockup modeling
   The mockup model is built in a reduced form with a scale ratio of 1:10. The mockup roof cover uses a transparent plastic sheet to help visualize the stack effect system. The simulation process uses 1 mockup with two roof covering treatments, the first is the intact roof covering and the second the top of the roof covering is opened to produce a stack effect

Ume kbubu building	3D models	Jacket model with a transparent plastic roof cover

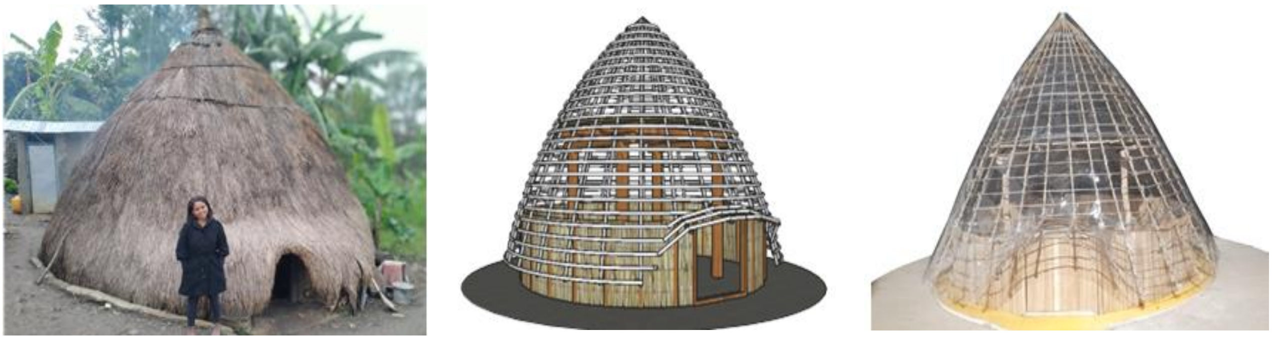


Fig. 7. The *ume kbubu* mockup model

   b. Simple smoke generator
   The stack effect system in the existing model model requires replacement smoke from the ume kbubu fireplace. The smoke effect is produced by a simple device assembled using a dynamo powered by a battery. The way this device works uses a 10 cm long paper roll to be burned in a pipe connected to a dynamo that works to apply opposite pressure to suck in the smoke and throw it out through another pipe. This tool is installed under a mock-up which is perforated at the point where the fireplace is so that the smoke from the tool becomes material for a simulation of the stack effect work system on the *ume kbubu*.

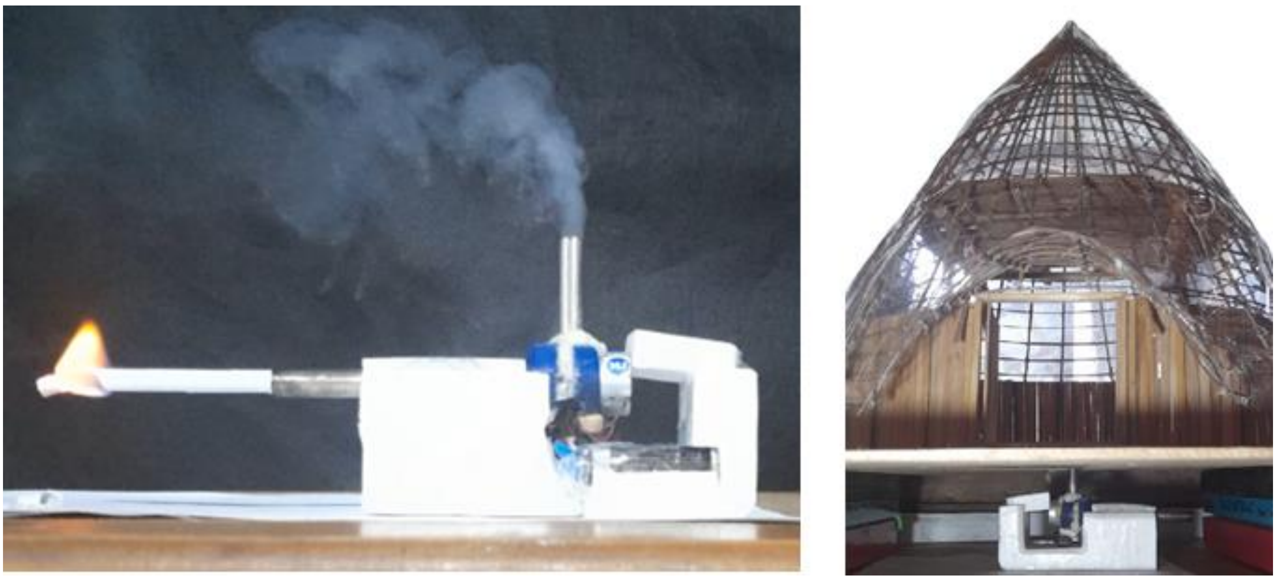


Fig. 8. A simple smoke generator

2. Testing stage

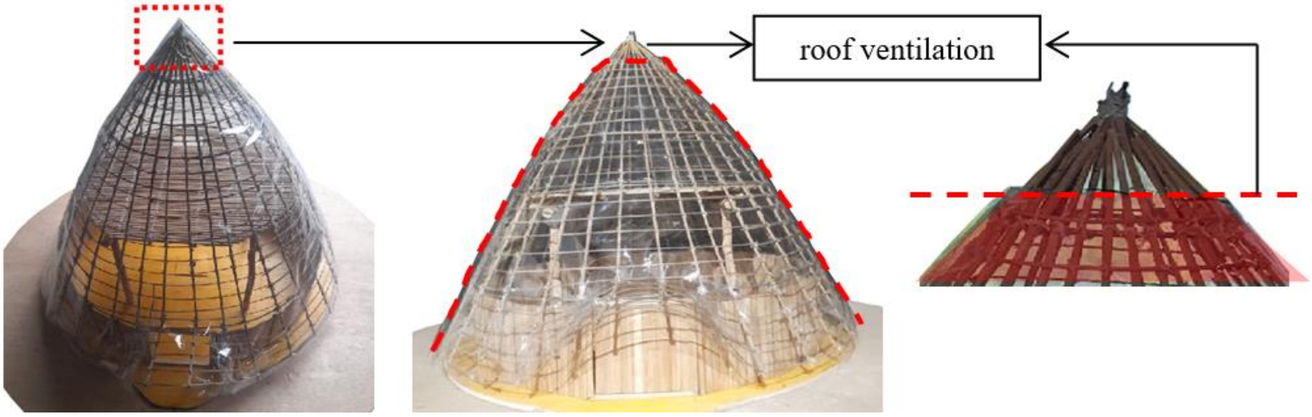
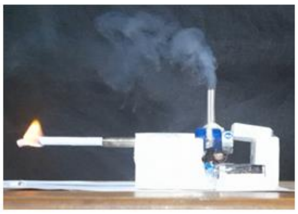
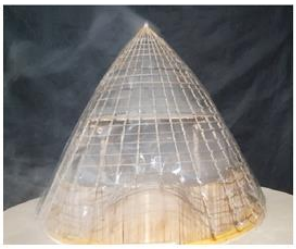


Fig. 9. Ventilation on the roof

This stage is to test the speed of smoke coming out of the building. The test was carried out in several trials; firstly, with the condition of the roof covering intact and the model door open, secondly with the condition of the roof covering intact and the door closed, thirdly with the condition that the roof cover is opened on the ridge side and the door is closed.

Table 3. Smoke movement time test

Simple smoke tool	Experiment 1 Open door	Experiment 2 The door is closed	Experiment 3 Closed door + stack effect
			
The time it takes for the smoke to come out until it is visible is 2 minutes	The length of time the smoke is trapped in the building is 10 minutes	The length of time the smoke was confined to the building was 15 minutes	The length of time the smoke is trapped in the building is 6 minutes

Validation of Research Results

The research results are then validated to ensure its success and benefits for society. This research is said to be valid if the research results show that the carbon contamination level is below the maximum number required by the Ministry of Health of the Republic of Indonesia. In addition to the level of carbon contamination, another indicator is the length of time carbon contamination lasts indoors.

Table 4. Validation of research results

No.	Research indicators	Ministry of Health of the Republic of Indonesia	Research results	
			Results	**Description**
1.	CO_2 contamination levels	1000 ppm	700 ppm	Carbon contamination below the threshold so that it is safe for the occupants inside
2.	Length of time of indoor CO_2 contamination	8 hours	6 minutes	The length of time for carbon contamination with the addition of ventilation on the roof with the door closed is under 10 minutes so that this ventilation becomes very effective

CONCLUSION

The testing process using CFD simulations or mockups shows some very significant research results as follows:

1. Additional ventilation on the roof can affect the difference in air pressure so that it can produce a stack effect phenomenon to expel smoke faster from inside the ume kbubu.
2. The simulation results with the use of roof ventilation show indoor carbon contamination of 700 rpm or below the threshold for chemical air quality (carbon dioxide) requirements in the house, namely 1000 rpm.
3. The speed of smoke moving outside the building with the stack effect system shows 9 minutes faster than the existing conditions.
4. The effectiveness of the stack effect system reaches 60%.

From the results of the above study it can be concluded that the addition of ventilation on the roof ridge of ume kbubu affects indoor air quality with carbon dioxide contamination below the required threshold so that the stack effect system can be applied to the actual ume kbubu building because it can produce safer indoor air quality to its users. The addition of ventilation on the roof affects the reduction of carbon dioxide levels in ume kbubu because the smoke moves out of the building faster. The results of this study are very important for the Atoni people who continue to use ume kbubu as a place for activities and shelter from the cold throughout the year and for postpartum mothers who need warm air but with healthier air quality.

ACKNOWLEDGMENT

Thanks are extended to Widya Mandira Catholic University for supporting all research processes by funding all research costs.

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