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Low energy measures for residential buildings in tropical regime

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Abstract. Towards the direction of developing sustainable building in tropical regime in general and in Indonesia in particular, facing multiple dilemmas, one of the dilemmas starting from the issue of the core variables in the green building which is low-energy buildings. By definition the main target for low energy building is the target for self-sustaining its energy supply while improving its efficiency. The issue of low energy building, in recent years, gained attention and moved towards a large-scale introduction in the residential sector. During this process, international criteria for energy use in buildings have become stricter, whilst the national standard for low energy building have not move forward only Jakarta municipality and Bandung municipality have developed its strategic regulation to achieve those targets. With a primary focus on landed house both for semidetached and detached houses, this study analyses how the measures the low-energy buildings which may further developed to reduce the energy use in the residential sector. The main attention is on the designing the façade, wind flow and local material performances. A thermal and fluid dynamics approach is applied, which here means that the concept of low-energy buildings is investigated from two main perspectives, namely thermal comfort with low energy uses by means of optimization for natural cooling. The thesis thus encompasses methods from both engineering approaches the studied areas through design, assessments and simulations. The thesis reveals how an increased process integration of the building's energy system can improve the thermal comfort in low-energy buildings. Moreover, local climate data was use, local material was collected – to study how the heat influences can be predicted in a low-energy building in the Bandung climate. The thesis further focuses on the low-energy building as an element in our society.

1. Introduction

Energy demand are increasingly increasing, while fossil energy sources are decreasing in number. The International Energy Agency (IEA) predicts that by 2035, global energy-related CO₂ emissions have exceeded today's levels by 20 percent [1]; this should appear rather thought-provoking. Although there are other energy sources besides fossil energy, renewable energy, but the amount is limited and still not as comfortable as fossil energy use. Besides that, the use of fossil energy causes an increase in greenhouse gas emissions that cause global warming. Data from KEMENLH (2009) shows, compared



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to other sources, the energy sector is the largest contributor to greenhouse gases (GHG), especially CO₂. So saving energy use is very important for the continuity of the comfort of human life on earth. Moreover, it is known that the cost of Rp. 1 (one rupiah) for each energy saving effort is equivalent to the cost of Rp. 2 (two rupiahs) for the construction of a new power plant. This is exacerbated by the fact that the efficiency of electricity generation, distribution networks and electricity use is very low. Moreover, the reliance on renewable energy for its vast growing energy consumption, the capacity of renewable energy (with the current technologies) will not be sufficient to supply the vast growing of energy demands, for which 150 GW is required by 2030 [2]. As a result, the country is compelled to rely on fossil fuel particularly the natural gas and coal, as it is predicted that the cost of crude oil will drastically increase during the next 10 - 20 years. The future electricity demand growth is estimated using trend from economic growth. Moreover in average of 6.84% up to 2050 and 2008 capacity is accounted to 21 GW and assumes to be increase up to 415.6 GW in 2050 (in line with the demand measurement) [3].

Buildings represent in terms of primary energy use around 40 percent in most IEA countries (IEA, 2013b) [1]. Therefore, if dangerous and irreversible climatic consequences are to be avoided, the implementation of low-energy buildings in our society is crucial. The built environment has throughout history been influenced and renewed by various factors, and innovations that have induced this development have originated from either technological progress or social change. Today, however, climate change has added a new dimension, presenting our society with major challenges including a need to change how we define buildings [4].

Among the large energy users for buildings is residential, in this case including the region. Based on this background, it is necessary to design a residential area that can support energy savings, namely a low-energy area. Regional design is very important in designing energy saving housing. According to Kurniawaty [5] aspects of regional design contribute 67% and aspects of building design contribute 33% to the creation of a comfortable and energy-efficient dwelling. This is not excessive because based on several studies indicate that the micro climate (micro climate) is very decisive for the creation of comfortable housing without the need for active air conditioning such as air conditioning. Shady areas and water features can have lower air temperatures up to 6 C compared to arid regions, even though the two areas are in the same area, thus reducing the burden on buildings to create comfort in the building. Differences in outside air temperature and air temperature in the building are the main factors driving the heat transfer process from the outside into the building. The smaller the temperature difference outside and inside the building, the less amount of heat that enters the room. This results in a reduced thermal cooling system load. Thus the mind-set needs to be changed from building oriented towards site oriented (exterior and regional). Moreover according to Utama [6], the most load in cooling at residential building for landed houses from its perimeter load, or the heat from the façade. Building enclosures contribute 10–50% of the total building cost and 14–17% of the total material mass. The direct as well as indirect influence of the enclosure materials plays an important role in the building life cycle energy. Single landed houses, the typical houses in Indonesia, have been chosen for this study [7].

2. Methodology

2.1. Thermal comfort in buildings

Performance from thermal comfort refers to the process of simulation and modelling of energy transfer between buildings and the surrounding environment. For buildings with AC (Air Conditioning), estimating the cooling and heating loads, so that the calculation and measurement of HVAC size (Heating Ventilation Air Conditioning) can be accurately done. For buildings without air conditioning, this process calculates the variation of room temperature in a given period of time and helps to calculate the duration of the times when the condition of the room is uncomfortable. This quantification method produces an effective way to design buildings and help improve the quality of design with energy efficiency and comfortable space.

Some heat exchanges are very possible between buildings and the environment outside. Parts of buildings such as walls, roofs, ceilings, floors, etc. Heat exchange also occurs from various building surfaces through convection and radiation. Besides solar radiation transmitted through translucent glass is also absorbed by the surface inside the building. Heat also arises from the presence of occupants in the building and also the use of lights and household appliances.

1 As seen in **Figure 1** which describes the heat properties of water vapor in graphical form. Understanding this psychrometric chart can provide conceptual understanding visually in controlled environmental conditions such as examples of how hot air can hold moisture, and vice versa how moist air cools and produces moisture. The green boundary shows a comfort zone that shows the average condition of the Indonesian people in general, where the average temperature is between 22-27° C and humidity between 40-60% [6][7].

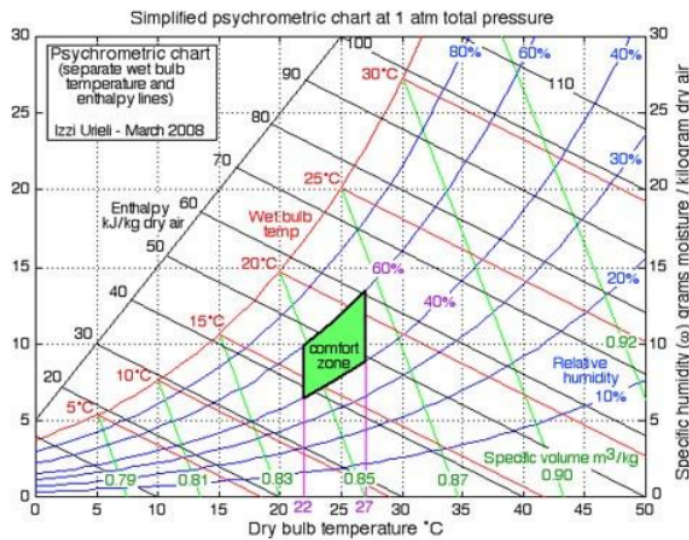


Figure 1. Psychrometric diagram for comfort zone, typical residential and typical industrial in Indonesia

2.2. Heat balance in the building

Designing low-energy buildings, also must take into account the heat balance, as shown **Figure 2**. Where information regarding heat coming from ambient, the heat coming from inside the building (internal heat), building orientation, windows, walls and type of roof, including climate data such as radiation, temperature (temperature) and wind speed. Material data including density, specific heat, conductivity and others. The heat balance in this building can help design buildings with thermal comfort and energy consumption in buildings.

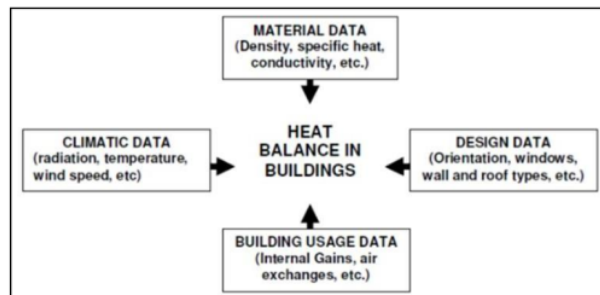


Figure 2. Heat balance in the building

As an example of the graphical analysis **Figure 3**, the conditions of the heat comfort (shows as temperatures) profile of a room with a brick wall are also shown here, where the temperature or room temperature shows a lower figure than the temperature outside the building, meaning that the brick wall provides comfort to the occupants of the building by prevent heat through by reducing

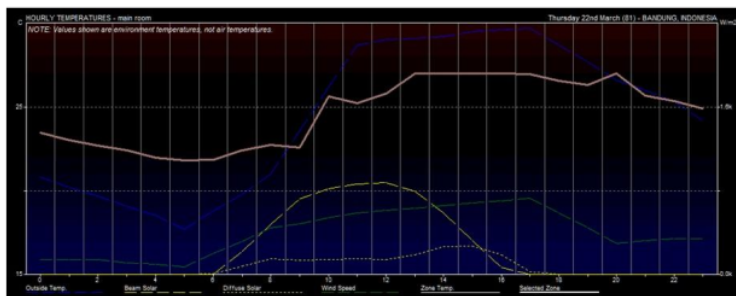


Figure 3. Example of a temperature profile with typical bricks wall

temperature.

Bandung was chosen as a study and analysis of low-energy buildings, the average temperature in this area is between 14-36° C, and the lowest position reaches 14-1° C at night and as high as 35-36° C which occurs during summer time during the day. The conditions of temperature, radiation, humidity in the study area as shown in the graph below, as seen that the hottest temperature peak points outside temperature occur between April, May and June. Air humidity is between 20% and the highest reaches 100% in heavy rain conditions. As shown in the air humidity in **Figure 4** below.

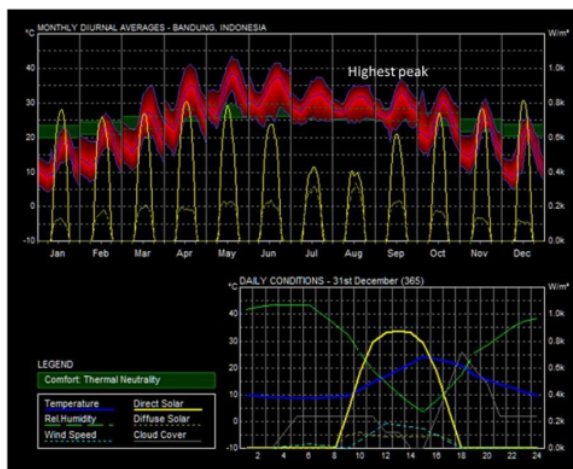


Figure 4. Temperature and humidity in the studied areas

2.3. Thermal comfort through fluid dynamic analysis

Many buildings in windy areas can use this energy to push air into a building on the side of the wind (the direction of the breeze) and cause it to come out on the side of a quiet wind (the direction of the wind is quiet). This type of natural ventilation can reduce the energy needed to move air inside the building, especially in large open plan offices. Restricting internal air movement will defeat the purpose of natural ventilation, which requires engineers and architects to make this decision at the beginning of the building design process. Because it is very difficult to get the right wind conditions

for natural ventilation, most of these types of buildings use a mixed-mode approach, installing fans to help air movement in stagnant wind conditions. In colder climate ventilation systems it is necessary to combine with a heat recovery system, so that hot air leaving the building can release some of its energy into the incoming air, thus avoiding some "energy penalties" to increase ventilation.

Natural ventilation is very important for conserving energy, reducing carbon emissions, and increasing the level of comfort of the built environment and indoor air quality. The Computational Fluid Dynamics (CFD) represents a combination of modern fluid dynamics, numerical mathematics and computer science. By using CFD wind environment simulation technology, architects can accurately project and intuitively describe the building's wind environment from design proposals, conduct analysis combined with knowledge in building technology science and simulation results, and analyze the strengths and weaknesses of various design choices and according to design revisions architecture [4].

Software for performing computational fluid dynamics is OpenFOAM and is an open source code. The power of OpenFOAM is a breaker and new utilities can be created by users with some prerequisite knowledge about basic techniques, physics and existing programming techniques. OpenFOAM is included with the pre and post-processing environment. The pre-and post-processing interface is an OpenFOAM utility, ensuring consistent data handling in all environments. The overall structure of OpenFOAM is shown in Figure 5.

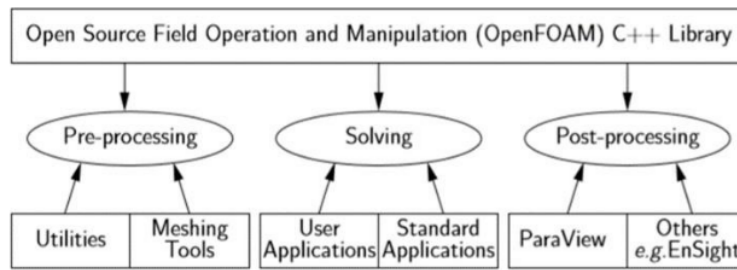


Figure 5. The overall structure of OpenFOAM

In summary, this module uses the following equations:

The continuity equation

$$\frac{\partial \bar{u}_j}{\partial x_j} = 0, \quad (1)$$

The Momentum Equation

$$\frac{\partial \bar{u}_i}{\partial t} + \frac{\partial}{\partial x_j} (\bar{u}_j \bar{u}_i) - \frac{\partial}{\partial x_j} \left\{ \nu_{eff} \left[\left(\frac{\partial \bar{u}_i}{\partial x_j} + \frac{\partial \bar{u}_j}{\partial x_i} \right) - \frac{2}{3} \left(\frac{\partial \bar{u}_k}{\partial x_k} \right) \delta_{ij} \right] \right\} = - \frac{\partial \bar{p}}{\partial x_i} + g_i [1 - \beta (\bar{T} - T_0)] \quad (2)$$

Where ν_{eff} is the effective kinematic viscosity, β is the coefficient of expansion.

The energy equation

$$\frac{\partial \bar{T}}{\partial t} + \frac{\partial}{\partial x_j} (\bar{T} \bar{u}_j) - \frac{\partial}{\partial x_k} \left(\kappa_{eff} \frac{\partial \bar{T}}{\partial x_k} \right) = 0. \quad (3)$$

Where κ_{eff} is the effective heat transfer coefficient

3. Result and discussion

3.1. Thermal result and analysis

The building to be simulated uses a simple building with a triangle shape as shown below. Assuming a wall height of 5 meters, the depth of space between the roof and ceiling is 1 meter deep, using red brick walls, tile floors and clay roof tiles and without using insulation. With building material properties such as seen in this picture Assuming ceiling thickness or ceiling is 10 mm, density or specific gravity 1100 kg / m³, specific heat is 840 j / kg. K and conductivity is 0.65 W / m. K.

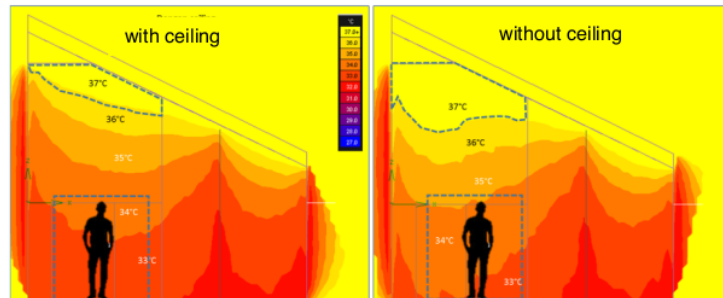


Figure 6. comparison of a studied house with and without ceiling

From the analysis (as seen in *Figure 6*), it can be seen that the usage of ceiling is not inevitable, since the ceiling can be strong enough to withstand radiation and heat convection generated from solar radiation through the roof of the building. As seen in the right picture when no present of the ceiling the radiated area shown in bright yellow colour (37°C) is larger than the design with ceiling, also reflected in the coverage area where human are standing. The area largely covered with temperature around 34°C where with ceiling is one degree less.

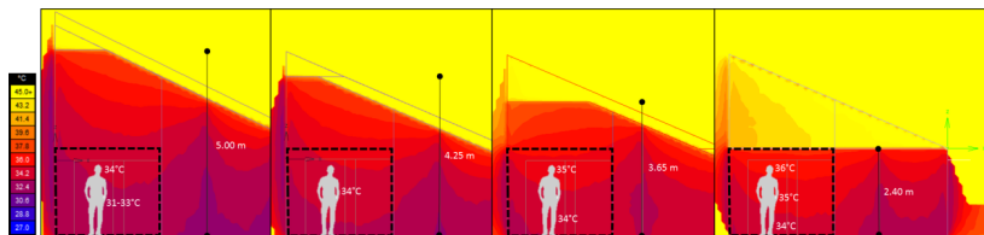


Figure 7. ceiling height simulation

Several simulation processes have been carried out in the study to determine the ceiling height, the ceiling height is simulated to get the lowest temperature area of various heights with some scenarios such as:

- 5.00 m (A),
- 4.25 m (B),
- 3.65 m (C),
- 2.40 m (D)

The results showed in *Figure 7* that the temperature difference that was not so dramatically changed from the ceiling with a height of 2.4 m and 3.65 m, where areas with temperatures of 35 ° C and 36 ° C were dominant. Whereas with the ceiling height at 4.25m the room temperature of 34-35 ° C dominates most of the room. As for the ceiling height at 5m the average temperature at the height of the human body in the range of 32.4 ° C.

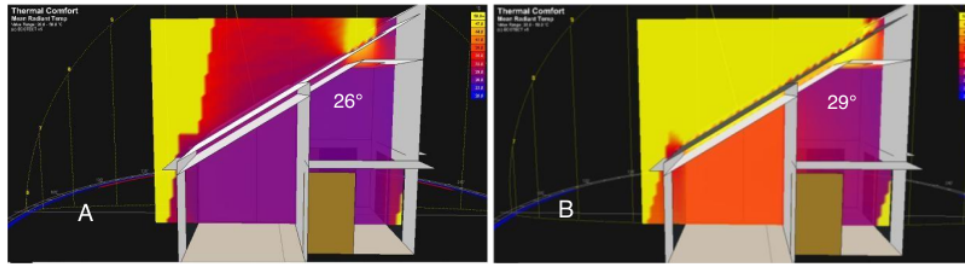


Figure 8. A: clay roof and B: corrugated metal roof

Two alternatives material for the design with 5 meter ceiling height is selected, namely A: clay roof and B: Corrugated metal roof (*Figure 8*). The simulation result shows a significant temperature different between two materials (up to 3 C), this is due to the thermal properties of both materials, mainly its conductivity, specific heat as well as its density.

3.2. Fluid dynamic result and analysis

It is also in our interest to investigate the effects of natural winds on air circulation in the design of our homes. Let's consider the wind coming from the front of the house with a wind speed of 5 km / h, which is a typical wind speed in Ciparay, see the sketch below in *Figure 9*. We want to design a good location from wind vents to take advantage of this natural wind. The CFD simulation results can be seen in **Figure 9** below. In this picture, shows the air velocity profile in this cutting plan which shows that the wind connects the house from the air vents below and above the front door. Currents from leaving the room from similar vents close to the back door. Likewise the wind that also entered the front bedroom from the front ventilation around the window.

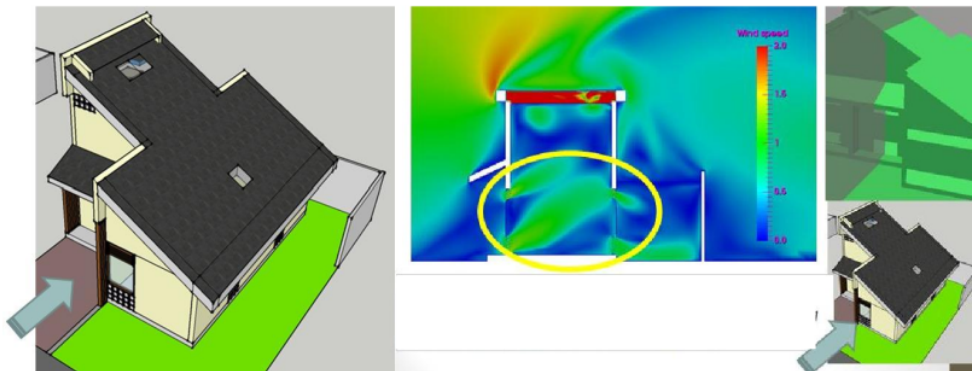


Figure 9. Natural wind direction to the model and its effect

There needs to be a hole in the bottom of the roof ceiling as an inlet for the natural convection process on the roof, under the tile. The width of the opening of this hole is as wide as possible by keeping in mind that rainwater does not enter, insects / birds not to enter, good aesthetics and safety. The choice for ceiling with holes is quite a lot and can be seen in the *Figure 10*.

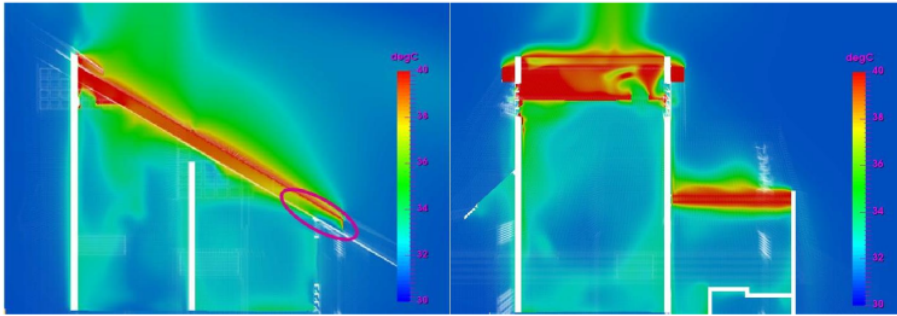


Figure 10. Opening in ceiling for increasing wind enter from ambient and exhaust fan to reduce heat trapped in the lower ceiling

There needs to be an exhaust hole in the living room ceiling to help cool the roof space and help circulate air in the living room. This exhaust hole is intended to drain the relatively hot upper air from the living room to the hotter roof area. To prevent backflow, ie from the roof area to the bottom, we recommend that the exhaust hole be equipped with a fan so that the reverse air flow will not occur.

More over the study reveals an interesting result for the case city of Bandung, Indonesia. However the possible similar study with relatively similar result may be possible to be implemented in the tropical regime with similar climate condition with Bandung, where the day-night temperature different are relatively high during dry season and relative humidity in between 40-60% during dry season and 60-80% during rainy season.

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