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Cost Benefit Analysis of Energy Retrofitting with the Addition of Ventilation Holes in Middle Low-Income Houshold Buildings

Rhesa A. Elvarettno[1], Nur L. Hamidah[2], and Mohamad F.N. Aulady[3]

Departemen Teknik Fisika, Fakultas Teknologi Industri dan Rekayasa Sistem, Institut Teknologi Sepuluh November[1,2]

Departemen Teknik Teknik Sipil, Fakultas Teknik Sipil dan Perencanaan, Institut Teknologi Adhi Tama Surabaya[3]

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ABSTRACT

The current climate change is characterized by an increase in the earth's surface temperature; one of the impacts that is felt quite significantly is the thermal comfort conditions in buildings. This will encourage residents to use air conditioning to provide the required level of thermal comfort. From the results of electricity demand forecasts, from 2017 to 2036, electricity demand will increase by 6.4% annually, dominated by the household sector at 38.49%. Efforts can be made to condition the room's thermal comfort to reduce the AC's operating time. This can be realized through building energy retrofitting, especially in middle-low-income households. Retrofitting will also not require high costs, so it suits middle-low-income households. In this research, retrofitting was carried out by implementing ventilation. It is hoped that ventilation will naturally provide air to specific rooms through air movement and exchange. This study implemented 12 variations in ventilation, namely variations with cross ventilation and non-cross ventilation, then varied the size of the ventilation and the number of ventilations. This research was carried out based on simulations using Computational Fluid Dynamics. After carrying out the simulation, it was obtained that the most significant decrease in indoor temperature was when cross ventilation was applied at night with ventilation measuring 30 cm x 70 cm with a total of 4 vents, namely with a decrease in the average indoor temperature of 1.614℃. After that, a cost-benefit analysis was carried out to compare the costs and benefits of a project; a cost-benefit ratio of 1.26 was obtained, where the profits were more significant than the expenditure costs, a payback period value of 0.402 was obtained, or the capital could be returned for five months, and savings were obtained. Electricity consumption costs up to year five amount to IDR 24,340,306.

Keywords: *Temperature, Retrofitting, Ventilation, Cost Benefit Analysis*

E-MAIL

elvarettano11@gmail.com
nurlaila.hamidah88@gmail.com
mohamadaulady@itats.ac.id

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LPPM- Adhi Tama Institute of Technology Surabaya
Address:
Jl. Arief Rachman Hakim No. 100, Surabaya 60117, Tel/Fax: 031-5997244

ABSTRACT

Perubahan iklim yang terjadi saat ini ditandai oleh peningkatan suhu permukaan bumi, salah satu dampak yang dirasakan cukup signifikan adalah kondisi kenyamanan termal dalam bangunan. Sehingga hal tersebut akan mendorong para penghuni untuk menggunakan AC untuk mengondisikan tingkat kenyamanan termal yang di butuhkan. Dari hasil prakiraan kebutuhan listrik, dari tahun 2017 sampai 2036 kebutuhan listrik akan meningkat 6,4% setiap tahunnya yang didominasi oleh sektor rumah tangga sebesar 38,49%. Sehingga upaya mengondisikan kenyamanan termal ruangan untuk mengurangi jangka waktu pengoperasian AC dapat dilakukan. Hal tersebut dapat diwujudkan melalui building energy retrofitting, khususnya pada rumah tangga middle low income. Retrofitting juga tidak akan memakan biaya yang tinggi sehingga cocok untuk rumah tangga middle-low income. Pada penelitian ini, retrofitting dilakukan dengan menerapkan ventilasi, diharapkan ventilasi menyediakan udara menuju ruangan tertentu secara alami melalui perpindahan dan pertukaran udara. Penelitian ini menerapkan 12 variasi pada ventilasi yaitu variasi

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dengan cross ventilation dan non cross ventilation kemudian divariasikan ukuran ventilasi dan jumlah ventilasi. Penelitian ini dilakukan berbasis simulasi dengan Computational Fluid Dynamics. Setelah dilakukan simulasi, diperoleh penurunan temperatur dalam ruangan yang paling besar adalah ketika malam hari menerapkan cross ventilation dengan ventilasi ukuran 30 cm x 70 cm dengan jumlah 4 ventilasi, yaitu dengan penurunan temperatur rata-rata dalam ruangan sebesar 1,614℃. Setelah itu, dilakukan cost- benefit analysis untuk membandingkan biaya dan manfaat dari suatu proyek, diperoleh rasio cost-benefit 1,26 dimana keuntungan lebih besar dari biaya pengeluaran, diperoleh nilai payback period sebesar 0,402 atau modal dapat kembali selama 5 bulan dan sehingga diperoleh penghematan biaya konsumsi listrik sampai tahun ke 5 sebesar Rp 24.340.306.

Keywords: *Temperatur, Retrofitting, Ventilasi, Cost Benefit Analysis*

INTRODUCTION

The use of the Earth has repeatedly experienced climate change, which has been happening for millions of years. Human activities and natural factors cause climate change with different impacts. Climate changes that have occurred over the years have caused rises and falls in temperatures on the earth's surface. However, climate change that is currently occurring is characterized by an increase in the earth's surface temperature or what is known as global warming. Global warming is the process of increasing the average temperature that occurs in the atmosphere, sea or land. The Intergovernmental Panel on Climate Change (IPCC) concluded that most of the increase in global average temperature that has occurred since the mid-20th century was most likely caused by an increase in greenhouse gas concentrations caused by human activities through the greenhouse effect phenomenon [1]. This will cause the phenomenon of climate change to become greater so that the risk of increasing global warming will be even higher. Climate change is considered one of the greatest challenges facing humanity. There is a global push to reduce greenhouse gas emissions in all sectors [2]

One of the impacts that is felt quite significantly is the thermal comfort conditions in buildings. As we know, residents who live in a building will need a certain level of comfort. The comfort aspect felt in the building will greatly influence the health and productivity of the occupants. However, due to an increase in the earth's surface temperature, areas with tropical climates will experience excessive heat, which will have a significant impact on the level of thermal comfort in buildings. Then, this will encourage occupants to use the HVAC (Heating, Ventilating, Air Conditioning) system to condition the required level of thermal comfort. In the Future, HVAC energy consumption will increase further due to increased population growth, rapid expansion and demand for new residential and commercial buildings, and increased global warming due to climate change [3].

The behavior of residents who have the habit of using AC every day will greatly influence the level of electrical energy consumption in the household. Of course, we know that operating an AC system requires a large consumption of electrical energy. During peak hours, the electrical load of residential AC systems can cause an imbalance between electricity supply and demand. Expenditures to finance electrical energy consumption are one of the main important expenses in a household. From the results of electricity demand forecasts, from 2017 to 2036 electricity demand will increase 6.4% every year, dominated by the household sector at 38.49%, the industrial sector 36.62%, the commercial sector 19.35%, and public sector. 5.54% [4]. Excessive electrical energy consumption will cause an increase in household expenses. And this will greatly affect the household economy, especially middle-low income households.

To anticipate this, a residential building with a good level of thermal comfort is needed so that the occupants of the building do not need to consume excessive electrical energy to operate the HVAC system at all times. However, for middle-low income households, it is felt that they cannot afford to implement such a complex green building concept where various aspects must be considered so that it will incur high costs in its implementation. Thus, a method is needed to realize a building design that is able to condition the level of thermal comfort at a low cost and is easy to implement. One effort that can be made to make this happen is by carrying out building energy retrofitting. Building operations can meet individual needs after retrofit. Likewise, annual energy consumption can be reduced by 57% compared with the national average of office buildings in China. These findings provide useful input for future energy-efficient building retrofit practices as well as policy-making processes [5].

Need to know that retrofitting is the process of modifying something after it has been produced. Meanwhile, building energy retrofitting or retrofitting carried out on buildings involves changes to the system or structure after initial construction and occupation. This effort can increase the comfort felt by building occupants and improve the performance of the building. Retrofitting can be applied to one aspect of a building to obtain ideal conditions in the building. Retrofitting will also not require high costs so it is suitable for use by middle-low income households. Building retrofitting can provide direct economic benefits in the form of reducing building heating and cooling costs. Apart from that, building energy retrofitting can also provide indirect economic benefits in the form of increasing property values or rental levels in buildings and increasing the level of living comfort.

There are several retrofitting efforts that can be implemented to achieve the required level of thermal comfort. For retrofitting carried out on the building envelope, if replacements are carried out using appropriate materials on windows, retrofitting on external windows shows higher cost effectiveness than retrofitting carried out on external walls. By retrofitting carried out on building windows, the WWR (Window to Wall Ratio) value can be varied to determine the most significant impact in reducing the cooling load. Retrofitting heat sources and outdoor heating pipe networks is cost-effective, while retrofitting building envelopes is not economically profitable [6]. So retrofitting which is carried out by adding additional ventilation holes can be carried out considering that this effort does not require high costs to implement. Retrofitting of ventilation holes can be done by varying the number and diameter of ventilation holes in the building.

That the presence of vents on the roof and window grilles in buildings can influence thermal comfort conditions, especially areas inside the building [7]. So retrofitting which is carried out by adding additional ventilation holes can be carried out considering that this effort does not require high costs to implement. Retrofitting of ventilation holes can be done by varying the number and diameter of ventilation holes in the building.

After retrofitting is carried out, of course you need to know how much influence it has on the electrical energy consumption of the building. Thus, a cost-benefit analysis is carried out on the use of electrical energy. It should be noted that cost-benefit analysis is used for the process of identifying, measuring and comparing social benefits, as well as project costs or investment programs in evaluating the use of scarce economic resources so that they can be used efficiently [8]. From the cost benefit analysis carried out, it will be known how effective the retrofitting has been so that electrical energy savings can be achieved in the building.

Based on this, research is needed related to building energy retrofitting in order to create buildings with a level of thermal comfort that meets specified standards so that efficient use of electrical energy in middle-low income households can be achieved. In this research, retrofitting of ventilation holes in buildings will be carried out as part of efforts to condition the building's thermal comfort. After retrofitting is carried out, it is necessary to carry out a cost benefit analysis to find out how much influence retrofitting has on the use of electrical energy in middle-low income households.

METHOD

Data collection

The data that needs to be taken is the size of the building, namely the length, width and area of the building which is the object of research, then data collection on building temperature and humidity is carried out 3 times, namely in the morning, afternoon & evening as thermal comfort parameters and data collection on electricity consumption costs per month.

Creation of Residential Geometry

Building design for middle-low residential houses located in rusunawa Jl. Siwalankerto is located on tower E, 1st floor, residence number E-109. Using Solidwork software, a 3D design was created. You can see in the picture below the E-109 residence before retrofitting

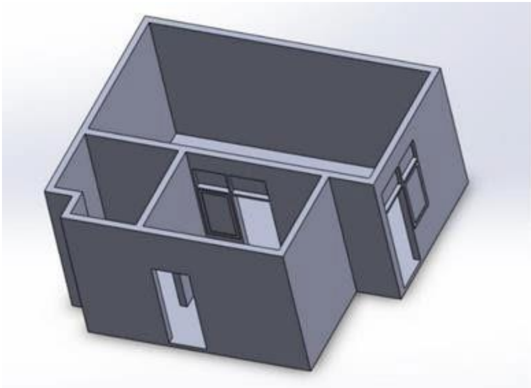
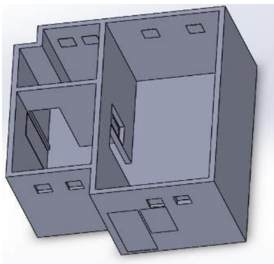
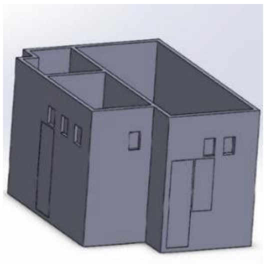


Figure 1. Geometry of the E-109 Residential Building before retrofitting
Source: editor's personal document, 2023

After making the geometry before retrofitting, then modeling the geometry of the E-109 building after retrofitting by varying the ventilation using the theory of cross ventilation and non-cross ventilation and then varying the number of ventilation and position of ventilation as shown in the picture below.



(a)



(b)

Figure 2. a) Cross Ventilation Building Geometry, b) Non Cross Ventilation Building Geometry

Source: editor's personal document, 2023

Computational Fluid Dynamic (CFD) Simulation

This research was carried out using the Computational Fluid Dynamics method to simulate the air convection process in a room. In the simulation carried out, there are several steps such as entering 3-dimensional building geometry, doing meshing, doing set up where the data obtained is then entered for processing purposes, doing processing where the software carries out calculations or iterations to produce the desired output, and post -processing where the results of the simulations appear in the form of average indoor temperature values and temperature distribution contours in the E-109 residence

Data validation

The validation stage is to compare the simulation results with the simulation results and the grid independence test with theory. By comparing we will know whether the simulation we have carried out is correct or wrong, if it is still wrong then the simulation needs to be carried out again and if the simulation results are valid according to the parameters we want then we can proceed to the next step.

Analysis of Simulation Results

After carrying out a simulation using Computational Fluid Dynamics, the simulation output will be obtained in the form of temperature distribution contours in the building (room) in 2 types of building designs have been designed. In a series of Computational Fluid Dynamics methods, this process is called postprocessing. From the simulation output, you can observe the disparity between the temperature distribution contours in the building before the retrofit concept is applied & after the retrofit concept is applied through the use of a predetermined diameter and number of ventilation. Then, an analysis of the simulation output is carried out in order to find out what the impact is in terms of thermal peace obtained from the retrofitting efforts implemented in the building design that has been designed.

Cost Benefit Analysis

When carrying out a cost-benefit analysis, it is necessary to calculate two main aspects, namely calculating the costs required for implementing retrofitting and calculating the profits or benefits obtained from implementing retrofitting. As for obtaining ventilation costs, it is obtained from field research in building shops and prices in online shops, while calculating aspects of labor costs and total costs.

RESULTS AND DISCUSSION

Validation

Validation was carried out by comparing the simulation results using Computational Fluid Dynamics with the results of direct measurements at the E-109 residential location at the data collection stage which had been carried out previously. Simulations carried out using Computational Fluid Dynamics are carried out with parameters adjusted to the real conditions from which the data is collected. Please note that data collection for validation purposes was carried out on Tuesday, March 15 2022 at 19:00 WIB in clear weather. Based on the results of the simulation, the indoor temperature obtained at the temperature measurement position was 27.9℃. Meanwhile, the temperature measured when collecting data was 27.1℃. Thus, an error value is obtained based on the following calculation. The results of the simulation that has been carried out can be seen in Figure 3 as follows. Thus, the error value obtained is based on the following calculation.

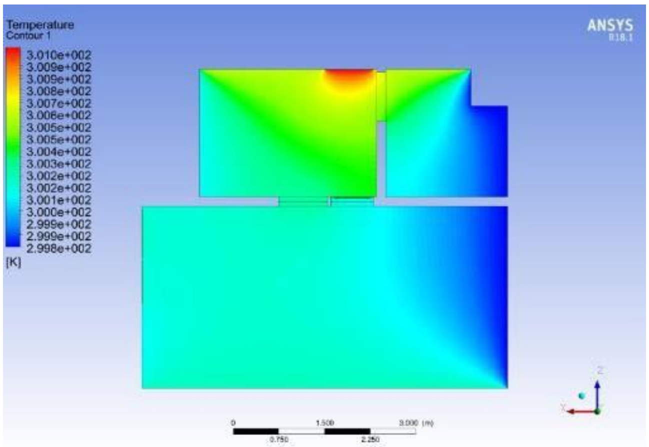


Figure 3. E-109 Residential Temperature Contour Without Retrofitting

Source: editor's personal document, 2023

Grid Independence Test (GIT) Results

This research carried out 7 iterations with variations in max face size ranging from 50 mm to 20 mm which resulted in a number of elements ranging from 1,537,231 to 10,458,267. The parameter that is considered in the GIT process is the average temperature in the room. After carrying out the GIT process, the results obtained are shown by the graphic plot in Figure 4 Grid Independent Test Results in the following image.

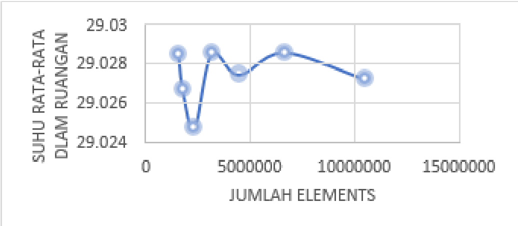


Figure 4. E-109 Residential Temperature Contour Without Retrofitting

Source: editor's personal document, 2023

It can be seen that when the number of elements is more than 3113638, the average temperature value in the room begins to approach a constant state. Thus, a mesh arrangement with a number of elements of 3113638 is used as a reference for the entire simulation in this study.

Analysis of the Effect of Ventilation Variations

This research has variations in the form of ventilation positions using the theory of cross ventilation (front and back) and non cross ventilation (front and left), then also variations in ventilation area 30 cm x 70 cm, 40 cm x 40 cm & 50 cm x 20 cm and Variations in the number of ventilation, namely 3 ventilation and 4 ventilation, are applied to the E-109 residence in order to condition thermal comfort.

A. Mathematical Calculation Results of Heat Transfer in Wall Layers

At the data collection stage, indoor and outdoor temperatures were measured on the west, east, north and south sides. The temperature value is then calculated mathematically for the heat transfer rate to obtain values for the indoor and outdoor temperatures of the building wall layers.

B. Indoor Contour Results

As has been mentioned, the indoor temperature contour is the result of a simulation of the air convection process carried out using the Computational Fluid Dynamics method with the help of ANSYS Fluent R18.1 software. The resulting temperature contour represents the room heat distribution when implementing retrofitting variations in E- 109 residential. The following is an example of the results of a simulation that has been carried out, namely the best simulation results at night are as follows:

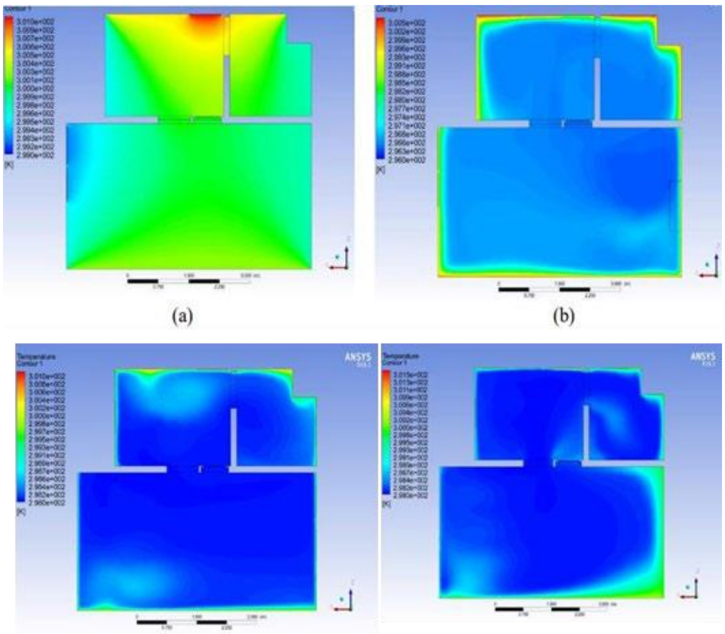


Figure 5. Indoor Temperature Contour is best at night (a) Before Retrofitting without AC, (b) Before Retrofitting with AC, (c) Cross Ventilation_30cm x 70cm_4 vent, (d) Non-Cross Ventilation_30cm x 70cm_4 vent *Source: editor's personal document, 2023*

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