Portable humidifier for refrigeration systems isolation room in a simple residential house

N Ruhyat[1*], *A* Firdaus[2]

[1]Mechanical Engineering Department, Mercu Buana University, Indonesia
[2]Industrial Engineering Department, Mercu Buana University, Indonesia

Abstract. Humans need fresh and clean air to live healthily. However, being in a dense and dense residential environment can potentially transmit diseases such as infections, bacteria, viruses, airborne microorganisms (airborne microorganisms), fungi, and other sources of infectious diseases. This is a concern in the air conditioning system. The air conditioning system regulates the air conditioning in the room to meet ideal conditions such as temperature and humidity. If you look at the Technical Guidelines for Buildings and Infrastructure Standards for Emerging Infectious Diseases (PIE) Isolation Rooms from the Ministry of Health of the Republic of Indonesia in 2020, at least the air temperature of residential rooms can reach an air temperature of 24 ± 20°C, with a relative humidity of 60%, so that fresh air is fulfilled. Experiments on portable humidifiers using single and double condensers from a refrigeration system provide design data on the need for air temperature and humidity for isolation rooms in simple residential houses. The standard temperature can be reached in a portable humidifier with a single condenser, namely 26-28°C. However, the humidity is still relatively high, at 80%, so bacteria can survive. However, when the air temperature in the lowest section (evaporator) is conditioned (10, 15, and 20°C), the air temperature exceeds the standard limit (39,38°C), even though the humidity is very low, reaching 34%. In experiments using a double condenser, the standard temperature and humidity can be said to be achieved; the temperature is 31°C, and the humidity is at 67%.

1 Introduction

Temperature, humidity, and air velocity are the most dominant factors in thermal comfort. Air refreshing is a process of cooling the air to reach the required temperature and humidity for the air condition of a particular room. In addition, it also regulates airflow and cleanliness [1,2]. Air freshener units are generally used for comfort, creating comfortable air conditions for people in a room. Various cooling, heating, and ventilation systems can be designed and used accordingly to achieve this. So, when selecting an air freshener system, users and designers must agree on how to meet the conditions and requirements set as well as possible [1]. The impact of indoor temperatures that are too low can cause health problems up to hypothermia, while temperatures that are too high can cause dehydration to the point of heat

* Corresponding author: nanang.ruhyat@mercubuana.ac.id

stroke. If the air temperature is above 30ºC, reduce it by increasing air circulation by adding mechanical/artificial ventilation. If the temperature is less than 18ºC, it is necessary to use space heaters using energy sources that are safe for the environment and health [3].

The Refrigeration System was used in this study to obtain the ideal temperature and humidity for self-isolation rooms, especially for simple dwellings. The system is designed with single and double condenser modifications that are used in a portable way. The function of the condenser, which dissipates heat into the environment, is used to kill bacteria or potentially infectious diseases that are sucked into the dehumidifier. The air temperature is lowered by adding moisture, which passes through the evaporator pipe and then flows back into the air around the room.

The isolation room is one of the rooms with special treatment, both in terms of planning and implementation. This specificity is aimed at preventing the occurrence of diseases that have the potential to be transmitted, both from patients to people in the environment, as well as from the environment to patients. In the planning process, especially in the air conditioning process, the isolation room pays attention to thermal comfort and controlling temperature and humidity. The 2020 Technical Guidelines for Buildings and Infrastructure for Emerging Infectious Disease Isolation Rooms (PIE) from the Ministry of Health of the Republic of Indonesia requires the air temperature in the Hospital Isolation Room to be 24 ± 2°C with a relative humidity of 60% [4].

This study aims to make an air freshener for a simple prototype-shaped residential house in an individual isolation room. The need for air conditioning devices for independent patients at home drives this need. The test is expected to produce a fresh, clean exhaust air temperature of 24°C-26 °C. Meanwhile, it will be the object of further research for planning purposes of space ventilation, cooling load, and others.

2 Materials And Method

2.1 Air Quality

Ventilation is where air enters and exits a room in a building. Air entry and exit are intended as air circulation, which makes the room conditions comfortable, maintains normal humidity, and meets the requirements [4]. Suppose the ventilation airflow rate is produced from permanent air holes, windows, or doors. In that case, it will significantly impact the growth of microorganisms in the room if the air exchange that is made does not meet the requirements and will eventually disrupt human health [5].

One method to reduce the time and/or the number of microorganisms to which a person is exposed is to increase the degree of dilution of clean air into a space [6]. This reduces the exposure time to microorganisms generated indoors by objects, staff, or patients. Table 1 below shows the time needed to clean the filtered air room, assuming perfect mixing.

As shown in Table 1, microbes can stay in a room for 14 minutes at 20 minutes of air change per hour (ACH 20) and 28 minutes at ACH 10. ACH (Air Change Hour) is essential for human respiratory health. ACH is a measure used to describe how often the air in a room is entirely changed in one hour. This is important for human respiratory health because indoor air quality can affect our health. When the air in the room is not sufficiently exchanged with fresh air from outside, the air condition can deteriorate. Polluted air, containing particles such as dust, air pollution, allergens, cigarette smoke and chemicals, can be trapped indoors. Breathing this contaminated air continuously can cause respiratory problems, such as eye irritation, nasal congestion, coughing, shortness of breath, allergies, and even more serious health problems. By increasing the number of indoor air changes through the ACH value, we can reduce the accumulation of indoor pollutants and improve the air quality. Fresh air entering the room helps remove existing pollutants and provides sufficient oxygen for breathing. In addition, the ACH value is also important in controlling humidity in the room. High humidity can create an ideal environment for the growth of mold, dust mites and other organisms that can affect respiratory health. By having a high ACH value, indoor humidity can be controlled and prevent humidity-related health problems. For this reason, the ACH value will be a reference in research in setting ACH achievement targets in the room.

Table 1. Effect of air change rate on particle removal.

Air Changes per Hour, ach	Time Required for Removal Efficiency of 99%, min	Time Required for Removal Efficiency of 99.9%, min
2	138	207
4	69	104
6	46	69
8	35	52
10	28	41
12	23	35
15	18	28
20	14	21
50	6	8

2.2 Classification of Isolation Rooms in Hospitals

An isolation room is a room that has a technical specialty as a ward for patients who need isolation treatment due to their illness and has modular physical limitations per patient, walls, and door and window openings with other isolation rooms [4]. This room is reserved for patients suffering from infectious diseases and vulnerable patients. Exposed to transmission from other people, patients suffering from diseases that cause odor (such as tumor disease and diabetic gangrene), and patients suffering from diseases that make noise in the room. The following details the classification of the isolation room according to its function, including:

- Individual isolation room = negative class (N),
- Infant isolation room = standard class (S)
- Isolated emergency room = positive class (P).

The discussion of this research is more focused on individual isolation rooms (class N) conditioned for simple occupancy.

2.3 Class N (Negative Pressure)

Classification for individual isolation rooms is class N (negative) isolation rooms, where class N is a room for isolating patients capable of transmitting infections through the air. One of the requirements for air conditioning in class N includes an air ventilation system in the isolation room, which uses a ventilation system where 100% of the air is discharged outside the isolation room, or no air is recirculated. Requirements for air conditioning in class N, among others:

1) The Class N Isolation Room temperature is conditioned around 24 - 26°C.
2) Humidity for Class Negative isolation rooms must reach a 30 – 60% RH humidity. If the moisture does not get the recommended level, use a desiccant base dehumidifier unit to reduce high humidity.

3) Negative Classroom airflow is recommended to follow the flow pattern as follows:
   a. Recommended airflow pattern from corridor to anteroom.
   b. Airflow from the anteroom to the isolation patient room.
   c. Airflow from the isolation patient room to the toilet room.
4) The air pressure between the Negative Class Room in the isolation room and other rooms is no more than 15 Pascals (Pa).
5) If the air in the patient room is recirculated, passing through a HEPA filter is recommended before entering it back into circulation.
6) Recirculation can be used, if conditions are not possible, use a HEPA filter (99.97% @ 0.3μm DOP) when air is recirculated.
7) Exchange in Class N Isolation Rooms is recommended to have 12 air exchanges per hour (ACH 12) or 145 litres per second per supply of air.
8) Recommended Air Supply should at least meet the patient's fresh air requirements (a minimum of 7.5 l/s/person [15 CFM per person] / Fresh air.
9) The air ventilation system in the isolation room uses a ventilation system where 100% of the air is discharged outside the isolation room.
10) At a minimum, the air supplied to the isolation room must be filtered using a MERV 7 prefilter with an efficiency of 75% and MERV 14 rating air filters (90% dust spot test filters).

The minimum area requirement for residential houses in Indonesia is regulated in SNI 03-1733-2004. Based on SNI 03-1733, 2004, the minimum area of a simple house (assuming one family consists of 4 people) is 36m² or 9m² per person [7]. The minimum area requirement is calculated based on the human need for fresh air when doing activities indoors. [7,8 and 9]. The need for fresh air per hour for adults is 16-24 m^3 and for children per hour is 8-12 m^3, with air changes in the room as much as 2 times per hour (ACH = 2) and an average ceiling height of 2.5 m [9], then the floor area per person can be seen in Table 2.

Table 2. Residential floor area per person.

Floor Area	Minimum Area	Maximum Area
Adults	6,4 m^2	9,6 m^2
Children	3,2 m^2	4,8 m^2
Residential Area	28,28 m^2	43,2 m^2
Average Residential Area		36 m^2
Residential area per person (4 people/house)		9 m^2

Sumber: (SNI 03-1733-2004)

The space requirements for a landed house are based on SNI 03-1979-1990 concerning Dimensions of Space: a sitting room, dining room, bedroom, kitchen, bathroom, toilet, bathroom + toilet, room, ironing room, and warehouse [9]. The need for fresh air is calculated based on the formula [10]:

$$L \text{ per person} = U / Tp \quad (1)$$

With:

L per person = Residential floor area per person,
U = Fresh air requirement/person/hour in m^3 units,
Tp = Minimum ceiling height in m units,

CMH (Cubic meters per hour) = room volume x Air Changes Per Hour (ACH) (2)[11]. In this study, the room width is 2.5 meters; the room length: is 3 meters, and the room height is 2.5 meters. Included in the criteria for a simple house, where the area of the room is 2.5 x

3 is 7.5. This value is included in the category of adult floor area [7], namely (6.4 to 9.6 m2). So, the volume of the room is 15 m3.

The ACH value for class N individual isolation rooms is 12 times per hour, meaning that the number of air changes that occur within one hour in a room is 12 times. Then, the target airflow into the room with a total volume of space of 15 m3 x 12 = 180 CMH (Cubic meters per hour). So, if the target is in a room with a volume of 15 m3, then the minimum volume of air flowing into the supplied room is 180 CMH. This value is used as a reference to determine the booster fan of the dehumidifier to provide a minimum air supply of 180 CMH. When the space initially with ACH was 2 after being set up to be an isolation room, the CMH changed to 180 CMH.

2.4 Tools and materials

Testing is carried out by collecting several tools and materials that will be used during testing and tools in testing must be prepared. The following tools and materials will be used in prototype testing:

2.4.1 Tool

The tools used for data collection during testing are shown in the following Table 3:

Table 3. Auxiliary tools

Description	Specification
Stopwatch Pressure Gauge Hygrometers Thermocouple Thermometers Thermocouple Cable	Casio HS3 HTC 2 Hti HT-9815 Type K
Condenser dan Evaporator Compressor Capillary pipeCoil filter X-Ray blue light Fan	Ø 8 inci/200 mm, L = 4 m Fuji Kobe SR52 No. 1231000708/ 220V-240V-50Hz/ 1 PH- R134a Ø 2 inci Ø 0,28 inci KIDZLABS 00-03315 VDS-25WK (A) AC AXIAL

Fig. 1 shows the prototype of the dehumidifier:

https://doi.org/10.1051/bioconf/202515906003

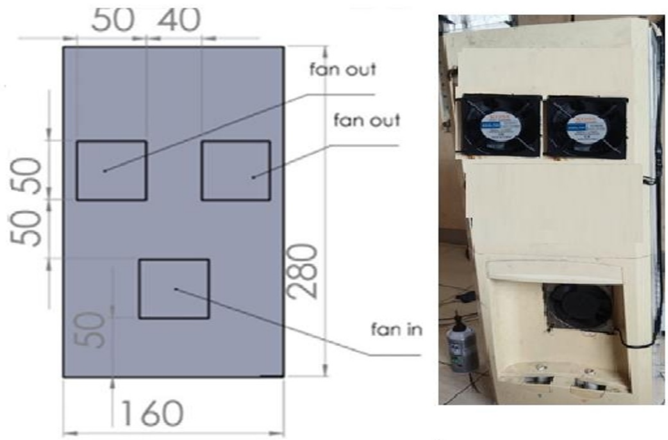
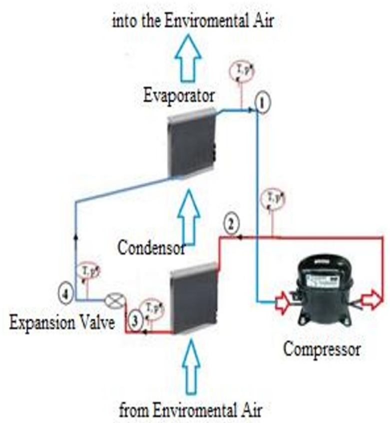


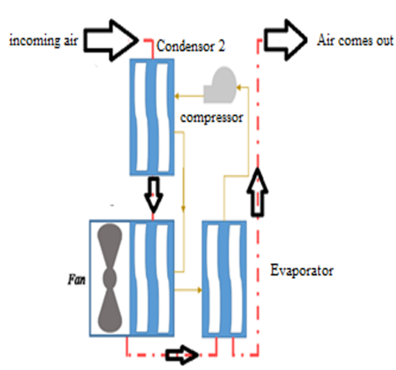
Fig. 1 The 1:5 Scale Prototype Design (CAD)

2.4.2 Testing

After the test preparation is carried out and all testing requirements are met, the test implementation can be carried out in the ways shown in Fig. 2.



(a)



(b)

Figure 2. Test implementation

2.4.3 Work Steps in the Experiment

The refrigeration system used in this study consisted of a 1 HP hermetic compressor, condenser, evaporator, expansion valve, and blower. The workings of the refrigeration system are not changed; they are only modified by heating the air with the condenser and then flowing it into the evaporator room and the ambient air. In the first step, air from the environment with a temperature range of 25-30°C is measured with a thermometer-thermocouple. The fan sucks in air from the environment around the refrigeration system. The airflow rate is continued towards the outside of the condenser pipes as a step for air heating. The condenser is a heat exchanger that functions as a place for refrigerant condensation. Heat is released due to the high pressure and temperature of refrigerant vapor at the end of the condensation process. The heat released by the condenser is received by the air flowing outside the pipes, increasing air temperature. Then, it is passed outside the first condenser pipes as the initial step in heating the air. The air completely absorbs the heat from the first condenser and flows into the second condenser room. The air temperature when leaving the outside of the condenser pipes is 40, 50, and 60°C.

Meanwhile, the refrigerant temperature in the condenser is 50, 6,0, and 70°C. Furthermore, the hot and dry air from the first condenser flows into the second pipe. This air heating process can kill disease bacteria that enter from the air in the room, and then flow it into the evaporator pipes.

In the second step, the evaporator is a heat exchanger that functions to lower the temperature of the incoming air from the condenser and then flow it into the environment so that the air that passes through the outside of the evaporator tube pipe experiences a temperature change, i.e., the air is more humid and has a lower temperature after leaving the evaporator. The pipes that surround the evaporator. In this section, you can add HEPA filters and ultraviolet light.

By adjusting the pressure on the refrigerant, namely by rotating the expansion valve (needle valve) in the refrigeration system, the temperature of the air coming out of the outside of the evaporator pipes is measured without causing the air to freeze. Freezing can be seen on the surface of the expansion valve. Measurements with thermocouples on the input and output sides of the air passing through the outside of the evaporator pipes, the air is humidified/condensed to get a low temperature of the air coming out of the outside of the evaporator pipes, which is obtained at a temperature of: 10, 15, and 20°C. As well as the RH value on the air outlet from the outside of the evaporator pipes is also measured using an RH meter. In this step, the evaporator utilizes low temperatures to condense water vapor in the air. Air entering the outer side of the evaporator pipes decreases the water vapor content in the air, reducing temperature and air condensation. Evaporation as a liquid refrigerant vaporization occurs by adding heat from the environment to the refrigeration system. Heat can be supplied by separating the vapor from the liquid by condensing the refrigerant. The refrigerant used is R134a, intended to obtain a low operating temperature. The specific humidity of the air is kept constant during the cooling process, but the relative humidity will increase. If the relative humidity increases, then the moisture content of the air must be removed. This requires cooling the air below the air dewpoint temperature. When passing through the cold side of the outside of the evaporator tubes, the air temperature decreases, and the relative humidity with the specific humidity of the air is constant. As the air reaches its maximum relative humidity, it reaches its dew point or saturated air. If the air is cooled, the water vapor will condense. Condensation is the process by which vapor is converted to liquid due to the significant internal energy difference between the liquid and vapor states, which is significant during condensation.

3 Result and Discussion

Two types of testing are used: a refrigeration system with one condenser and two condensers. Table 4 Testing with One Condenser as follows:

Table 4. Dehumidifier testing with one condenser.

Air from the environment		Air temperature outside the condenser pipe	Air temperature outside the evaporator pipe	Air to the environment	
Temperature	RH			Temperature	RH
°C	%	°C	°C	°C	%
30.8	70.3	47.7	10	39.84	43.24
30.3	63.8	47.9	10	39.80	43.33
30.4	66.5	46.3	10	34.60	57.55
29.6	83.1	44.3	10	40.50	41.74
30.0	80.0	44.4	10	40.20	42.42
29.8	82.0	44.4	10	39.40	44.27
29.1	65.9	51.4	15	34.14	59.04
28.9	75.8	51.3	15	44.70	33.48
29.5	72.2	49.5	15	44.60	33.66
29.4	71.2	44.2	15	38.91	45.46
30.4	77.8	35.5	15	39.00	45.24
29.8	80.5	35.8	15	40.80	41.08
29.8	70.4	45.9	20	39.46	44.13
29.7	72.7	44.9	20	33.90	59.83
29.1	71.4	45.7	20	44.47	33.88
29.8	68.6	44.9	20	42.42	37.71
29.2	70.3	43.7	20	38.92	45.43
29.7	78.8	36,4	20	33.10	45.43
31.0	70.5	32.4	27	28.10	83.30
30.0	74.6	33.0	26	27.70	80.32
29.0	79.1	37.0	27	27.30	82.23
30.1	74.2	42.0	25.5	27.40	81.74
29.4	77.3	41.3	25.0	26.40	86,69
29.1	78.6	40.4	25.1	27.00	83.68

Air humidity is the water vapor content in the air. In contrast, relative humidity is the ratio between the amount of water vapor in the air and the maximum amount of water vapor that can be accommodated at a specific temperature. Humidity is an essential factor in thermal comfort when the air temperature approaches or exceeds the comfort threshold, and the air humidity is between 40 and 80%, as shown in the test results in Table 4. Utilization of wasted heat from the condenser to kill bacteria and others, of course, by conditioning low air in the passage of air through the evaporator. The refrigerant inside the evaporator is conditioned at a temperature of 10, 15, or 20°C by adjusting the pressure on the compressor or the air temperature in the outer pipe of the evaporator under normal conditions without changing the pressure on the compressor. Then air comes out of the dehumidifier at 20-40°C, with a relative humidity of 40-60%.

However, if the temperature and pressure of the compressor, where the expansion valve is not set in such a way, then the resulting air temperature is 25-30°C with high humidity, which is 80%. Under indoor conditions, this air humidity affects heat release from the human body. High air humidity will make it difficult for the heat in the human body to be released, so that this condition will create a feeling of discomfort. Sufficient wind speed is needed in the room to compensate for this high humidity condition. In contrast, relative humidity is the ratio between the amount of water vapor in the air and the maximum amount of water vapor that can be accommodated at a specific temperature.

Table 5. Dehumidifier Testing with Two Condensers.

Air from the environment		The air temperature outside the pipe			Air to the environment	
Temperature	RH	Condenser 1	Condenser 2	Evaporator	Temperature	RH
°C	%	°C	°C	°C	°C	%
29.4	77.25	70.9	37.6	31.2	31.5	68.49
29.9	75.05	74.9	37.9	30.8	30.3	64.51
30.3	73.35	75.3	38.3	32.5	32.5	64.72
30.9	70.87	76.2	38.6	33.4	30.3	69.09
31.5	68.49	68.4	33.2	29.1	29.7	71.51
32.1	66.2	72.5	37.2	38.7	31.6	64.15

As seen in Table 5, the effort to kill bacteria in the air is increased in the first condenser and in the second condenser. Furthermore, until the air comes out of the dehumidifier, the air temperature is around 31°C with a relative humidity of 67%. This slightly corresponds to the ideal conditions for an isolation room, where the temperature is 24 ± 2°C with a relative humidity of 60%.

The comfort limits due to air temperature for the equator are 19°C (lower limit) - 26°C (upper limit). At a temperature of 26°C, humans generally start to sweat. Human endurance and workability begin to decline at temperatures of 26–30°C. The environmental temperature starts to feel quite challenging to accept at a temperature of 33.5°C TE– 35.5°C TE, and at a temperature of 35°C TE – 36°C TE, the environmental conditions can no longer be tolerated. Uncomfortable air conditions reduce productivity levels, such as being too cold or hot, while human work productivity can increase in comfortable (thermic) temperature conditions. So, the recommended dehumidifier is a refrigeration system designed for an isolation room in a simple residential house with a double condenser.

To add to the disease elimination function by filtering or trapping unwanted particles in the air, a High-Efficiency Particulate Air (HEPA) Filter can be used. Filters are made of several regular fiber composites mixed randomly. These fibers generally consist of fiberglass with a diameter of 0.5 – 2 micrometers. An important point that is useful for this filter function is the diameter of the fiber [12], with a filtering efficiency of up to 99.997%.

Furthermore, it is recommended that Ultraviolet be used. Ultraviolet light (UV) is part of the electromagnetic spectrum with a wavelength between 100 – 400 nm between the spectrum of X-rays and visible light. UV is classified into several groups based on its wavelength, namely UV-A, with wavelengths between 315 nm and 400 nm, can cause changes in human skin color to brown or black (tanning); UV-B, with wavelengths between 280 nm and 315 nm, causes burning human skin and often used for irradiating cancer, UV-C with a wavelength between 200 nm to 280 nm is an effective germicidal region for killing bacteria and viruses [13]. According to the Regulation from the Ministry of Health (1204/Menkes/SK/X/2004), it is required that the number of microorganisms for maximum sterilization purposes is bacterial contamination, especially from indoor air contamination or indoor air quality and the activities of staff and patients who participate as a source of contamination rather than bacteria.

4 Conclusion

Based on testing of 2 types of refrigeration systems against dehumidification for isolation rooms, it can be concluded that:

1) The results of the prototype air dehumidifier that will be used in individual isolation rooms have been successfully made and tested with the resulting air outlet temperature of 3°C. Meanwhile, the targeted air temperature is 24°C-26°C. Significantly, it can meet the temperature target based on the 2020 Technical Guidelines for Building and Infrastructure for Emerging Infectious Diseases (PIE) Isolation Rooms from the Ministry of Health of the Republic of Indonesia, in isolation rooms with ACH 12 standards.
2) A portable humidifier prototype from a refrigeration system with a double condenser for individual isolation rooms in simple residential houses achieved an air RH of 67%. There is still an opportunity for further development on the amount of power in the tested compressor.

References

1. Setyawan, Andriyanto. Bahan Ajar Sistem Tata Udara II. Bandung: Politeknik Negeri Bandung. (2010).
2. Y. Hadi, T. Azaria, N. K. Putrianto, T. Oktiarso, Y. Ekawati, and S. Noya, “Analisis Kenyamanan Termal Ruang Kuliah”. [Online]. Available: http://ojs.atmajaya.ac.id/index.php/metris]. (2020)
3. Kementrian Kesehatan Republik Indonesia. Pedoman Teknis Prasarana Sistem Tata Udara pada Bangunan Rumah Sakit. Jakarta. (2012).
4. Direktorat Jenderal Pelayanan Kesehatan Kementrian Kesehatan Republik Indonesia. (2020). Bangunan dan Prasarana Ruang Isolasi Penyakit Infeksi Emerging (PIE). Jakarta.
5. Riyanto, Tito. Kriteria Sistem Tata Udara Ruang Isolasi dalam Penanganan Infeksi Covid-19. Yogyakarta: Deepublish]. (2021).
6. ASHRAE. HVAC Design Manual for Hospitals and Clinics Second Edition. Atlanta: American Society for Healthcare Engineering. (2013).
7. Badan Standar Nasional Indonesia 2004. SNI 03-1733-2004 tentang Tata Cara Perencanaan Lingkungan Perumahan dan Perkotaan. (2004).
8. Keputusan Menteri Kipraswil. Keputusan Menteri Kimpraswil Nomor 403/KPTS/2002 tentang Rumah Sederhana Sehat. (2021).
9. Badan Standar Nasional Indonesia. SNI 03- 1979-1990 Spesifikasi Matra ruang untuk Rumah dan Gedung. (1990).
10. Neufert, Ernst. Data Arsitek Jilid 1. Jakarta: Erlangga. (1996).
11. Mahatma Sindu Suryo. Jurnal Permukiman Vol. 12 No. 2 November 2017: 116 – 123, Analisa Kebutuhan Luas Minimal Pada Rumah Sederhana Tapak di Indonesia. Pusat Litbang Perumahan dan Permukiman Badan Litbang Kementerian Pekerjaan Umum dan Perumahan Rakyat. (2017).
12. Afian Ferdi, Budhijuwono Ardhito, Agustina Amilya, and Anditiarina Dasti, “Efektifitas Hepa Filter Dengan Charcoal Dalam Penyaringan Organofosfat Di Kabin Pesawat”. (2021).
13. T. Ariyadi and S. Sinto Dewi, “Pengaruh Sinar Ultra Violet Terhadap Pertumbuhan Bakteri Bacillus sp. Sebagai Bakteri Kontaminan,” vol. 2. (2009).