35-Energy Consumption

By Jaka Nugraha
ENERGY CONSUMPTION AND THERMAL COMFORT FAVORED BY THE OCCUPANTS IN THE AIR CONDITIONED HOUSE

SUGINI¹, Jaka NUGRAHA²

ABSTRACT: This paper is part of a research report sponsored by the Indonesia Higher Education titled PMVtapsem Model of Thermal Comfort Saving Energy in Air Conditioned Building. Phase previous studies have found the best PMVtapsem thermal comfort models. From the test results it can be concluded that the model PMVtapsem models are models that can explain the concept of the relationship of thermal comfort hierarchical variable appropriately. However, for the determination of comfortable thermal range in order to thermally comfortable standard setting, it turns out the model PMVtap Sugini 2007 more precision and more simple than the models PMVtapsem. The next research phase will include the following steps: (1) Looking for a model of the relationship between the energy consumption of air conditioned homes with thermal comfort settings favored by the occupants; (2) Test the comfortable range of thermal based thermal index PMVtap Sugini 2007 experimentally in controlled air conditioned room; (3) Connect a comfortable thermal range of the result of step (2) with a model of the relationship of energy consumption in homes air conditioned in step (1). Observation in the air conditioned house is the method being used in this research. The variable observed are the thermal comfort indicated by the Air Conditioned option and energy consumption variable indicated by the raising of electricity account as the result of AC usage per unit AC loads. The population in this research are the air conditioned house with its occupants. The data collection involve 234 family. The second is to determine the setting of thermal comfort in the air conditioned room and the relation between the energy consumption and thermal comfort setting in air conditioned room to figure out the increasing energy consumption due to the favorite thermal comfort option. The conclusion of this research shows that the relation between the comfort thermal (AC setting) with the energy consumption could be shown in the pattern $y = 0.342 + 0.00432 x$ and $y = 1.44 - 0.0291 x$. Thermal comfort range perceived comfortable by 80% of occupants between PMV-0.75 up to 1.7 or PMVtap-1.29 up to PMVtap 1.21 and 23° ET up to 30.5° ET in AC setting with the temperature 25 and fan 1 and 5 up to 30 and fan 1. The increasing of energy consumption on the thermal comfort option of 0.45% per one unit workloads (per day per PK) for 25 degree Celsius temperature setting with the low fan, 0.88% per unit workloads for 25 degree Celsius temperature setting with the maximum fan and 0.47% per unit workloads with 30 degree Celsius temperature with low fan. By ignoring the fan setting, thus with the 25 degree Celsius fan setting will increase the energy consumption for 2.3% per unit workload.

KEYWORDS: Sustainability, thermal comfort, energy consumption, air-conditioned house

1. INTRODUCTION

1.1. BACKGROUND OF THE PROBLEM

Global warming happening nowadays have a strong relation with the number of world energy consumption. The whole world energy consumption was used 45,36% for the building. Out of the highest energy used for the building operational was used for the artificial air in the air conditioned room (Wigginton dkk, 2006). Thus, this research was directed to the operational of artificial air energy efficient using air conditioned is urgent and important.

The development of index model of the energy efficient thermal comfort become very urgent and fundamental to be done. By this research, the standart range of comfort thermal could

¹ Architecture Department, FTSP, Uii. Email: sugini@uili.ac.id
² Department of Statistics, Mathematics and Science Uii. Email: jnugraha@gmail.com
be composed by considering the physical-physiological and psychological aspect, also the aspect of energy efficient will be the correction of the existing standard thermal quality. In the end, the corrective standard of comfort thermal will reduce the air-condition (AC) workload in a air-conditioned room. The regression of one AC for 600 watt by one hour in a day will save the operational expenses for the Rp 150,000,000,00 energy a year and reduce the pollutant gas production CO2 by 160 kg/year. This saving would be multiplied with the number of AC operated in Indonesia. Next, the thermal comfort standard based on this energy efficient thermal index PMVtapsem will be the basic of the development of design direction.

Sugini, 2007 based on the index model of PMVtap already construct the thermal comfort range. This range will be decreased mathematically. By mathematic calculation, Sugini assumed the resulted range will have the chance to reduce the thermal energy workload in air-conditioned room. The question is how the reality in the real operational level? Comfort thermal for the air-conditioned room measured by several index. SNI put the thermal comfort standard on ET while ISO put the standard on PMV index thermal. Those standard developed by Sugini 2007 into the PMVtap and expanded its development on 2013-2014 by Sugini and Jaka Nugraha on research funded by higher education directorate using Fundamental Scheme research. This paper were part of those research.

The attainment of the comfort thermal air-conditioned room done by the occupants by the option of AC setting on the temperature and fan. While the energy consumption due to the AC usage could be seen on the amount of electricity account bill.

1.2. THE FORMULATION OF THE PROBLEM

- How is the relation pattern between the thermal comfort setting air-conditioned house with the increasing of energy consumption?
- How was the range of favourite comfort thermal in the air-conditioned house?

1.3. THE PURPOSE OF THE RESEARCH

- To figure out the relation pattern between the thermal comfort setting air-conditioned house with the increasing of energy consumption
- To find out the favourite comfort thermal range in a air-conditioned house
- To find out the energy consumption due to the favourite AC setting

2. THEORITICAL FRAMEWORK

2.1. STATE OF ART THERMAL RESEARCH THE RANGE OF THERMAL COMFORT AND ENERGY EFFICIENCY

Study about the range of comfort thermal has been done inside and outside Indonesia. Based on Sugini's research (Sugini, 2007) can be concluded that based on the equation of PMVtap Sugini and the regression relationship between PMW with ta and ET* for the scope of case on the air conditioned room group could be known that every increasing 0.1 degree PMW would impact the increasing temperature for 0.56 Celcius Degree. This meant that by principle the standard of thermal comfort in air conditioned room could be increase by 2.968 degree celcius.

If this theory being implemented in a practical level, especially in a air-conditioned building, it will give a significant impact. According to Oseland (1994) every one degree regression on AC usage it will reduce at least 10% energy consumption of the artificial operational air in the building, save 5 % or household energy consumption and 3% save the office operational
expenses. Thus the increasing air temperature for 2,968 degree celcius will save 29,68 energy consumption on operational building artificial air. The next question arise, by using
the analysis SEM model is it possible to produce the thermal index model PMVtapsm which
have more chance to formulate the range of the energy-efficient comfort thermal? This
research was trying to answer that question.

Muhammad Nur Faji Alfata Fanny Kusumawati, 2011, compare two of the Triharsokaryono
research on 1998 and 2011. In 18 years range on the same object and group sample shows
the similarity that comfort thermal based on thermal index PMV and PPD was not suitable
with the range of thermal comfort by the occupants. Respondent could receive the higher
comfort thermal range. The conclusion of those research shows that there are still enormous
opportunity to develop better standard seen from the demands of the occupants nor the
energy conservation. The next question that should be answered are (1) how high the range
of thermal comfort range which is acceptable so it can give significant impact on the
decreasing energy need for the air control; (2) If the index PMV and PDD can not be used to
predict the range of comfort thermal, what is the suitable index thermal for the Indonesian
condition? These two question can be answered by this research.

Sujatmiko Wahyu, 2010 found out that based on perception of the occupant condition
thermal comfort of the observation area below the neutral point. This research shows the
same indication that during this time the building operation with the setting of comfort thermal
setting has not suitable with the potention of the occupant ability to adapt with the comfort
thermal room. Thus, the real search of the comfort thermal range suitable with the ability of
human psychological to adapt and the pursuit the better index thermal will be an important
ting to do. So this research is significant to be done because it will give significant effect.

In the previous year, this research already produce the index model of thermal comfort
PMVtapsm (Sugini, Jaka Nugraha, 2013). However, for the interest of the thermal comfort
range prediction, prove that Sugini's model, 2007 more appropriate compare with those
PMVtapsm

3. DESIGN AND RESEARCH METHOD

3.1. POPULATION AND SAMPLE

The Purpose of this research require building unit could technically controlled. The unit which
technically observed with the relative variable could be controlled by the limitation of the
research is the air-conditioned house.

The observation step on energy consumption done by transversal way by increasing the
number of respondent into 240 family. Questionner being distributed were 350. The
searching of the range favourite thermal were done by the experiment method of controlled
room with 15 conditioning involving 30 respondents. From this stage, 450 unit data were
being processed.

4. RESEARCH FINDING

4.1. THE CONTROLLED RANGE OF THERMAL COMFORT IN AIR-CONDITIONED ROOM

Based on this research, the description of the sample are as follows; out of 450 data, only
399 up to 400 data could be analysed with the setting of the combination of experiment room
which has the range of comfort thermal based on ET index with mean 28.045° ET by the
range 21.100 ° ET and 33.000 ° ET. Based on PMV index room have the thermal comfort
level by mean of 0.917 or inclined to warm with the value range between PMV -1.9600 dan PMV 2.1400. Based on the index PMVtap for the air-conditioned room formula by the thermal comfort 0.3755 or nearly warm with the scope of values between -2.4900 and 1.6100. However, based on the respondents' perception, thus the combination of experimental room have the thermal comfort -0.1654 or rather cool.

![Figure 1. Room Thermal Comfort Profile based on Occupants Perception](image1)

![Figure 2. Room Thermal Comfort Profile based on thermal index PMVtap](image2)

![Figure 3. Room Thermal Comfort Profile based on thermal index PMVtap2](image3)

![Figure 4. Room Thermal Comfort Profile based on thermal index PMV](image4)

The following Table 1 explains setting and respondent percentage distribution on the perception of -3 (cold), -2 (cool), -1 (pretty cool), 0 (neutral), 1 (pretty warm), 2 (warm), 3 (hot). If the perception tolerance considered to accept the thermal condition is between pretty cool (-1) and pretty warm (1), so the result of measurement result analysis shows that thermal comfort range that can be accepted by 80% room occupants is as showed on the following table:

<table>
<thead>
<tr>
<th>Setting</th>
<th>Perception</th>
<th>sum</th>
<th>% recieve</th>
</tr>
</thead>
<tbody>
<tr>
<td>AC25fan1</td>
<td>3,333333</td>
<td>6,666667</td>
<td>33,33333</td>
</tr>
<tr>
<td>AC25fan5</td>
<td>0</td>
<td>1</td>
<td>2</td>
</tr>
<tr>
<td>AC30fan1</td>
<td>0</td>
<td>0</td>
<td>3,333333</td>
</tr>
<tr>
<td></td>
<td>0</td>
<td>0</td>
<td>3,333333</td>
</tr>
</tbody>
</table>

From the table above, it can be known that experiment setting favored by 80% respondents are setting AC25fan1, AC25fan5 and C30fan1.
Based on probability analysis, lower limit and upper limit of thermal comfort range can be formulated based on ET, PMV, PMVtap. Based on analysis, it can be inferred that thermal comfort range which is perceived comfortable by 80% room occupants is from PMV-0.75 to 1.7 or PMVtap-1.29 to PMVtap 1.21 on air-conditioner setting of 25 temperature degree and fan 1 and 5 until 30 temperature degree and fan 1.

4.2. THE SEARCH OF ENERGY CONSUMPTION OF AIR-CONDITIONERIONED HOUSE TO DETERMINE ENERGY SAVING THERMAL COMFORT RANGE

4.2.1. The Implementation of Data Networking, Processing and Formulation of Relationship Model of Energy Consumption and Life Style of Air-conditionerioned Thermal

As explained on the research method, energy consumption observation is conducted with transverse observation. From the data networking that was designed for 350 respondents, based on the data inputted, there were 234 people/house involved as respondents. Based on the data, filtering was done and finally central tendency could be obtained from sample characteristic.

The data above is the result of remuneration from raw data enclosed. From the raw data of air-conditionerioned thermal life style signed by air-conditioner setting variable as independent variable (X1), while the dependent variable (Y2) is energy consumption variable. To get equivalent value, energy consumption variable is obtained by dividing the increase of electrical expense caused by the usage of air-conditioner with the workload. Burden is obtained by multiplying air-conditioner operation time variable (hour/month) and AC Capacity (PK).

The analysis of relationship model searching is done by using Regression Analysis. From the data, based on analysis, relationship pattern between thermal life style attitudes measured based on AC setting and energy consumption.

4.2.2. Sample Description

Based on sample average, the tendency can be described as following:

- **Air-conditionerioned Thermal Life Style**

Thermal Life Style viewed from the usage of air-conditioner can be explained as following. Air-conditioner setting of overall respondent average i 21.59°C. However, house air-conditioner setting outside Yogyakarta Spesial District, which is 23,25 °C, tends to be higher than in Yogyakarta, which is 21,4°C. Fan setting tends to be chosen by house occupants is medium 76,38%. The duration of air-conditioner average usage in one day is 8,66 hours, while the frequency of air-conditioner usage per month is 26,25 days. Therefore, the air-conditioner average workload is 233,54 hours/month. Air-conditioner capacity dominantly used on air-conditioner with 1 PK capacity is 59,49 %, while the one with 0,5 PK capacity is 34,8% and another is 6,32%. From three reason backgrounds (comfort, savings, both comfort and savings) to choose, the result shows 44% because of comfort, 48,9% because of both comfort and savings and 7,1% because of savings.

- **The Increase of Energy Consumption**

The increase of energy consumption shown by % increase of electricity expense caused by air-conditioner usage on the house research sample is 80,16%. In detail, the increase as shown on the following table 4 and figure 3:
The increase actually relates to temperature setting, fan setting, capacity and workload. In detail, it can be seen on the table 5, table 6, and figure 4 and 5. Therefore, to calculate the search for relationship between the increase of energy consumption and air-conditioner setting, the measures are equalized by using the increase parameter per workload unit. Workload unit itself is multiplication between the air-conditioner capacity and the duration of air-conditioner usage (hour/month).

4.2.3. The Model of Relationship between Energy Consumption and Air-conditioner Setting

Thermal Life Style

The Model of Relationship is sought by analyzing linear regression. In this case, % of increase per workload unit is Y2 dependent variable and air-conditioner setting is independent variable. Air-conditioner setting in this case is measured using temperature parameter, fan and its multiplication (x1).

1. The Model of Regression between Y2 and air-conditioner setting (x1)

From two models, linear and quadratic (enclosed), based on R value, the best one is following model on regression equation 1 as following illustration on figure 6.

\[ y = 0.342 + 0.00432 \times x \]  

(1)

2. The Model of Regression between Y2 and temperature setting

The detailed model on regression equation 2 as illustrated on figure 7.

Regression Equation 2

\[ y = 1.44 - 0.0291 \times x \]  

(2)

4.3. THERMAL COMFORT RANGE AND ENERGY CONSUMPTION

Based on analysis and discussion on 4.3 and 4.5, it can be simulated the calculation of energy consumption consequence seen from regression forumula 1 and 2, also setting range, as following.
Table 2. Setting and the increase of energy consumption

<table>
<thead>
<tr>
<th>Setting</th>
<th>Temperature</th>
<th>Fan</th>
<th>Temperature</th>
<th>Increase of Energy Consumption</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Regression 1</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>(temperature x fan)</td>
</tr>
<tr>
<td>AC25fan1</td>
<td>25</td>
<td>1</td>
<td>25</td>
<td>0.45</td>
</tr>
<tr>
<td>AC25fan5</td>
<td>25</td>
<td>5</td>
<td>125</td>
<td>0.342</td>
</tr>
<tr>
<td>AC30fan1</td>
<td>30</td>
<td>1</td>
<td>30</td>
<td>0.4716</td>
</tr>
</tbody>
</table>

From the table above, it can be explained that air-conditioner setting of 25°C with low fan will increase the energy consumption 0.45% per one unit of workload (per day per air-conditioner per PK). Air-conditioner setting of 25°C with high fan increases the energy 0.882% per workload unit. Air-conditioner setting of 30°C with low fan increases the energy 0.47% per workload unit. If seen from temperature setting by ignoring fan setting, fan setting of 25°C will increase the energy consumption 2.2% per workload unit and fan setting of 30°C increases the energy consumption 2.3% per workload unit.

5. CONCLUSION

Based on the research, it can be concluded that:

1. Thermal Comfort Range perceived comfortable by 80% room occupants is from PMV-0.75 to 1.7 or PMVtap-1.29 to PMVtap 1.21 and 23° ET to 30.5° ET on air-conditioner setting of 25 and fan 1 and 5 to 30 and fan 1.

2. Relationship pattern between thermal comfort and energy consumption can be described as model of \( y = 0.342 + 0.00432x \) and \( y = 1.44 - 0.0291x \). In which \( y \) is the increase percentage of energy consumption for each air-conditioner, each PK and hour/month usage and \( x_1 \) is temperature setting and fan, \( x_2 \) is temperature setting.

3. The increase of energy consumption on the thermal comfort setting of 25°C with low fan is 0.45% per one unit of workload (per day per air-conditioner per PK), 0.882% per workload unit on the setting of 25°C with maximal fan setting and 0.47% per workload unit on the setting of 30°C with low fan. If ignoring fan setting, fan setting of 25°C will increase the energy consumption 2.2% per workload unit and setting of 30°C will increase the energy consumption 2.3% per workload unit.

6. ACKNOWLEDGEMENTS

This paper is the result of research was supports by research funding of higher education (DIKTI) for fundamental research grant scheme. Therefor author thanks to DIKTI and also University of Islamic Indonesia (UII), especially the Architecture Department of FTSP and DPPM UII for the supports that given to the author. Thank you, all students who have helped as surveyor in, including to the entire respondents and building owners because of the opportunity to use their house as the research object.

7. REFERENCES


Khamis Mansour, M.. "Development of novel control strategy for multiple circuit, roof top bus air conditioning system in hot humid countries", Energy Conversion and Management, 200806

Crossref
Berita Acara Hasil Pengecekan Keaslian Karya Ilmiah
Atas Nama Jaka Nugraha, Dr., S.Si., M.Si. Untuk kenaikan Jabatan
Dari Lektor Kepala (400 AK) ke Guru Besar (850 AK)

Pada tanggal 23 Oktober 2020 telah dilakukan pengecekan *Originality* atau *Similarity* terhadap karya Ilmiah Dosen Tetap Universitas Islam Indonesia:

<table>
<thead>
<tr>
<th>NO</th>
<th>KARYA</th>
<th>REPORT ORIGINALITY</th>
<th>KETERANGAN</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.</td>
<td>Menghasilkan karya ilmiah berupa jurnal internasional terindeks bereputasi dengan impact factor pada Sustainable Chemistry and Pharmacy, Scopus &amp; Scimagojr, SJR=0.62 pada bulan Juni 2018, dengan judul 'Preparation, characterization, and modelling activity of potassium fluorode modified hydrotalcite for microwave assisted biodiesel conversion'. ISSN: 2352-5541. Volume 8; issue 43252; pages 63-70; jumlah halaman 8</td>
<td>14%</td>
<td></td>
</tr>
<tr>
<td>No.</td>
<td>Judul dan Detail Terjemahan</td>
<td>Persentase</td>
<td></td>
</tr>
<tr>
<td>-----</td>
<td>-----------------------------</td>
<td>-------------</td>
<td></td>
</tr>
<tr>
<td>7.</td>
<td>Menghasilkan karya ilmiah berupa jurnal internasional terindeks pada The Turkish Online Journal of Design Art and Communication, Copernicus-DOAJ pada bulan September 2018, dengan judul 'Brown's Weighted Exponential Moving Average (B-Wema) with Levenberg-Marquardt Optimization to Forecasting Rate of Return'. ISSN: 2146-5193 . Volume Special Edition; issue ; pages 1744-1749 ; jumlah halaman 6</td>
<td>19%</td>
<td></td>
</tr>
<tr>
<td>8.</td>
<td>Menghasilkan karya ilmiah berupa jurnal internasional terindeks pada International Journal of Engineering and Technology, ProQuest-DOAJ pada bulan September 2018, dengan judul 'Sentiment Analysis on Mobile Banking Application Using Naive Bayes Classifier and Association Methods'. ISSN: 2227-524X. Volume 7; issue 4.15 (Special Issue); pages 244-247; jumlah halaman 4</td>
<td>2%</td>
<td></td>
</tr>
<tr>
<td>11.</td>
<td>Menghasilkan karya ilmiah berupa prosiding seminar internasional terindeks pada 2nd International Conference on</td>
<td>0%</td>
<td></td>
</tr>
<tr>
<td>No.</td>
<td>Judul dan Ringkasan Karya Ilmiah Berupa Prosiding Seminar Internasional Terindeks atau Kongres Lainnya</td>
<td></td>
<td></td>
</tr>
<tr>
<td>-----</td>
<td>--------------------------------------------------------------------------------------------------</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Judul dan Details</td>
<td>Persentase</td>
<td></td>
</tr>
<tr>
<td>---</td>
<td>------------------</td>
<td>------------</td>
<td>---</td>
</tr>
</tbody>
</table>

Pengecekan di atas menggunakan alat Ithenticate dengan meniadakan (exclude) beberapa hal dengan ketentuan sebagai berikut:

1. Meniadakan (exclude) hasil cek kesamaan karya yang kurang dari 2 persen.
2. Meniadakan (exclude) hasil cek kesamaan karya yang disitas oleh pihak lain.
3. Meniadakan (exclude) hasil cek kesamaan karya yang terindikasi plagiasi kepada karya ilmiah yang bersangkutan.

4. Meniadakan (exclude) hasil cek kesamaan karya yang menunjukan url atau laman karya ilmiah yang bersangkutan.

5. Meniadakan (exclude) hasil cek kesamaan karya yang diupload dalam bentuk yang berbeda (online pribadi) yang terdeteksi merupakan karya sendiri bukan merupakan laman publikasi Jurnal resmi hanya untuk kepentingan sharing (seperti https://www.researchgate.net, facebook.com dll) sehingga bukan termasuk auto-plagisasi/self plagiarism.

Berdasarkan hasil pengecekan di atas, maka karya ilmiah tersebut di atas dapat diteruskan usulannya ke Lembaga Layanan Dikti Wilayah V.

Yogyakarta, 23 Oktober 2020
Rektor

[Signature]

Prof. Fathul Wahid, S.T., M.Sc., Ph.D.