

30904-Aulia

by UMB IJIMEAM

Submission date: 10-Apr-2025 08:54PM (UTC+0700)

Submission ID: 2636584576

File name: 30904-87464-3-SM_5.docx (244.67K)

Word count: 3508

Character count: 19689

VIABILITY OF R-290 REFRIGERANT AS RESIDENTIAL AC RETROFIT: MASS VARIATIONS

Irham Aulia, S.Pd¹, Dr. Ir. Hafirman, M.Eng¹, Ega Taqwali Berman, S.Pd, M.Eng²

¹Departemen Magister Teknik Mesin, Universitas Mercu Buana
²Departemen Pendidikan Teknik Mesin, Universitas Pendidikan Indonesia

Abstract

The issue of ozone depletion and global warming due to synthetic refrigerant use is the primary motivation for this study. The adoption of environmentally friendly natural refrigerants has become a viable option for addressing ozone depletion and supporting international agreements like the Montreal and Kyoto Protocols. This research aims to evaluate the effects of varying R-290 refrigerant charge mass on the performance of a wall-mounted residential air conditioner using the drop-in substitute method. The study involves direct observation of system performance by testing R-290 refrigerant charge masses of 140 grams, 165 grams, and 190 grams. The baseline system, a ¼ HP residential AC unit, initially operates with 550 grams of R-22 refrigerant. Thermodynamic performance analysis of R-290 and R-22 was conducted using the standard vapor compression cycle. The results show an increase in Refrigeration Effect (RE) by up to 75%, Compression Work (W_k) by 58%, a reduction in Mass Flow Rate by up to 42%, a 12% reduction in Theoretical Power, and an improvement in Coefficient of Performance (CoP) by up to 14% post-retrofit. Additionally, the time required to reduce room temperature from 29°C to 21°C decreased by 28.5%. The retrofitted unit also achieved a reduction in electricity costs of approximately 14-15%.

Keywords: Refrigerant mass variation, retrofit, R290, natural refrigerant, hydrocarbon refrigerant

*Corresponding author: Tel. +62 821 2211 4030
E-mail address: irhamaulia1103@gmail.com

1. Introduction

In recent years, human needs have diversified significantly, with comfort becoming a primary concern in daily indoor activities. A highly effective way to achieve such comfort is through the installation of indoor air conditioning systems. These systems, commonly referred to as air conditioning (AC) units, are essential for cooling indoor spaces. According to Arismunandar & Saito (1996) [1], air conditioning is the process of cooling air to a temperature and humidity level suitable for the conditions of a specific room [1]. AC units are widely chosen due to their recognized efficiency in cooling indoor environments.

AC systems function as heat exchange mechanisms based on a closed vapor compression cycle, which consists of four primary stages: compression, condensation, expansion, and evaporation. The main components of AC systems include the compressor, condenser, expansion valve, and evaporator, with refrigerants serving as the working fluid in this cycle.

Refrigerants are fluids used in heat pumps and refrigeration cycles to absorb and release heat, thus cooling or heating a space. They must possess favorable thermodynamic properties, be non-

corrosive, and exhibit low toxicity. Initially, chlorofluorocarbons (CFCs) were introduced as refrigerants in the 1930s due to their desirable thermophysical and safety characteristics. However, in 1974, the link between CFC refrigerants and ozone depletion was discovered, leading to the development of environmental metrics such as Ozone Depletion Potential (ODP) and Global Warming Potential (GWP). ODP measures a substance's impact on ozone depletion relative to CFC-11, while GWP indicates a refrigerant's potential to contribute to global warming over 100 years, compared to CO₂ [2].

In response to environmental concerns, Hydrochlorofluorocarbon (HCFC) refrigerants, such as R-22, were introduced as alternatives to CFCs. However, R-22 still has a non-zero ODP value (0.055) and a high GWP of 1810. Consequently, under the Montreal Protocol (1987), refrigerants containing chlorine, which contribute to ozone depletion, were scheduled to be phased out by 2020 in industrialized countries and by 2030 in developing nations, in favor of more environmentally friendly alternatives [3].

The Kigali Amendment to the Montreal Protocol (2016) expanded the protocol's scope by addressing

Commented [AN1]: [1] Arismunandar, W., & Saito, H. (1995). *Penyegar Udara*. Penerbit Pradnya Paramita, Jakarta.

Commented [AN2]: [2] Molina, M. J., & Rowland, F. S. (1974). Stratospheric sink for chlorofluoromethanes: chlorine atom-catalysed destruction of ozone. *Nature*, 249(5460), 810-812.

Commented [AN3]: [3] Montreal Protocol on Substances that Deplete the Ozone Layer. (1987). *United Nations Treaty Collection*. Retrieved from <https://treaties.un.org/doc/publication/untst/volume%201522/volume-1522-i-26369-english.pdf>

hydrofluorocarbons (HFCs) which, though not harmful to the ozone layer, have high GWPs and thus contribute significantly to climate change. Although R-22 itself is an HCFC, the Kigali Amendment's regulation of HFCs has accelerated the transition to refrigerants with lower GWP values, as both environmental and climate impacts have become central to refrigerant selection [4].

The next generation of refrigerants, including R-410A, R-32, and R-407C, have zero ODP but still possess relatively high GWP values (2018, 675, and 1770, respectively). Higher GWP values indicate a greater contribution to global warming over a century. In line with the Kigali Amendment, the industry is now shifting towards natural refrigerants, such as R-290 (propane), which has both a low GWP and zero ODP, making it a promising candidate for residential AC retrofits.

To address both ozone depletion and global warming concerns, the use of natural refrigerants has gained attention as an environmentally friendly alternative [15-17]. Research has demonstrated that natural refrigerants offer high energy efficiency and a lower environmental impact compared to synthetic refrigerants. For example, Zhout et al. (2010) found that R-290 requires only 30-40% of the mass and flow rate of R-22 due to its lower density [8]. Similarly, Shrivastava & Chandrakishor (2016) noted that R-290 has significantly better thermophysical properties than R-22, with specific heat capacities up to 53% and 67% higher in liquid and vapor states, respectively [9]. Moreover, R-290's thermal conductivity in both states is also higher by 10.5% and 40%.

Widodo (2022) reported that substituting R-32 with R-290 in an AC unit reduced energy consumption by 13.3% and increased the Coefficient of Performance (CoP) by 14% [10]. Anam (2016) found a 15% reduction in energy consumption when using R-290 as a drop-in substitute for R-410A [11]. Wei et al. (2024) stated that in residential AC unit applications in the California area, retrofitting existing units with R-290 could yield greenhouse gas (GHG) savings of 15 to 64 million metric tons [12]. Wellid et al. (2024) also conducted experimental research on retrofitting HFC-410A with R-290 in residential AC units in Karawang, achieving a 31.91% reduction in the Total Equivalent Warming Impact (TEWI) [13].

While several studies have investigated the use of R290 as a substitute for R22 and R410A, limited research specifically addresses the optimal refrigerant mass for R290 in retrofitted systems. Ding et al. (2009) stated that determining the precise refrigerant mass is critical for maximizing

performance and energy efficiency, as inadequate or excessive refrigerant quantities can lead to suboptimal cooling capacity, higher energy consumption, or system inefficiencies. Insufficient refrigerant charge may raise the outlet temperature of the AC unit, and excessive charge could lead to compressor damage and high heat discharge [14].

Current studies have largely focused on general performance characteristics of R290 retrofits, but there is a need for experimental data that examines how varying refrigerant masses impact CoP, energy efficiency, and cooling effectiveness. This research therefore addresses this gap by exploring mass variations in R290 retrofitted AC units to identify the optimal refrigerant charge for enhanced system performance in R22 systems.

2. Methodology

This research was carried out using the drop-in-substitute method, which did not involve replacing any components of the existing air conditioning unit. The unit was tested in a classroom at the HVAC-R Engineering Workshop, Department of Mechanical Engineering Education, UPI Bandung. The classroom had a floor area of 13 m² and a heat load of 2 kW, which 1.5 kW simulated using an electrical heater. The air conditioning equipment used in this

Table 1. Unit Specification

Description	Specification
Brand	LG
No. Model	HS-C076QDA2
Capacity	2.0 kW
Power Source	1Ph/220-240V/50Hz
Power Input	590 W
Running Current	3.1 A
Rated COP	3.39
Refrigerant	R-22 (550 gr)

experiment was a wall-mounted AC unit from LG, model number HS-C076QDA2, with a cooling capacity of 2.0 kW. Additional details can be found in Table 1.

The installation used in this study adheres to standard specifications, specifically ASTM B280 for the pipes. The pipes have an outer diameter of 6.4 mm x 9.5 mm paired with a wall thickness of 0.76 mm. The piping system spans a length of 3 meters, which is the minimum requirement for residential air conditioning units.

This experiment involved the retrofitting of the previously mentioned AC unit with R-290 with specification shown in Table 2 with R-22 as comparison. The testing commenced with data collection on the standard unit using R-22 refrigerant as the baseline. Subsequently, the unit was retrofitted

Commented [AN12]: [14] G. Ding, X. Ma, P. Zhang, W. Han, S. Kasahara, and T. Yamaguchi, "Practical methods for measuring refrigerant mass distribution inside refrigeration systems," *International Journal of Refrigeration-revue Internationale De Froid*, vol. 32, no. 2, pp. 327-334, Mar. 2009. doi: <https://doi.org/10.1016/j.ijrefrig.2008.05.002>

Commented [AN4]: [4] Kigali Amendment to the Montreal Protocol on Substances that Deplete the Ozone Layer. (2016). *United Nations Treaty Collection*. Retrieved from https://treaties.un.org/Pages/ViewDetails.aspx?src=IND&mt_dsg_no=XXVII-2-fk&chapter=27&clang=en

Commented [AN5]: [5] Yu T, Teng T. (2014). Retrofit assessment of refrigerator using hydrocarbon refrigerants. *Applied Thermal Engineering* 66, 507-518

[6] Miyara A. (2008). Condensation of hydrocarbons – a review. *International Journal of Refrigeration* 31, 621-632.

[7] Palm B. (2008). Hydrocarbons as refrigerants in small heat pump and refrigeration systems – a review. *International Journal of Refrigeration* 31, 552-563.

Commented [AN6]: [8] Zhou G, et al. (2010). Performance of a split type air conditioner matched with coiled adiabatic capillary tubes using HCFC22 and HC290. *Applied Energi* 23, 232-242

Commented [AN7]: [9] Shrivastava AP, Chandrakishor C. (2016). Evaluation of Refrigerant R290 as a Replacement to R22. *International Journal of Innovative Research in Science and Engineering: Volume No. 2, Issue 03*

Commented [AN8]: [10] Widodo, et al. (2022). Analisis Kinerja R290 sebagai Pengganti R32 pada Unit AC-Split Kapasitas 9.000 Btu/hr. *Jurnal Asimetrik: Jurnal Ilmiah Rekayasa dan Inovasi*. 221 - 230

Commented [AN9]: [11] Anam AN, Raharjo S, Prihadi RJ. (2016). *Perbandingan Penggunaan Refrigeran R-410a dan Miscool-22 Melalui Proses Retrofit Pada AC Merk Daikin 2 PK*. Universitas Muhammadiyah Semarang.

Commented [AN10]: [12] M. Wei et al., "Benefits and challenges in deployment of low global warming potential R290 refrigerant for room air conditioning equipment in California," *Sustainable Energy Technologies and Assessments*, vol. 70, pp. 103937-103937, Oct. 2024. doi: <https://doi.org/10.1016/j.seta.2024.103937>.

Commented [AN11]: [13] None Ismail Wellid, None Bowo Yuli Prasetyo, None Sugiyarto, N. Mahamad, None Sumeru, and None Andriyanto Setyawan, "Technical Training on Replacement of R410a with R290 in Split Air Conditioners as an Effort to Reduce Global Warming for BLK Instructors in Karawang Regency," *ABDIMAS Jurnal Pengabdian Masyarakat*, vol. 7, no. 2, pp. 762-770, Apr. 2024. doi: <https://doi.org/10.35568/abdimas.v7i2.4753>.

Table 2. Refrigerant Characteristics

Refrigerant	R22	R290
Chemical Formula	CHClF2	CH3CH2CH3
ODP	0.055	0
GWP	1.760	3
Critical Temperature (°C)	96	97
Boiling Point (°C)	-41	-42.5
Triple Point (°C)	-157.4	-187.6
Working Pressure (Psia)	117.04	106.9

with R-290 refrigerant with varying refrigerant masses of 25, 30, and 35% of R-22 refrigerant which are 140 grams, 165 grams, and 190 grams. During each test, the unit underwent vacuuming, minimal compressor oil addition, and refrigerant recovery to ensure data accuracy and environmental safety. A 15-minute test run done to stabilize excess pressure and ensure there were no faults in the components or installation. The research steps conducted are summarized in the flow diagram depicted in Figure 1 below.

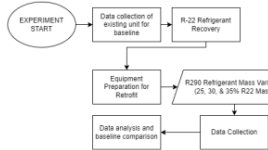


Figure 1. Research Flowchart

Data collection began once the room temperature reached the initial temperature of 30°C, typically achieved by 13:00. After collecting data for both the baseline and retrofitted units, analysis was conducted on the results to derive performance parameters of the research unit, as shown in Figure 2. The calculations for key parameters, including Refrigeration Effect (RE), Compression Work (Wk), Theoretical Power Value (HP), and Coefficient of Performance (CoP), were based on equations and methodologies outlined in the ASHRAE Handbook [15]. Enthalpy values were determined through interpolation using data adjusted to the Thermodynamic Properties Table for each refrigerant, which were then plotted on the p-h diagram in Figure 2. Additional parameters, such as cooling time (t) and Power Consumption (P), were also evaluated to provide a comprehensive assessment of system performance in this study.

Data logging equipment was calibrated before

each session to maintain precise measurements of temperature and pressure. The experimental setup included sensors placed at critical points within the system to capture real-time data. Ambient temperature was recorded concurrently to account for any environmental influences on the system's performance.

3. Result and Discussion

3.1 Refrigeration Effect Analysis

Refrigeration Effect (RE) refers to the amount of heat absorbed by the evaporator. The RE is determined by calculating the Δh value along the Evaporation process line in p-h Diagram. The calculation is shown in the equation below:

$$RE = h_4 - h_1 \quad (1)$$

Figure 3 illustrates the Refrigeration Effect values for each unit per 1°C decrease in both baseline and retrofit units.

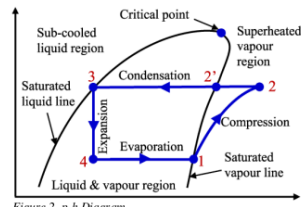


Figure 2. p-h Diagram

Based on the test results, the average Refrigeration Effect (RE) value obtained for R-22 units is 151.78 kJ/kg. For units using R-290 refrigerant, the values obtained for each refrigerant mass variation of 140 grams, 165 grams, and 190 grams are 266.36 kJ/kg, 262.82 kJ/kg, and 264.36 kJ/kg respectively. Overall, the average increase in Refrigeration Effect values can reach up to 75%.

Commented [AN13]: ASHRAE. (2022). ASHRAE Handbook—HVAC Systems and Equipment. Atlanta, GA: ASHRAE.

However, for the unit utilizing R290 with a refrigerant mass variation of 140 grams was unable to achieve a room temperature of 21°C.

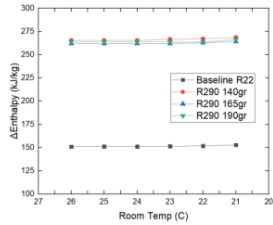


Figure 3. Refrigeration Effect Value

3.2 Compression Work Analysis

The value of Wk is obtained from the difference between two enthalpies, specifically at the compression point (superheat) and the saturated vapor point (suction). The Wk value indicates the amount of heat generated by the refrigerant compressed by the compressor, as shown in equation (2)

$$Wk = h_2 - h_1 \quad (2)$$

The magnitude of the Wk value from the baseline unit and the R-290 retrofit unit per 1°C decrease in room temperature is illustrated in Figure 4.

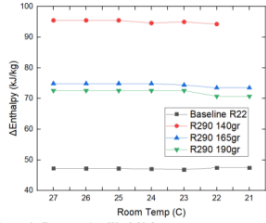


Figure 4. Compression Work Value

The average compressor work values for the R-22 baseline unit are 47.22 kJ/kg. For the R-290 unit with variations of 140 grams, 165 grams, and 190 grams, average values of 95 kJ/kg, 74.42 kJ/kg, and 72.05 kJ/kg are obtained, respectively.

Based on the test result, the Wk values obtained show an increase in the R-290 retrofit unit. However, this increase in Wk values corresponds to a significant increase in the RE value. The increase in average compressor work values reaches 53% for unit masses of 165 grams and 190 grams. Meanwhile for unit with a mass variation of 140 grams, it increases by up to 101%, attributed to the insufficient mass of refrigerant to meet its minimum requirements.

3.3 Theoretical Power Analysis

Theoretical power analysis is the compressor power required to operate at the same cooling capacity based on the calculation of its parameters. The first data to be obtained is the magnitude of the refrigerant mass flow rate, as shown in equation (3) and the HP value could be obtained as shown in equation (4) [11].

$$m = \frac{200}{RE} \quad (3)$$

$$HP = \frac{W_k \times m}{42,42} \quad (4)$$

The mass flow rate in the baseline unit averages 1.32 kg/s. In units retrofitted with R-290, the average mass flow rate of the refrigerant is 0.75 kg/s. This indicates that R-290 refrigerant requires a lower flow rate compared to R-22. Attributed to a smaller theoretical pressure drop of the refrigerant in that application. This reduction in refrigerant flow rate reaches up to 43%.

Regarding theoretical power values, baseline data shows 1.48 HP, while retrofitting with R-290 results in 1.7 HP, 1.35 HP, and 1.30 HP values. In installations with 140 grams of refrigerant, the HP values increase due to insufficient refrigerant mass flow to meet the heat load, causing the compressor to work harder. Meanwhile, installation with 165 grams and 190 grams show a decrease of 9 – 12%. This means that the electrical energy consumption of units retrofitted with R-290 will be lower compared to R-22.

The comparison of values of m and HP for each installation per temperature decrease is shown in Figure 5 and Figure 6.

3.4 Coefficient of Performance Analysis

The Coefficient of Performance (CoP) is the

Commented [AN14]: ASHRAE. (1990). *Fundamentals Handbook*. American Society of Heating, Refrigerating, and Air Conditioning Engineer.

ratio of the Refrigeration Effect produced to the work input of the compressor. The CoP calculation is obtained using the following equation (5):

$$CoP = \frac{RE}{Wk} \quad (5)$$

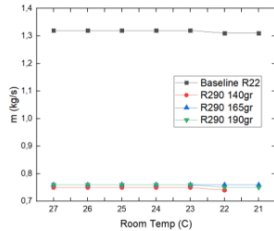


Figure 5. Refrigerant Flow Rate Value

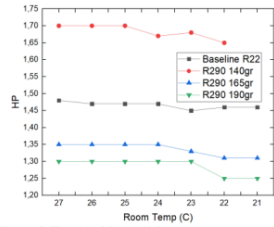


Figure 6. Theoretical Power Value

The test findings reveal average Coefficient of Performance (CoP) values of 3.21 for baseline unit R-22. For retrofitted R-290 unit the test reveal CoP values of 2.80, 3.53, and 3.67 for 140 grams, 165 grams, and 190 grams respectively. This represents an improvement in CoP values of approximately 10-14% compared to the baseline R-22 unit. Figure 7 illustrates how CoP values vary with each 1°C decrease in room temperature.

This indicates an increase in the Coefficient of Performance (CoP) values after using R-290. This is due to a significant rise in the Refrigeration Effect (RE) values, which is also balanced by an increase in Wk values.

3.2 Analysis of Achievement Time and Power Consumption

The achievement time analysis is conducted to determine how long the system takes to cool the conditioner room. This time is calculated from when the unit is first turned on at 27°C until it reaches 21°C. Table 3 presents the time durations required.

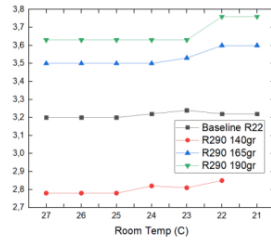


Figure 7. Coefficient of Performance

Test results indicate that the R-290 unit with a mass of 190 grams achieves room temperature cooling the fastest, outperforming the baseline R-22 unit by 33%. The reduced time required to lower room temperature significantly impacts its electricity consumption. This is because achieving room temperature faster results in an earlier system cut-off by the thermostat, thereby reducing electricity consumption when the compressor resumes operation. On the other hand, the configuration using R-290 with a mass of 140 grams failed to reach the desired room temperature, thereby disqualifying any reduction in power consumption attributed to its inability to achieve optimal cooling conditions.

Table 3. Achievement Time for 1°C Room Temperature Decrement

Room Temperature	R-22	R-290 140gr (25%)	R-290 165gr (30%)	R-290 190gr (35%)
°C	min	min	min	min
27	6	16	7	5
26	8	16	7	4
25	6	9	6	5
24	13	28	8	11
23	17	32	14	12
22	25	48	17	14
21	25	-	18	13

The electricity consumption heavily depends on the magnitude of the Ampere value when the compressor operates to lower room temperature. The Ampere values corresponding to each 1°C decrease in room temperature are shown in Table 4.

Table 4. Electrical Ampere Comparison for PC Room Temperature Decrement

Room Temperature °C	R-22	R-290 140gr (25%)	R-290 165gr (30%)	R-290 190gr (35%)
	min	min	min	min
27	2,45	1,95	2,10	2,13
26	2,46	1,95	2,07	2,11
25	2,45	1,96	2,10	2,10
24	2,44	1,96	2,05	2,08
23	2,43	1,96	2,05	2,06
22	2,36	1,9	2,03	2,05
21	2,36	-	2,03	2,05

Based on the obtained electrical Ampere data when the compressor is running, an analysis of electricity consumption is conducted assuming the unit runs for 9 hours per day over 30 days. The electricity tariff used to follow the Basic Electricity Tariff rate for a household with a 2.200 VA electrical capacity, which is Rp. 1.444,70 / kWh. Comparative data for each installation is shown in Table 5.

There is a reduction in electrical consumption cost around 14% - 15% in 30% and 35% setup. The 25% R-290 refrigerant mass setup could be ignored due to inability to achieve the desired room temperature. The cost reduction could be bigger due to lower ambient temperature and faster compressor cut-off by thermostat due to achieved room temperature.

4. Conclusion and Recommendations

This study investigated the performance of a wall-mounted AC unit retrofitted with R-290 refrigerant as a substitute for the commonly used R-22. The results showed that although R-290 increased compression work, this was offset by a substantial rise in refrigeration effect (RE), ultimately resulting in a 10-14% improvement in the coefficient of performance (CoP) compared to the baseline R-22 system.

The analysis revealed that a refrigerant mass of 140 grams (equivalent to 25% of the original R-22 charge) was insufficient to achieve the desired cooling capacity, primarily due to reduced refrigerant flow and inadequate heat exchange. However, increasing the R-290 mass to 190 grams

significantly enhanced system performance, reducing the time required to reach the target temperature by 28.5% and lowering operational costs by 14-15%, based on a 9-hour daily operation schedule over a 30-day period. Additional cost savings could be achieved in scenarios with lower cooling loads, as the unit's thermostat automatically deactivates the compressor upon reaching the set temperature, further conserving energy.

Based on these findings, it is recommended that retrofitted wall-mounted, non-inverter AC units with a 2.00 kW cooling capacity should ideally use 165 grams of R-290 refrigerant (equivalent to 35% of the original R-22 mass) to achieve optimal performance. This approach not only improves cooling efficiency but also reduces operational costs, making it a viable and environmentally friendly alternative for residential air conditioning retrofits.

5. Acknowledgements

The author would like to express their deepest gratitude to Aurn R. Geraldine S.Pi. for her unwavering support and encouragement throughout this research journey. Special thanks are also extended to Mr. Muhamad Fitri, ST., M.Si., Ph.D., for his invaluable guidance and insightful feedback during the course of this study. Additionally, the authors appreciate the support from Universitas Pendidikan Indonesia for providing access to the facilities and resources essential for this research. Lastly, the main author acknowledges the contributions of Dr. Ir. Hafirman, M.Eng, and Ega T. Berman, S.Pd, M.Eng, for their collaboration and assistance in various aspects of this research project.

References

- [1] W. Arismunandar dan H. Saito, *Penyegaran Udara*. Jakarta: Pradnya Paramita, 2005..
- [2] M. J. Molina and F. S. Rowland, "Stratospheric sink for chlorofluoromethanes: chlorine atom-catalysed destruction of ozone," *Nature*, vol.249, no. 5460, pp. 810-812, 1974.
- [3] "Montreal Protocol on Substances that Deplete the Ozone Layer," United Nations Treaty Collection, [Online]. Available: <https://treaties.un.org/doc/publication/untst/volume%201522/volume-1522-i-26369-english.pdf>
- [4] "Kigali Amendment to the Montreal Protocol on Substances that Deplete the Ozone Layer," United Nations Treaty Collection, [Online].
- [5] Y. Yu and T. Teng, "Retrofit assessment of refrigerator using hydrocarbon

- refrigerants," *Applied Thermal Engineering*, vol. 66, pp. 507-518, 2014, doi: 10.1016/j.applthermaleng.2013.11.004.
- [6] A. Miyara, "Condensation of hydrocarbons - a review," *International Journal of Refrigeration*, vol. 31, pp. 621-632, 2008, doi: 10.1016/j.ijrefrig.2008.02.008.
- [7] B. Palm, "Hydrocarbons as refrigerants in small heat pump and refrigeration systems - a review," *International Journal of Refrigeration*, vol. 31, pp. 552-563, 2008, doi: 10.1016/j.ijrefrig.2007.12.004.
- [8] G. Zhou, et al., "Performance of a split type air conditioner matched with coiled adiabatic capillary tubes using HCFC22 and HC290," *Applied Energy*, vol. 87, pp. 232-242, 2010, doi: <https://doi.org/10.1016/j.apenergy.2009.10.005>
- [9] A. P. Shrivastasa and C. Chandrakishor, "Evaluation of Refrigerant R290 as a Replacement to R22," *International Journal of Innovative Research in Science and Engineering*, vol. 2, no. 3, pp. 739-747, 2016.
- [10] Widodo, A. I. Tauvana, F. Rachmanu, L. Nulhakim, Syafrizal, & M. I. Subekti. (2022). Analisis Kinerja R290 sebagai Pengganti R32 pada Unit AC-Split Kapasitas 9,000 Btuh/hr. *Jurnal Asimetrik: Jurnal Ilmiah Rekayasa Dan Inovasi*, 4(2), 221-230.
- [11] A. N. Anam, S. Raharjo, and R. J. Pribadi, "Perbandingan Penggunaan Refrigeran R-410a dan Musicool-22 Melalui Proses Retrofit Pada AC Merk Daikin 2 PK," Universitas Muhammadiyah Semarang, 2016.
- [12] M. Wei *et al.*, "Benefits and challenges in deployment of low global warming potential R290 refrigerant for room air conditioning equipment in California," *Sustainable Energy Technologies and Assessments*, vol. 70, pp. 103937-103937, Oct. 2024, doi: <https://doi.org/10.1016/j.seta.2024.103937>.
- [13] N. Ismail Wellid, B. Y. Prasetyo, Sugiyarto, N. Muhamad, Sumeru, and A. Setyawan, "Technical Training on Replacement of R410a with R290 in Split Air Conditioners as an Effort to Reduce Global Warming for BLK Instructors in Karawang Regency," *ABDIMAS Jurnal Pengabdian Masyarakat*, vol. 7, no. 2, pp. 762-770, doi: 10.35568/abdimas.v7i2.4753, Apr. 2024.
- [14] G. Ding, X. Ma, P. Zhang, W. Han, S. Kasahara, T. Yamaguchi, "Practical methods for measuring refrigerant mass distribution inside refrigeration system," *International Journal of Refrigeration-revue Internationale Du Froid*, vol. 32, no. 2, pp. 327-334, Mar. 2009, doi: <https://doi.org/10.1016/j.ijrefrig.2008.05.002>
- [15] ASHRAE, *Fundamentals Handbook*, American Society of Heating, Refrigerating, and Air-Conditioning Engineers, Atlanta, GA, USA, 1990.

ORIGINALITY REPORT

3%

SIMILARITY INDEX

3%

INTERNET SOURCES

2%

PUBLICATIONS

1%

STUDENT PAPERS

PRIMARY SOURCES

1

conf.montreal-protocol.org

Internet Source

1%

2

Submitted to College of Professional and Continuing Education (CPCE), Polytechnic University

Student Paper

<1%

3

www.researchgate.net

Internet Source

<1%

4

www.scribd.com

Internet Source

<1%

5

journal.umtas.ac.id

Internet Source

<1%

6

www.c2es.org

Internet Source

<1%

7

repository.unimus.ac.id

Internet Source

<1%

Exclude quotes On

Exclude matches < 17 words

Exclude bibliography On