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Residential Heat Pump Operation in The UK (LATENT Project) And Deferral Situation with Air Conditioning Operation in Indonesia

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Abstract: Heating, cooling, and dehumidification to assess the thermal comfort in buildings contributed around one-third of the worldwide energy demand, which are crucial in the energy decarbonization prospect. Electrification with renewables and building archetype arrangements in building energy utilization contribute to reducing carbon emissions. The paper aims to evaluate the energy performance of differential residential heat pumps and air conditioners in the different areas of study to optimize the energy consumption in the UK and Indonesia by considering the archetype and separate local climate in regions within the countries by using the optimum thermal comfort adjustments. The research involves TRNSYS17 software analyses to simulate the building retrofit configurations and energy behavior in the residential retrofit to assess thermal comfort. The evaluation of energy consumption index performance in the different archetypes and heat source are investigated to overlook how their effect on the energy efficiency and operational practices.
Keywords: Thermal Comfort, Archetype, Heat Pump, Air Conditioner, Dehumidification

1. Introduction

Building energy contributed around 33% of the worldwide energy demand and 15% of carbon emissions in 2020, which plays a crucial part in a sustainable energy system (IEA, 2021). Building thermal comfort conditioning (heating, cooling, and dehumidification) consumes more than half the total energy demand, especially natural gas (EIA, 2021). A residential heat pump could be an alternative to decarbonize natural gas usage by integrating the energy system with renewable energy supplies such as Solar Photovoltaics and Wind Turbines. This means that utilizing a residential heat pump to reduce the natural gas boiler consumption also supports the UK's new standard for using less than 75-80% carbon emissions energy by 2025 (Ministry of Housing, 2021). Besides, the flexibility of electric heat pumps in the UK could benefit the user to involve in the cooling operation during the heat wave phenomena to adapt the thermal comfort. Furthermore, the volatility price of global natural gas drives the electric heat pump and enables energy security for the heating application.

Meanwhile, in Indonesia, the application of heat exchangers primarily uses air conditioners to afford the hot-humid climate. Most of the building energy consumption in Indonesia utilizes electricity consumption on an air conditioner (AC) throughout the year of the stable humidity and temperature, especially in the big capital cities such as Jakarta and Surabaya (Damiati et al., 2016). Practically, cooling operation in most of Indonesia's buildings consumes 60% higher than the efficient standard described in the Minister of Energy and Mineral Resources Regulation no. 13, 2012 (Tifa, 2014). To reduce the carbon emissions due to the cooling load, the building configuration and thermal comfort adjustment behavior in Indonesia will be vital for Indonesia's greener future, mainly in the household aspects, as Indonesia has a considerable population worldwide and diverse building archetypes.

As the countries worldwide have different thermal comfort adjustments due to climate condition variations, the differential thermal comfort operations (i.e., heating, cooling, and dehumidification) affect the energy performance of different archetype buildings, especially in Indonesia as one of the largest air conditioner consumers. The heat pump usage in the cold temperate climate, which has a similar work principle to the air conditioning in a hot-humid climate, will give another perspective on thermal comfort adjustment for global buildings. Therefore, this study aims to evaluate the energy performance of differential residential heat pump and air conditioner in the different areas of study to optimize the energy consumption (archetype, location, thermal comfort assessment, and source of heat transfer equipment).

2. Background

Köppen and Geiger classify the United Kingdom as an oceanic climate (as Cfb) with a temperate climate without a dry season and warm summer (Climate Data, n.d.). The country has different temperature ranges depending on the location of the cities, from the southern to the northern, which is affected by six major air masses from the tropical and arctic regions (Metoffice, 2012). ASHRAE 55 suggests implementing the temperature range between 18-28°C for the daily activity across the year. Basically, as the UK is classified as a cold temperate climate with less humid air, the residents apply the heating operation by using the gas boiler, which accounts for 40% of the UK's total energy demand and carbon footprint. Therefore, the UK government applies the Energy Performance Certificates (EPC) and Display Energy Certificates (DEC) as the regulations of building construction for renting and selling purposes with the different standards for each constituent country (DLUHC, 2022). Furthermore, as the households' activities involve the dynamic behaviour of energy consumption, the energy intensity represents the actual heating performance in the residential buildings, which mostly consumed about 88 kWh/ m^2 per year of energy heating.

Being part of the equatorial region, Köppen and Geiger classify most of the Indonesian cities as Af climate (wet equatorial) due to the intertropical convergence zone (ITCZ) location across the nation, where the country earns stable solar radiation within the belt of wind, and rising air intersects from the continents, resulting in a hot, humid climate on the most locations (Dewa et al., 2020). Indonesian building design implements some regulations in assessing thermal comforts, such as The American Society of Heating, Refrigerating and Air-Conditioning Engineers (ASHRAE) 55 Standard for Human Occupancy and Indonesian Standardization Board (BSN) Standard SNI 6390:2011. The principles involve the environment parameter range to afford the indoor activities in dwelling and commercial retrofits (i.e., temperature and relative humidity). The BSN standard suggests applying a temperature range of 25.5 ± 1.5°C with 50-70% relative humidity, while ASHRAE 55 recommends a wider temperature range of about 20-28°C. Besides, several thermal comfort predictions and modelling suggested a temperature range between 24 - 29°C for optimizing the air conditioning consumption (Karyono, 2015).

As the relative humidity in most big cities lies about more than 80%, air conditioning plays a crucial role in dehumidification to optimize the resident's living quality, which should involve renewable energy integration for the electricity. Most buildings in Jakarta, the capital city, consumed about 163 kWh/m2 of electricity for cooling purposes only as 65% of the energy building demand (Amalia et al., 2020) Based on the Minister of Energy and Mineral Resources Regulation no. 13, 2012, the adequate cooling energy for a building should be less than 100.8 kWh/m2 as the efficient benchmark (Tifa, 2014). Thus, the optimization of thermal comfort and Energy Consumption Index (ECI) plays crucial role in investigating the best practices of air conditioning operation in Indonesia to cover the cooling and dehumidification energy.

3. Method

This study encompasses the simulation of residential heat pumps and air conditioners in two climate locations: the United Kingdom's temperate climate and Indonesia's hot-humid climate. The research uses the gas boiler/electric heat pump as a heating and air conditioner to determine the thermal comfort using Climate Consultant 6.0 and TNSYS 17 simulation. The simulations output covers the temperature profile of sensible and dehumidification needs for a dynamic situation depending on the current previous year's weather data with the specified temperature, humidity, and energy consumption load. The experimental study encompasses London, Southampton, and Stornoway in the UK for the heating and cooling operation to investigate the different three location and heatwave phenomena. The study involves Jakarta, Surabaya, and Ibu Kota Negara (IKN) Nusantara for the locations in Indonesia as the big cities and future of economic residential growth.

The used archetype design in this building covers the four most common dwelling retrofits: single/detached, semi-detached, terraced, and flat/apartment. The simulation for detached will be a simple cube with external roof and external sidewalls. The semi-detached houses will be designed as two series of cubes the with external walls with an adjacent wall for the coincident wall. The terraced houses will be designed as three series of dwellings with external walls with two adjacent walls for the coincident walls. The flat/apartment house will be designed as a single/detached cube with an external sidewall (balcony), internal roof, internal floor, and internal sidewalls, as it is considered that flat archetype has heat loss from the balcony side.

4. Results and Discussion

By generating the TRNSYS 17 simulation results, there are several concerns in this research regarding the thermal comfort analysis of several energy performances by utilizing heating, cooling, and dehumidification in the UK and Indonesia as the deferral location to investigate with. Furthermore, the sustainability aspects of this research will involve the cost and carbon analyses to compare the existing fossil fuels performance (i.e., residential gas boiler) with considering the projected forecast for the nations' targets in 2025 in the UK and 2060 in Indonesia.

4.1 Thermal Comfort Assessment

The simulation using Climate Consultant 6.0 gives the suggestion of thermal comfort adjustment depending on the location and thermal comfort standard (i.e., ASHRAE 55 and Current Handbook of Fundamentals Model for this research project) as showing temperature and relative humidity range. It shows that the temperature will be divided into two classifications: 15-20 °C for heating and and 20-25 °C for cooling in the UK. However, the temperature’s independence from relative humidity in Indonesia significantly affects the cooling and dehumidification energy demand. The TRNSYS simulations are done in Indonesia for several range combinations of temperature from climate analysis and previous literature on predicting the temperature comfort for hot-humid countries in the stable relative humidity point. Figure 4.1 below represents several energy consumptions index (ECI) based on different temperature ranges and setpoints in Jakarta as the hottest city in Indonesia.

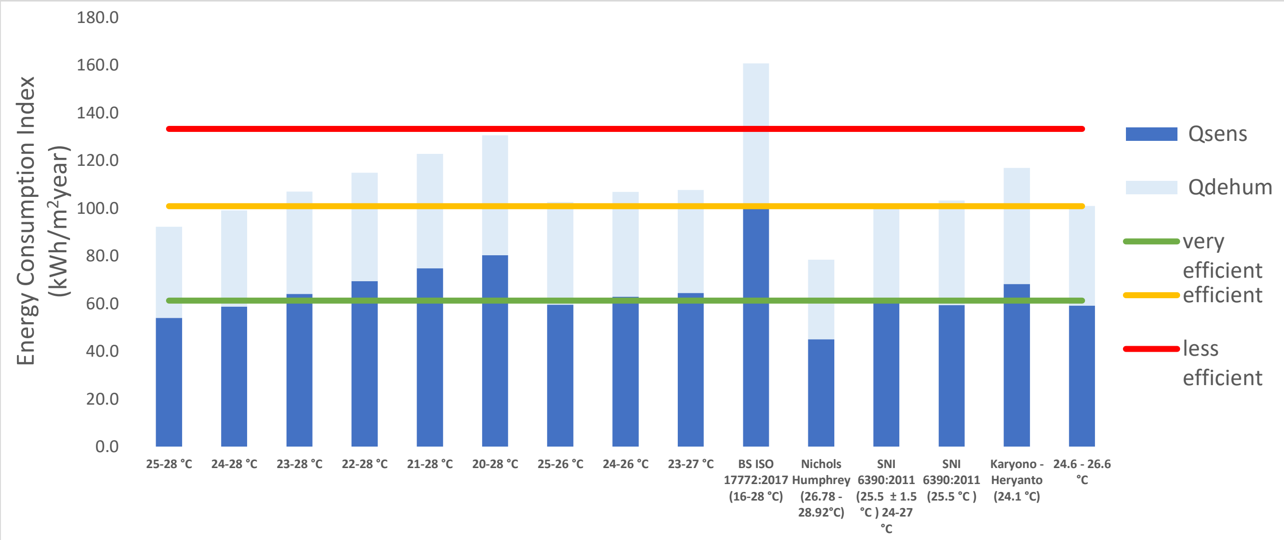

Figure 4.1 Several Energy Consumptions Index (ECI) Based on Different Temperature Setpoints in Jakarta.

By using some trial and error, the optimum point for cooling practice that fulfills the effectiveness of ECI in Indonesia is 24.6-26.6°C which covers about 100.8 kWh/m2.year ECI for the cooling and dehumidification process. Therefore, the range 24.6-26.6°C temperature and 60% relative humidity scheme will take place on Indonesia's TRNSYS simulations for further variable and parameters.

4.2 Building Archetypes Analysis in the UK

The UK's thermal comfort simulation will only involve heating and cooling operation with the different archetypes and locations in the UK region using TRNSYS 17, it evaluates the energy consumption index (ECI) to assess each variable's thermal comfort. Figure 4.2 below represents the ECI of different gas and heat pump heating with combined cooling operation to assess the thermal comfort for a year.

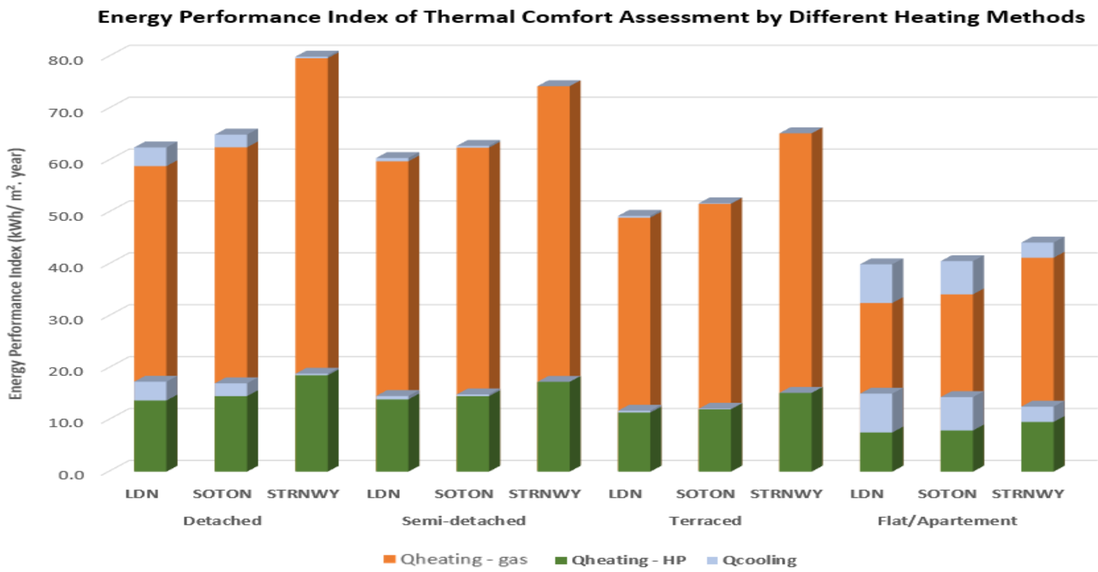

Figure 4.2 Energy Consumption Index of Heating and Cooling Operation in the UK for Thermal Comfort

Generally, utilizing electrical heat pump cuts off the total heating energy up to fourth time lower than gas boiler due to its COP 4 times higher than gas boiler (i.e., has about 93% efficiency. It also enables the terraced dwelling to perform the lowest total energy of cooling and heating among all archetypes, except in Stornoway as the coldest region. The flat/apartment retrofits have significant cooling energy amount to achieve the thermal comfort. The detached archetype has the most significant total energy consumption among all archetypes.

The apartment/flat's design which has a more significant number of internal walls prevents heat loss than the other archetype and consumes the lowest heating energy. However, the flat/apartment houses utilize more cooling energy to achieve the thermal comfort as they block the heat release through the internal walls (AECOM MHCLG, 2019). The presence of an adjacent wall/party wall also enables the heat transfer between the houses and the outdoor temperature. During the cold winter, this layer interacts with the cool air to the possibility of additional heat loss to the solid external walls, resulting in these dwellings having lower temperature during winter in the non-heating scenario (Palmer & Terry, 2022). Besides, the mid-terraced building gains more heat loss from both terraced-end buildings through the adjacent walls, causing the temperature of the mid-terrace will be slightly higher than terraced end/semi-detached buildings in the scenario. Therefore, the terraced buildings have the lowest ECI on heating-cooling performance in England because of the shared heat losses from the terraced-end buildings during winter and the passive cooling with the cold outdoor air during the summer.

4.3 Building Archetypes Analysis in Indonesia

The thermal comfort assessment in Indonesia involves cooling and dehumidification process to achieve the adjusted temperature 24.6-26.6°C and 60% relative humidity as the benchmark points. By generating the simulation with the different archetypes and location in Indonesia cities using TRNSYS 17, it generates the energy consumption index (ECI) for assessing the thermal comfort for each variable. Figure 4.3 below illustrates the ECI of combination of cooling and dehumidification operation in Indonesia for a year operation by using air conditioner.

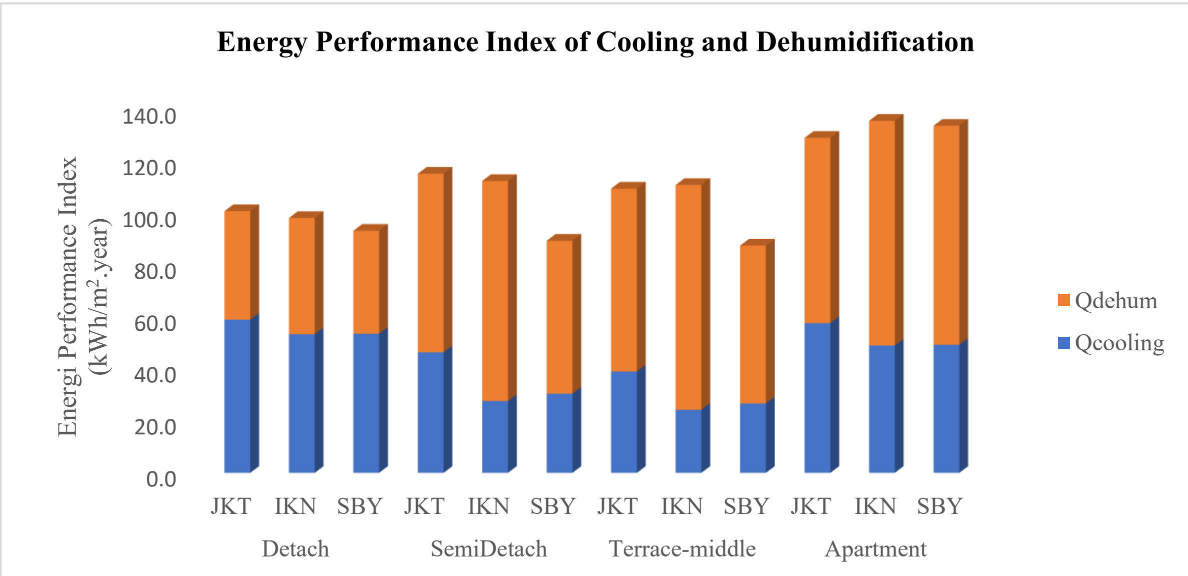

Figure 4.3 Energy Consumption Index of Cooling and Dehumidification Process in Indonesia

It shows that dehumidification energy in Indonesia's buildings takes around 40-80% of the total energy, impacting the total consumed energy for thermal comfort, especially in IKN Nusantara, which has extreme humidity (90-100%) across the year. During the hot mid-day, the adjacent walls benefit the building by maintaining the temperature inside by lowering the external interaction between the rooms with the outdoor air and the solar radiation (Shaeri et al., 2019). However, the effect of adjacent walls whose lower thermal conductivity than external walls increase the moisture transfer within buildings, resulting in a higher heat latent due to the process (Liu & Huang, 2018). It is also found that the presence of an adjacent wall makes the building interact with the other buildings whose relative humidity is higher than the outdoor to release the humidity amount. The flat/apartment has more dehumidification energy due to the lack of windows number, which plays a crucial role in dehumidification in passive cooling. (Leng et al., 2021). Since the extreme relative humidity number in Indonesia significantly affects the thermal comfort assessment, the planning of building establishments should consider energy consumption for dehumidification.

5. Conclusion

The evaluation of energy consumption index (ECI) on different archetypes in the UK and Indonesia is investigated. The different source heating affects the performance of total energy consumed to achieve the thermal comfort. The terraced houses with adjacent walls gain benefit on heating and cooling in the UK. However, it consumes more energy in Indonesia as the presence of dehumidification process. The further study of temperature profile of limited energy scenarios are needed to evaluate the energy building performance.

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