Journal of Science and Technology in Civil Engineering, HUCE, 2025, 19 (1): 109–119

INTEGRATION OF VARIABLE REFRIGERANT FLOW SYSTEM AND ENERGY RECOVERY VENTILATOR IN DIFFERENT CONSTRUCTION CLIMATE ZONES IN VIETNAM: CASE STUDY OF A PRIMARY SCHOOL

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Article history:
Received 03/01/2025, Revised 17/3/2025, Accepted 20/3/2025

Abstract

The heating, ventilation, and air conditioning (HVAC) system consumes a lot of electricity in the building to meet the demand for thermal comfort. The energy recovery ventilator (ERV) has been used in commercial, industrial, and residential buildings to save energy consumption for HVAC systems. In this study, we investigated the efficiency of ERV systems in different construction climate zones in Vietnam and the energy consumption of the sample primary school. We simulated the energy consumption of the sample building installed with the Variable Refrigerant Flow (VRF) system and the ERV integrated with the VRF system (ERV-VRF) by the OpenStudio model. The energy consumption of the sample building varied in different climate zones ranging from 129.76 kWh/m^2 to 156.96 kWh/m^2, following the decreasing order: Southern region > South Central region > North Central region > Northern Delta region > Northeastern midland and mountainous region > Northwest region > Central Highlands region. In most of the climate zones, except for the Central Highlands regions, installing the ERV-VRF system reduced the energy consumption of the sample building. The whole-building (HVAC) EUI saving of the ERV-VRF system depends on the outdoor climate, ranging from 1.19% (5.23%) to 3.29% (9.61%).

Keywords: building energy simulation; openStudio; variable refrigerant flow; energy recovery ventilation; climate zones.

https://doi.org/10.31814/stce.huce2025-19(1)-09

1. Introduction

Buildings consume large amounts of energy in the construction field worldwide. Energy consumption in the construction industry, including industrial and residential sectors, accounts for about 37-40% of the total national energy consumption [1]. According to reports from the Ministry of Construction (2023), the average annual growth rate of the construction industry is currently from about 7% to 9% [1, 2]. The urbanisation rate has reached about 42% by the end of 2023, and rapid urbanisation has increased pressures related to energy demand in the construction field [1]. Therefore, the development and implementation of policies and solutions to increase the use of energy saving and efficiency in the building sector plays an important role in reducing total energy consumption and minimising greenhouse gas emissions in the construction industry, while contributing to the implementation of the Vietnam Commitment at the COP26 conference on the goal of achieving net zero emissions by 2050.

The Variable Refrigerant Flow (VRF) system connects one outdoor unit to multiple indoor units. It controls the quantity of refrigerant flowing into the indoor unit according to the building's cooling

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and heating demand. Therefore, the VRF system is an effective air conditioning system that would save a building's energy consumption. The required amount of fresh air must be supplied into the building through a heating, ventilation, and air conditioning (HVAC) system to meet the demand for indoor air quality and occupant health. Fresh outdoor air removes stale indoor air and provides fresh, conditioned air to create a healthy indoor living environment [3.4,5,6,7]. The higher the outdoor ventilation rate, the greater satisfaction with the indoor air environment, and the better working performance [3–7]. However, the excess and overestimated ventilation rate would increase the energy consumption of the HVAC system for heating and cooling. The HVAC system consumes about 40% of the primary energy consumption in buildings [8]. Thus, optimising HVAC energy consumption is an important solution to reduce the carbon dioxide emissions and adverse impacts of climate change. Proper energy recovery technology would contribute to a cost-efficient and sustainable building HVAC system [3]. Energy recovery ventilation (ERV) processes the outdoor fresh air (preheating or precooling) using an air-to-air heat exchanger to reduce the energy consumed by the HVAC. The energy absorption of the outdoor air from the exhaust air results in indoor unit load reduction, and more economical and efficient HVAC systems [9]. The ERV system could save 70% of energy consumption for fresh air ventilation treatment [8]. The ERV could be integrated with the VRF system (ERV-VRF) to enhance the energy-saving of the HVAC system. However, the energy performance of ERV depends on the outdoor environmental conditions. Building energy modelling (BEM) is a practical tool for simulated energy consumption. It develops calculations that consider building materials, ventilation, air conditioning systems, and thermal load. Therefore, BEM has been used to optimise energy-efficient buildings during the whole building lifecycle such as the design stage, operation stage, and even retrofitting stage to ensure improvement of energy performance and carbon emission reduction. Many BEM software including OpenStudio [10], BuilderDesign [11], TRNSYS [12], DeST [13], and Modelica [14, 15] are widely used to simulate overall building performance by considering various building characteristics and specifications including schedules, internal loads, building geometry, construction materials, etc. Generally, most BEM models are physical model groups, using energy balance, conductivity, heat transfer, and mass balance to describe the building complex system.

There has been plenty of research around the world applying BEM to simulate the energy and environmental performance, to optimise the building design solution including building envelope, building geometry, building operation pattern, and HVAC system control [11, 16–20]. Many researchers simulated the energy consumption of a VRF system installed building using EnergyPlus [21, 22]. Some studies investigated the performance of ERV-integrated VRF systems [23–25]. However, a few studies have been related to BEM application in Vietnam. Nguyen Anh Tuan and Tran Anh Tuan [22] applied OpenStudio to investigate the impact of climate change on the building envelope of commercial and office buildings in Vietnam. Ngo et al. [23] applied building information modeling (BIM) technology and cloud-based energy analysis tools to model the energy behavior of an office building. Recently, we developed a building energy model of a primary school using OpenStudio to examine the effect of building envelope construction materials, sunshade solutions, and air conditioning systems on energy consumption. Nguyen et al. [24] recently assessed the energy saving potential of building envelope solutions for an office building in Vietnam. Pham and Dinh [25] collected the energy consumption data in office buildings to analyse the electricity saving of heat recovery ventilations. In addition, Nguyen et al. [26] reviewed the application of energy recovery ventilation (ERV) solutions to enhance the energy efficiency in buildings. Furthermore, according to our best knowledge, no research in Vietnam has established BEM to explore the working performance of ERV systems. Therefore, the main objective of this study is to investigate the energy efficiency of VRF and ERV systems in different construction climate zones in Vietnam using BEM. This study also analyses the applicability of the ERV system in different construction climate zones in Vietnam in this study.

2. Study Area and Methodology

2.1. Study Area

Vietnam is located in the humid tropical monsoon climate zone. Its territory has two regions: the North and the South, each with a different climate [27]. The North region has hot summers and cold winters, while the South region doesn't have winter. There are two distinct seasons in the South region: the rainy season and the dry season. The rainy season is from May to October, the dry season is from November to April. There are 7 construction climate zones in Vietnam: (1) Northwest region (zone I); (2) Northeastern midland and mountainous region (zone II); (3) Northern Delta region (zone III); (4) North Central region (zone IV); (5) South Central region (zone V); (6) Central Highlands region (zone VI); (7) Southern region (zone VII) [27]. We selected provinces and cities in all construction climate zones to evaluate the effective performance of ERV systems. The chosen provinces and cities are: Son La, Lang Son, Hanoi, Ha Tinh, Da Nang, Bao Loc, Can Tho, and Ho Chi Minh. Son La has a humid subtropical mountainous climate, cold dry non-tropical winters, and hot humid summers with lots of rain. The hottest months are from June to August. The coldest month is from December to January. The monthly average temperature ranges from 14.9 ℃ to 25.3 ℃ [28]. The monthly average relative humidity ranges from 82.7% to 86.6% [28]. Lang Son is characterised by a dry cold winter, with the lowest temperature of 14.6 ℃, and the lowest relative humidity of 78% in January [28]. The hottest months are from June to August with the temperature ranging from 24.8 ℃ to 25.3 ℃ [28]. The weather in Hanoi shows a clear difference between the hot and cold seasons. The average winter temperature of the city from November to March does not exceed 22 ℃, with January being the coldest month, averaging 16.4 ℃ [28]. The average summer temperature in Hanoi from May to September exceeds 27 ℃, with July being the hottest month, averaging 29.2 ℃, and reaching a high of 42.8 ℃ [28]. The monthly average relative humidity in Hanoi ranges from 82.7% to 86.6% [28]. Ha Tinh is a province located in a transitional climate zone, so its weather combines the cold characteristics of the North and the hot characteristics of the South. The climate of the province is divided into two distinct seasons: a hot, humid, and rainy summer (from May to October) and a cold, dry winter (from November to April of the following year). Da Nang City is located in a typical tropical monsoon climate region, characterized by high temperatures and little variation. The climate of Da Nang is a transitional zone that blends the subtropical climate of the North with the tropical savanna climate of the South, predominantly featuring a tropical climate in the South. Each year has two distinct seasons: the rainy season from September to December and the dry season from January to August, with occasional cold spells in winter that are not severe and do not last long. Located in the Savanna Tropical region, the climate in Bao Loc is divided into two seasons: the rainy season from May to the end of October and the dry season from November to April, with March and April being the hottest and driest months. Due to the influence of altitude, the climate is relatively cool and rainy. Can Tho City is located in the climate region of the Mekong Delta, characterized by high and stable temperatures, with a small temperature range between day and night; the climate is divided into two contrasting seasons: the rainy season and the dry season. Although influenced by the tropical monsoon climate, Can Tho has small variations in temperature, thermal radiation, and a high and stable sunshine regime throughout the two seasons of the year. Similar to Can Tho's climate, Ho Chi Minh City's climate is equatorial, with high and stable temperatures throughout the year [29].

The Typical Meteorological Year (TMY) expresses the weather conditions surrounding the building, and the design day year meteorological (DDY) data used to size the HVAC system automatically in all the provinces is downloaded from https://climate.onebuilding.org/.

Table 1. Monthly average temperature and relative humidity of the investigated provinces and cities according to QCVN 02:2022/BXD [28] and World Weather Information Service [29]

Province	Month	1	2	3	4	5	6	7	8	9	10	11	12
Son La	Relative humidity	84.2	85.1	85.9	85.2	83.5	84.0	84.4	86.6	86.1	84.3	82.7	81.6
	Temperature (ºC)	14.9	16.9	20.3	23.3	24.9	25.3	25.1	24.8	23.9	21.7	18.4	15.4
Lang Son	Relative humidity	80.4	82.5	83.6	82.7	81.6	83.6	84.2	85.9	84.7	82.0	80.0	78.0
	Temperature (ºC)	13.1	14.7	18.0	22.3	25.5	26.9	27.1	26.6	25.2	22.3	18.4	14.6
Hanoi	Relative humidity	79.9	82.5	84.5	84.7	81.1	80.0	80.7	82.7	81.0	78.5	77.1	76.2
	Temperature (ºC)	16.6	17.7	20.3	24.2	27.6	29.3	29.4	28.7	27.7	25.3	21.9	18.3
Ha Tinh	Relative humidity	89.9	91.3	90.4	87.0	80.5	74.8	73.4	79.3	85.1	87.3	87.4	87.3
	Temperature (ºC)	17.6	18.5	20.8	24.6	28	29.7	29.8	28.8	27	24.6	21.7	18.7
Da Nang	Relative humidity	84.2	83.9	83.7	82.7	79.3	76.4	75.8	77.4	82.1	84.4	84.7	85.4
	Temperature (ºC)	21.5	22.4	24.2	26.5	28.4	29.4	29.3	29.0	27.6	26.0	24.4	22.2
Bao Loc	Relative humidity	79.9	78.2	79.3	83.0	86.8	89.3	90.1	90.8	90.5	89.0	86.3	83.4
	Temperature (ºC)	20.0	21.0	22.2	23.0	23.3	22.6	22.2	22.1	22.0	21.9	21.2	20.2
Ho Chi Minh	Relative humidity	72	70	70	72	79	82	83	83	85	84	80	77
	Temperature (ºC)	26	26.8	28	29.2	28.8	27.8	27.5	27.4	27.2	27	26.7	26
Can Tho	Relative humidity	80.9	79.4	77.9	78.2	83.7	86.0	86.2	87.0	87.1	86.2	84.3	82.1
	Temperature (ºC)	25.4	26.1	27.3	28.5	28.0	27.3	26.9	26.8	26.8	26.9	26.9	25.7

2.2. Building description

In this study, the building energy simulation (BES) was conducted for a primary school type. The geometric representation of the primary school building is given in Fig. 1. The building summary information is provided in Table 2. The primary school floor plan was presented in [30]. The school floor plan includes classroom, gymnasium, kitchen, cafeteria, office, mechanical, corridor, lobby, and restroom. Table 2 presents detailed information on external window glass, external wall, Window to Wall Ratio (WWR), and sunshade for each case. The information on materials used to construct the building envelope was taken according to Bui [31] and Tri et al. [16] and listed in Table 3.

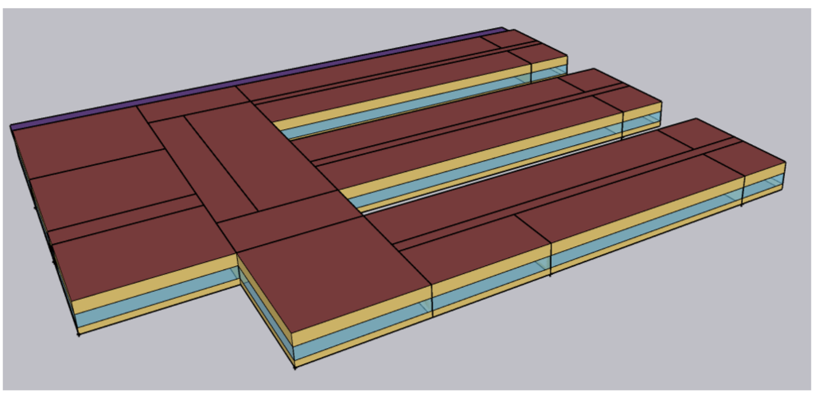


Figure 1. The geometric representathion of the primary school building

Table 2. Building information

Building type	Primary school
Window-to-wall ratio	0.4
HVAC system	VRF
Building height	4 m
Gross floor area	6344 m^2
Number of floor	1

Table 3. The detailed information of the building envelope constructions

External wall	Red brick external wall: 0.015 m of plaster; 0.22 m of red brick; 0.015 m of plaster
Flat Roof	0.015 of ceramic tiles; 0.01 m of plaster; 0.03 m polystirol layer; 0.05 m of cement mortar layer; 0.002m; 0.002 m of Polymer cement mortar for waterproofing; 0.12 m of Reinforced concrete; 0.015 m of internal cement mortar; 0.009 m of gypsum board.
Ground floor	0.1 m concrete poured directly onto the ground + 0.05 m Cement mortar + 0.02 m ordinary brick mixed with light mortar
Glass	Double glazing glass includes clear glass mm + Air 3mm + clear glass 6 mm (U = 3.63 W/m^2.K; SHGC = 0; VLT = 0.78)
Sunshade roof	Sunshades extending 1 m for west-facing windows

2.3. HVAC systems

The primary school was assumed to use VRF air conditioning system to supply cool air into the spaces. The VRF system controls the amount of refrigerant supplied to the indoor unit depending on the cooling or heating requirement of each space. The outdoor unit of the VRF system is equipped with a variable-speed compressor for high-efficiency performance. The component and working principle of VRF system were well-described by Park et al. [32]. The cooling and heating capacity of the VRF air conditioning system was auto-sized using design-day-year weather files by Openstudio. The ventilation ducts supply fresh outdoor air to the indoor unit (IU) of the VRF system. Each space type, including the gymnasium, cafeteria, and office, has a separate fresh outdoor air ventilation system. All classrooms share the same incoming outdoor ventilation system. The ERV was integrated into the VRF air conditioning system to treat the outdoor fresh air. The ERV is connected to the VRF system for energy-saving purposes. The setup of VRF-ERV is expressed in Fig. 2. The ERV recycles the energy contained in the exhausted building air to precondition the outdoor fresh air in HVAC systems. An ERV involves the process of outdoor fresh air and stale indoor air passing through a heat exchanger module. The fresh outdoor air is supplied into a building through supply air diffusers, resulting in the same volume of air being exhausted. The indoor stale air is sucked into the exhaust air grills. The incoming outdoor ventilation air is pre-cooled and dehumidified during warm weather times and humidified and pre-heated during cold weather periods. Therefore, the VRF-ERV system could effectively reduce the energy cost, and the heating and cooling loads of the building. The comparison of energy consumption of the VRF-ERV system with the VRF system was used to analyse the performance of the VRF system with ERV. The ERV system's efficiency, which depended on the air flow, was taken as the default values of the Openstudio (Table 4). The COP of VRF system is assumed to be 3.3 as the default values of OpenStudio. The ERV and the equipment of VRF systems are automatically sized.

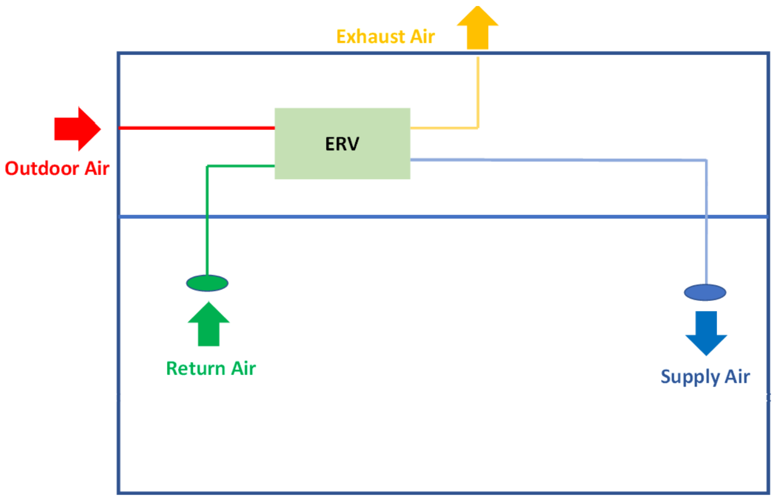


Figure 2. Schematic of VRF-ERV system

Table 4. Efficiency of ERV depending on air flow

ERV efficiency	100% cooling air flow	75% cooling air flow	100% heating air flow	75% heating air flow
Sensible	0.76	0.81	0.76	0.81
Latent	0.68	0.73	0.68	0.73

2.4. Building energy modelling approach

OpenStudio has been used widely and as a trusted tool for many research relating to BEM. Therefore, this research used EnergyPlus released by the National Renewable Energy Laboratory (NREL) in 2010 to optimise the time and expense of developing new BEM applications software to perform energy simulations of the primary school. We used Sketchup software to create detailed building geometry in three dimensions, create and assign individual spaces, assign building stories and exterior spaces, and assign the thermal zones. Then, OpenStudio was applied to specify the weather, materials, and construction assemblies of a building, define schedules applied to building loads, define building loads, set up the HVAC systems, and assign the equipment in each thermal zone. Finally, we simulated the case of the VRF-ERV system and VRF-only system for different climate conditions, reviewed the results, and analyzed, and compared the obtained results.

The input data used to set up the OpenStudio model includes occupancy and energy end use (lighting, electric appliances). The occupancy density, electric equipment power density, and lighting power density of the primary school were chosen according to TCVN 5687:2024/BXD [33], QCVN09:2017/BXD [34], and ASHRAE 90.1-2010 standard [35], and listed in Table 5. The total heat occupants release into the space, including sensible and latent heat, is assumed to be 132 W/person. We assume that the primary school is closed at the weekend. The cooling and heating set point temperature of the HVAC system are 25 °C and 21 °C, respectively.

Table 5. Occupancy, electric equipment power density and lighting power density of the building

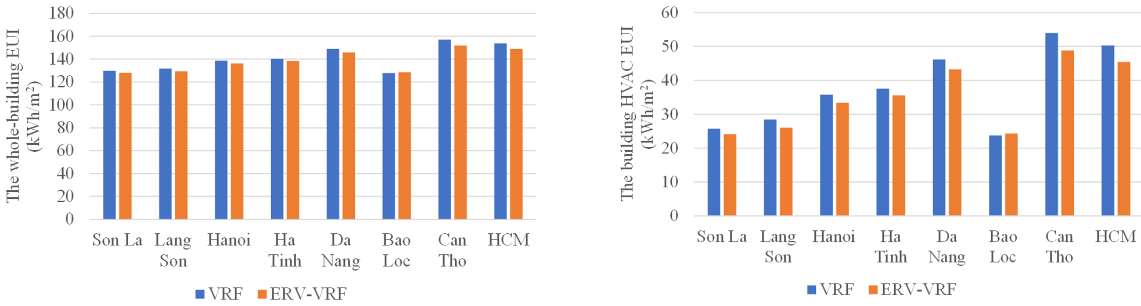
Space	Occupancy density (m^2/person)	Electric equipment power density (W/m^2)	Lighting power density (W/m^2)
Cafeteria	1	18.51	6.99
Classroom	2	10.98	12
Corridor	1	2.91	7.10
Gymnasium	3.33	3.66	12.92
Kitchen	6.67	3.66	10.66
Mechanical	100	3.66	10.23
Office	8	7.86	11
Restroom	10	2.91	10.55

3. Results and discussions

3.1. Energy consumption of the primary school building in different climate zones

Fig. 3 shows the whole-building Energy Used Index (EUI) of the primary school in 8 provinces and cities for different construction climate zones in Vietnam when the HVAC system of the building is VRF. The energy consumption of the sample building varied in different climate zones, following the decreasing order: Southern region > South Central region > North Central region > Northern Delta region > Northeastern midland and mountainous region > Northwest region > Central Highlands region. The whole-building EUI values ranged from 129.76 kWh/m^2 to 156.96 kWh/m^2. Generally, our obtained results were in the range of institutional buildings in Singapore (141.4 kWh/m^2 to 288.4 kWh/m^2) [17], except for Can Tho and Ho Chi Minh City. As shown in Fig. 3, Can Tho and Ho Chi Minh City in the Southern region featured hot weather all year round and experienced high EUI values (156.96 kWh/m^2 and 153.73 kWh/m^2, respectively). On the other hand, Son La, Lang Son, and Bao Loc located in the Northwest region, Northeastern midland and mountainous region, and Central Highlands region exhibited lower EUI values (129.76 kWh/m^2, 131.70 kWh/m^2, and 127.86 kWh/m^2). The whole-building EUI value of the same building information in Hanoi (138.59 kWh/m^2) was slightly higher than those in Son La, Lang Son, and Bao Loc. The primary school building installed a VRF air conditioning system in this study, which consumed less energy than the one installed package terminal air conditioning system (PTAC) reported in a previous study (156.08 to 178.81 kWh/m^2) [31]. This result could be explained by the higher coefficient of performance of VRF systems compared to the PTAC system. Furthermore, the same primary school in the North Central region (Ha Tinh) and South Central region (Da Nang) consumed 140.29 kWh/m^2 and 148.93 kWh/m^2 which were higher than those in Son La, Lang Son, Bao Loc, but lower than those in Can Tho and Ho Chi Minh City. The building HVAC EUI values in 8 provinces also followed the same the increasing order as the whole-buidling EUI: Bao Loc (23.74 kWh/m^2 for VRF system and 24.33 kWh/m^2 for VRF-ERV system) < Son La (25.71 kWh/m^2 for VRF system and 24.17 kWh/m^2 for VRF-ERV system) < Lang Son (28.40 kWh/m^2 for VRF system and 26.00 kWh/m^2 for VRF-ERV system) < Hanoi (35.75 kWh/m^2 for VRF system and 33.78 kWh/m^2 for VRF-ERV system) < Ha Tinh (37.50 kWh/$m^2$for VRF system and 35.53 kWh/m^2 for VRF-ERV system) < Da Nang (46.15 kWh/m^2 for VRF system and 43.22 kWh/m^2 for VRF-ERV system) < Ho Chi Minh City (50.26 kWh/m^2 for VRF system and 45.44 kWh/m^2 for VRF-ERV system) < Can Tho (53.95 kWh/m^2 for VRF system and 48.78 kWh/m^2 for VRF-ERV system).

The lighting and electrical systems of the primary school were unchanged for the model established in different climate zones. Thus, the energy consumption of lighting and electrical equipment



(a) The whole-building EUI

(b) The building HVAC EUI

Figure 3. The EUI of the sample building in 8 cities in different construction climate zones in Vietnam

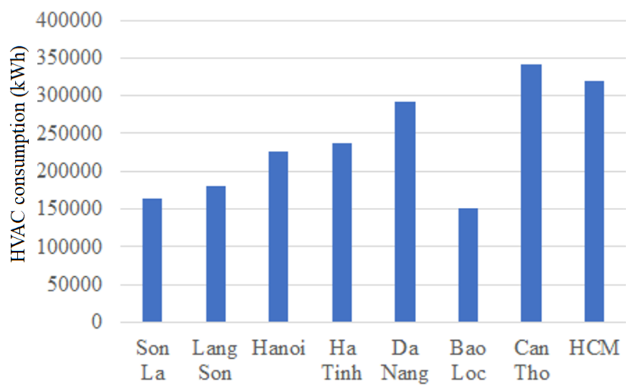


Figure 4. The annual energy consumption of VRF system in 8 cities in different construction climate zones in Vietnam

was the same in all climate zones. Therefore, the discrepancy in energy consumption of the primary school in different climate zones could be attributed to the various climate characteristics that lead to different energy consumption of HVAC systems. The annual energy utilisation of the VRF system of the primary school is shown in Fig. 4. As shown in Fig. 4, the annual energy consumption of the VRF system in 8 provinces and cities is similar to that of the annual energy consumption. The VRF energy consumption in 8 provinces followed the increasing order: Bao Loc (150611 kWh) < Son La (163131 kWh) < Lang Son (180144 kWh) < Hanoi (226800 kWh) < Ha Tinh (237877 kWh) < Da Nang (292844 kWh) < Ho Chi Minh City (318881 kWh) < Can Tho (342281 kWh). The building HVAC EUI values in 8 provinces also followed the increasing order: Bao Loc (23.74 kWh/m^2 for VRF system and 24.33 kWh/m^2 for VRF-ERV system) < Son La (25.71 kWh/m^2 for VRF system and 24.17 kWh/m^2 for VRF-ERV system) < Lang Son (28.40 kWh/m^2 for VRF system and 26.00 kWh/m^2 for VRF-ERV system) < Hanoi (35.75 kWh/m^2 for VRF system and 33.78 kWh/m^2 for VRF-ERV system) < Ha Tinh (37.50 kWh/m^2 for VRF system and 35.53 kWh/m^2 for VRF-ERV system) < Da Nang (46.15 kWh/m^2 for VRF system and 43.22 kWh/m^2 for VRF-ERV system) < Ho Chi Minh City (50.26 kWh/m^2 for VRF system and 45.44 kWh/m^2 for VRF-ERV system) < Can Tho (53.95 kWh/m^2 for VRF system and 48.78 kWh/m^2 for VRF-ERV system).

3.2. Energy-saving performance of ERV systems in different climate zones

Eight cities were chosen from seven construction climatic zones in Vietnam to conduct the energy simulation with the same primary school building, except for the different weather data. The EUI values of the sample building installed with the ERV-VRF system in 7 construction climate zones in Vietnam ranged from 128.21 kWh/m^2 to 151.79 kWh/m^2. Fig. 3 expresses the energy used index (EUI) of the primary school in the case of using the VRF and VRF-ERV systems. In general, the VRF-ERV system consumes less energy than the VRF system in most of the investigated provinces and cities, except for Bao Loc. The whole-building EUI saving of the VRF-ERV system compared to the VRF-only system ranged from 1.19% to 3.29% (Fig. 5). The HVAC EUI of the VRF system ranged from 23.74 kWh/m^2 to 53.95 kWh/m^2. The HVAC EUI of VRF-ERV system ranged from 24.33 kWh/m^2 to 48.78 kWh/m^2. The HVAC EUI saving of the VRF-ERV system compared to the VRF-only system ranged from 5.23% to 9.61% (Fig. 5). The HVAC EUI saving was higher than the whole-building saving because it does not include other end use energy consumption, such as lighting, electric equipment. The energy-saving of the ERV-VRF system in this study was lower than in Budapest (20-30%) [36], in Beijing, China (15%-30%) [9]. The lower energy-saving percentage of ERV in Vietnam than in other locations with extremely cold weather could be due to higher temperature differences between indoor-outdoor air during the cold winter in Budapest and Beijing.

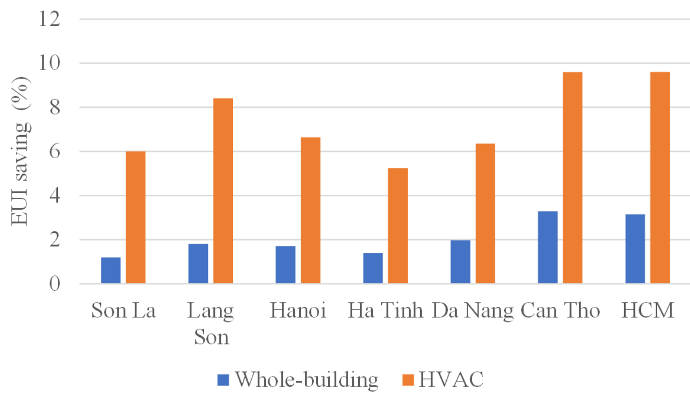


Figure 5. The energy saving of ERV-VRF systems in 7 cities in different construction climate zones in Vietnam

Interestingly, the highest whole-building EUI saving of HVAC systems was found in Ho Chi Minh City (3.14%) and Can Tho (3.29%) where the annual energy consumption was the highest among 7 construction climate zones. On the other hand, Son La expressed both relatively low annual energy consumption and low energy saving of the HVAC system (1.19%). Additionally, it is noticed that the VRF-ERV system in Bao Loc did not reduce the energy utilization of the VRF system. The VRF-ERV system in Bao Loc consumed 0.45% more than the VRF-only system. This result could be explained by the cool and temperate climate all year round of Bao Loc due to the impact of altitude and terrain. As shown in Table 1, the temperature in Bao Loc varied from 22 ℃ to 23.3 ℃ with an annual temperature of 21.8 ℃. A previous study also concluded the dependence of the energy-saving performance of ERV systems on outdoor climatic conditions .....()[9]. The energy consumption of the fan used to operate the ERV system in the sample building in Bao Loc would be higher than the energy reduction due to the heat exchanger, resulting in higher energy consumption of the ERV-VRF system.

4. Conclusions

In this study, we investigated the energy consumption of the sample primary school-installed VRF and ERV-VRF systems and the efficiency of ERV systems in different construction climate zones in Vietnam. The EUI values of the sample building installed VRF system and ERV-VRF system in 7 construction climate zones in Vietnam ranged from 129.76 kWh/m^2 to 156.96 kWh/m^2, and 128.21 kWh/m^2 to 151.79 kWh/m^2, respectively. Generally, the ERV-VRF system consumed less energy than the VRF-only system in 6 construction climate zones, except for the Central Highlands region. The whole-building (HVAC) EUI saving of the ERV-VRF system depends on the outdoor climate, ranging from 1.19% (5.23%) to 3.29% (9.61%). Therefore, the local climate conditions should be carefully considered to improve energy-saving performance.

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