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Investigating chillers' energy consumption and energy saving analysis of a primary school in Ho Chi Minh city, Vietnam

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KEYWORDS

Building energy simulation
OpenStudio
Chiller
Constant Air Volume
Variable Air Volume
Load distribution scheme
Indoor air temperature
Coefficient of performance

ABSTRACT

Air conditioning and chillers contributed much of the total building energy consumption. In this study, we investigated the impacts of the chillers' COP, the indoor air temperature, the air distribution approach, the load distribution scheme of the chiller system and the outdoor air temperature that influence the energy consumption of the sample primary school-installed water-cooled chiller system in Ho Chi Minh City, Vietnam. The EUI values of the sample building's installed water-cooled chiller system ranged from 115.25 kWh/m2 to 155.55 kWh/m2. While the energy consumption of the water-cooled chiller system showed a positive correlation with the outdoor air temperature, it expressed a negative relationship with the indoor air temperature and the chiller's COP. Generally, the water-cooled chiller system consumes less power with the VAV system than the CAV system and less power under the optimal load distribution scheme than the uniform load distribution scheme. The total annual energy-saving of the chiller system depends on the choice of chillers' COP, load distribution scheme, air distribution approach, and the set point of indoor air temperature, ranging from 7.43 % to 41.62 %.

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 will reach about 42 % by the end of 2023, 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 minimizing 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 key motivation for modelling and simulating the building energy consumption by by developing calculations considering building materials, ventilation, air conditioning systems, and thermal load using energy balance, conductivity, heat transfer, and mass balance to describe the building's complex system is to provide information and knowledge of building conditions to optimize the building energy performance. Building Energy Modelling (BEM) using computer software is a robust tool in the initial design stages, commissioning and operation stages of a building to optimise energy consumption. There are many BEM software including OpenStudio [3], Design Builder[4], TRNSYS [5], DeST [6], and Modelica [7], [8] that are widely used to simulate overall building performance. There have been many researches that optimised a set of parameters for a given function and achieved simulation-based optimisation of heating, ventilation, and air-conditioning (HVAC) systems [9][10][11].

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 [4], [12], [13], [14], [15], [16]. Many researchers have simulated the energy consumption of a building-installed Variable Refrigerant Flow (VRF) system [17][18][19][20][21], and the performance of a chilled water system [10][22]. However, a few studies have been related to BEM application in Vietnam. Nguyen Anh Tuan and Tran Anh Tuan [23] applied OpenStudio to investigate the impact of climate change on the building envelope of commercial and office buildings in Vietnam. Ngo et al., [24] applied building information modeling (BIM) technology and cloud-based energy analysis tools to model the energy behaviour 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 [25] and investigated the energy performance of the VRF system and the related energy saving measures using Energy Recovery System (ERV)[26]. Nguyen et al., (2024) [27] recently assessed the energy saving potential of building envelope solutions for an office building in Vietnam. Furthermore, according to our best knowledge, no research in Vietnam has established BEM to explore the working performance of a water-cooled chiller system. The selection of an HVAC

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system configuration plays an important role in optimizing the building power consumption since the energy consumption of the HVAC system accounts for about 30 % – 60 % of the total building energy consumption [27]. Water-cooled chillers are one of the main components of the central HVAC system and account for a large proportion of electricity utilization [28]. It is reported that chillers consumed about 40% of the total HVAC energy use [29]. Therefore, the main objective of this study is to provide an analysis of the power consumption of a primary school-installed chilled water system for cooling to support energy-saving strategies. We focused the investigation on the factors impacting the energy performance of the chiller system including the coefficient of performance (COP) of a chiller, the indoor air temperature, the load distribution among the chillers, the air distribution approach (the constant air distribution (CAV), and the variable air distribution (VAV)), and the outdoor air temperature.

2. Study Area and Methodology

2.1. Building description

In this study, the BEM was conducted for a primary school type. The primary school is assumed to be located in Ho Chi Minh City, Vietnam. Ho Chi Minh City's climate is equatorial, with high and stable temperatures throughout the year [30]. 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/.

The summary information and geometric representation of the primary school building were described in our previous study [25], [26]. The primary school was assumed to use a water-cooled chiller system with 2 chillers. The cooling capacity of the chiller air conditioning system was auto-sized using design-day-year weather files by Openstudio. The ventilation ducts supply fresh outdoor air to the Air Handling Unit (AHU) of the chiller system. The cooling air to maintain the occupant's thermal comfort in the indoor spaces was supplied from the AHU in two cases: constant air volume (CAV) and Variable Air Volume (VAV).

2.2. Building energy simulation approach

OpenStudio has been used widely and is a trusted tool for much research relating to building energy simulation. Therefore, this research used EnergyPlus released by the National Renewable Energy Laboratory (NREL) in 2010 to optimise the time and expense of developing new Building Energy Model 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. The input data used to set up the OpenStudio were chosen according to TCVN 5687:2024/BXD, QCVN09:2017/BXD, ASHRAE 90.1-2010 standard [31], and described in our previous study [26]. Finally, we simulated the case of different chillers' COP, indoor air temperatures, load distribution schemes, and the air distribution approach (CAV or VAV), reviewed the results, and analysed and compared the obtained results.

3. Results and discussions

3.1. Impacts of chillers' COP on the energy consumption of the sample primary school

The higher the chiller's COP values, the more efficient electricity that the chiller consumes to provide cooling, leading to less energy consumption and reduced operation costs [28]. Improvement of the chiller's COP values contributed to a more sustainable and eco-friendly HVAC system by reducing carbon emissions [28]. We investigated the impacts of chillers' COP on the energy consumption of the primary school in the case of the chillers' COP being 6, 6.5 and 7 with the assumption that the chillers were ultra high-efficiency Variable Speed Drives (VSD) water-cooled chillers that have an excellent range of COP [32]. For the investigation purpose, we only changed the chiller's COP and kept the other parameters unchanged, including the indoor air temperature of 26 ^oC, the chiller's load distribution scheme of Optimal, and the air distribution option of CAV. Fig.1 expresses the Energy Used Intensity (EUI) of the primary schools and the HVAC cooling capacity depending on the COP of the chillers. The energy consumption of the sample building decreased along with the increase of the chillers' COP. The EUI values ranged from 135.56 kWh/m^2 to 137.56 kWh/m^2. The primary school building installed a water-cooled chiller air conditioning system in this study, which consumed less energy than the one installed Variable Refrigerant Flow (VRF) air conditioning system reported in a previous study (153.73 kWh/m^2) [26]. This result could be explained by the higher coefficient of performance of water-cooled chiller systems compared to the VRF system. Furthermore, the EUI values of the sample primary schools were reduced by 1.69 % and 3.10 % when the chillers' COP increased from 6 to 6.5 and from 6 to 7, respectively. These results could be attributed to the reduction of the total annual HVAC cooling energy consumption as shown in Fig.1. The HVAC cooling energy consumption in the case chillers' COP of 6, 6.5, and 7 were 177634.11 kWh, 163969.92 kWh, and 152257.72 kWh, respectively. By increasing the chillers' COP from 6 to 6.5, and from 6 to 7, the total annual HVAC energy consumption decreased by 8.33 % and 14.29 %. As shown in Fig.2, the monthly HVAC cooling energy consumption also decreases with the increase of the chillers' COP. Considering the influence of the chillers' COP, the monthly HVAC cooling energy consumption ranged from 10031.83 kWh to 18109.92 kWh. The highest energy consumption of the HVAC system occurred in May, with values of 18109.92 kWh, 16716.83 kWh, and 15522.78 kWh for the COPS of 6, 6.5, and 7, respectively. The lowest energy consumption of the HVAC system happened in February (11703.81 kWh, 10803.53 kWh, and 10031.83 kWh for the COP being 6, 6.5, and 7, respectively).

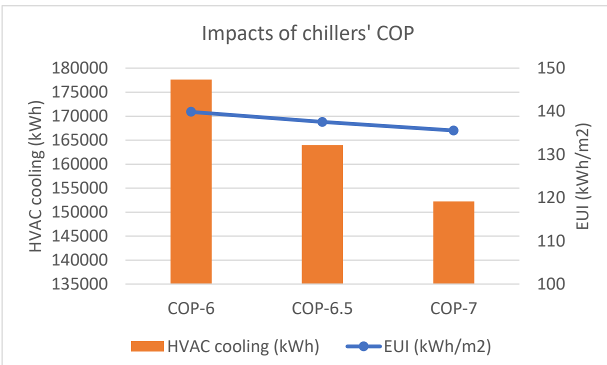

Fig.1. Impacts of chillers' COP on the EUI and the total annual power consumption for HVAC cooling of the sample building in Ho Chi Minh City.

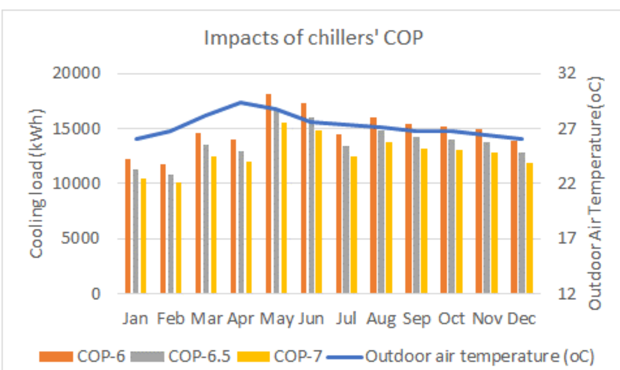

Fig.2. The monthly energy consumption for HVAC cooling of the primary school depends on the chillers' COP in Ho Chi Minh, Vietnam.

3.2. Impacts of indoor air temperature on the energy consumption of the sample primary school

Indoor air temperature is a key factor for controlling human thermal comfort that influences the energy consumption of the HVAC system [33]. The effective control approach of indoor thermal comfort air temperature not only ensures the maintenance of environmental thermal comfort but also plays an important role in reducing the energy waste of an HVAC system [34]. We investigated the impacts of indoor air temperature on the energy consumption of the primary school in the case of the indoor air temperature being 25 °C, 26 °C, and 27 °C. For the investigation purpose, we only changed the indoor air temperature and kept the other parameters unchanged, including the chillers' COP of 7, the chiller's load distribution scheme of Optimal, and the air distribution option of CAV. Fig.3 expresses the EUI of the primary schools and the HVAC cooling capacity depending on the indoor air temperature. The energy consumption of the sample building decreased along with the increase in the indoor air temperature. Furthermore, the EUI values of the sample primary schools were reduced by 12.75 % and 29.45 % when the indoor air temperature increased from 25 °C to 26 °C and from 25 °C to 27 °C, respectively. These results could be attributed to the reduction of the total annual HVAC cooling energy consumption as shown in Fig.3. The total annual HVAC cooling energy consumption in the case of indoor air temperatures of 25 °C, 26 °C, and 27 °C were 174508.44 kWh, 152257.72 kWh, and 123474.19 kWh, respectively. By increasing the indoor air temperature from 25 °C to 26 °C and from 25 °C to 27 °C, the total annual HVAC energy consumption decreased by 15.59 % and 30.43 %. As shown in Fig.4, the monthly HVAC cooling energy consumption also decreases with the increase in the indoor air temperature. Considering the influence of the indoor air temperature, the monthly HVAC cooling energy consumption ranged from 8270.22 kWh to 17445.94 kWh. The highest energy consumption of the HVAC system happened in May (17445.94 kWh, 15522.78 kWh, and 12369.58 kWh, for the COP being 6, 6.5, and 7, respectively). The lowest energy consumption of the HVAC system occurred in February (11829.89 kWh, 10031.83 kWh, and 8270.22 kWh for the indoor air temperature of 25 °C, 26 °C, and 27 °C, respectively).

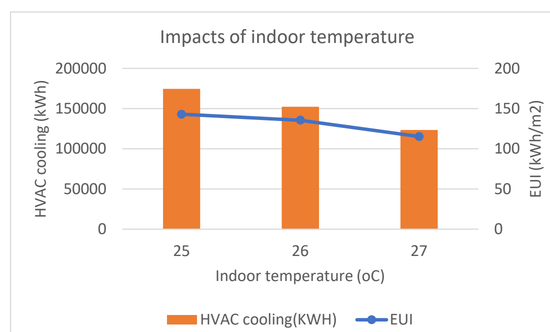

Fig.3. Impacts of indoor air temperature on the EUI and the total annual power consumption for HVAC cooling of the sample building in Ho Chi Minh City.

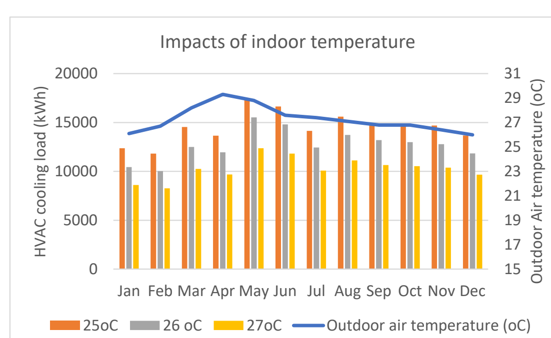

Fig.4. The monthly energy consumption for HVAC cooling of the primary school depends on the indoor air temperature in Ho Chi Minh, Vietnam.

3.3. Impacts of load distribution among the chillers on the energy consumption of the sample primary school

Optimization of the chiller system performance would improve energy consumption [35]. The load distribution among the chillers affects the performance of the chiller system. We investigated the impacts of two load distribution schemes of the chiller system on the energy consumption of the primary school in the case of optimal mode and uniform load mode. Regarding the optimal mode, each chiller works at its optimal part load ratio (PLR) [36]. The uniform load mode distributes Loop demand across all available components [36]. For the investigation purpose, we only changed the load distribution scheme and kept the other parameters unchanged, including the indoor air temperature of 26 °C, the chillers' COP of 7, and the air distribution option of CAV. Fig.5 expresses the EUI of the primary schools and the HVAC cooling capacity depending on the load distribution scheme of the chiller system. The energy consumption of the water-cooled chiller system with an optimal load distribution scheme (135.56 kWh/m^2) was lower than the uniform load mode (155.55 kWh/m^2). The EUI values of the sample primary schools operated under the optimal mode were 12.85 % smaller than the uniform load mode. These results could be the consequence of the decrease in the total HVAC cooling energy consumption as shown in Fig.5. The total annual energy consumption of the chilled water system under optimal mode (152257.72 kWh) was 41.62 % less than the one under Uniform Load (260788.75 kWh). Additionally, as shown in Fig.6, the monthly cooling energy consumed by the water-cooled chiller system under optimal mode was also less than the one under uniform load mode. Considering the influence of the load distribution scheme of the chiller system, the monthly HVAC cooling energy consumption ranged from 10031.83 kWh to 14846.56 kWh. The highest energy consumption of the HVAC system occurred in May (15522.78 kWh and 24846.56 kWh for the optimal and uniform load, respectively). The lowest energy consumption of the HVAC system happened in February (10031.83 kWh and 17344.83 kWh for the optimal and uniform load, respectively). Changing the operation from Uniform load to optimal results in the monthly HVAC energy saving from 37.42 % to 44.07 %.

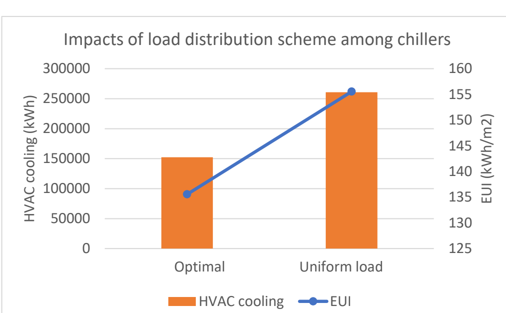

Fig.5. Impacts of load distribution scheme on the EUI and the total annual power consumption for HVAC cooling of the sample building in Ho Chi Minh City.

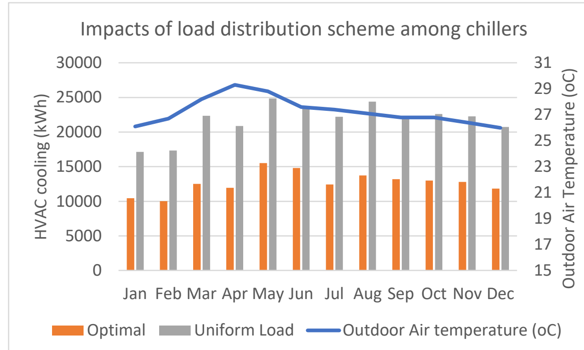

Fig.6. The monthly energy consumption for HVAC cooling of the primary school depends on the load distribution scheme of the chiller system in Ho Chi Minh, Vietnam.

3.4. Impacts of air distribution approach on the energy consumption of the sample primary school

The thermal comfort for the building occupants and power saving of an HVAC system go hand in hand with the VAV system [21]. We compared the energy consumption of the primary school in the case of CAV and VAV systems. For the investigation purpose, we only changed the air distribution approach (CAV or VAV) and kept the other parameters unchanged, including the indoor air temperature of 26 °C, the chiller's load distribution scheme of Optimal, and the chillers' COP of 7. Fig.7 expresses the EUIof the primary schools and the HVAC cooling capacity depending on the air distribution approach. The energy consumption of the sample building with the VAV system (127.93 kWh/m^2) was lower than the CAV system (135.56 kWh/m^2). The EUI values of the sample primary schools with the VAV system were 5.63 % smaller than the CAV system. These results could be attributed to the reduction of the total annual HVAC cooling energy consumption as shown in Fig.7. The total annual energy consumption of the chilled water system with VAV (140948 kWh) was 7.42 % less than the one with CAV (152257.72 kWh). Additionally, as shown in Fig.8, the monthly HVAC cooling energy consumption of the VAV system was also less than the one with the CAV system. Considering the influence of the air distribution approach, the monthly HVAC cooling energy consumption ranged from 9332.11 kWh to 15522.78 kWh. The highest energy consumption of the HVAC system observed in May (15522.78 kWh and 14739.08 kWh for the CAV and VAV systems, respectively). The lowest energy consumption of the HVAC system was observed in February (10031.83 kWh and 9332.11 kW for the CAV and VAV systems, respectively). Replacing the CAV system with the VAV system results in the reduction of monthly HVAC energy consumption from 3.96 % to 11.34 %. The obtained results could be explained by the fact that the VAV system varied the cooled air supply into the building zones to reduce the overcooling by lowering fan speeds and lowering the central conditioning requirements to ensure the occupants' comfort satisfaction and lower energy consumption.

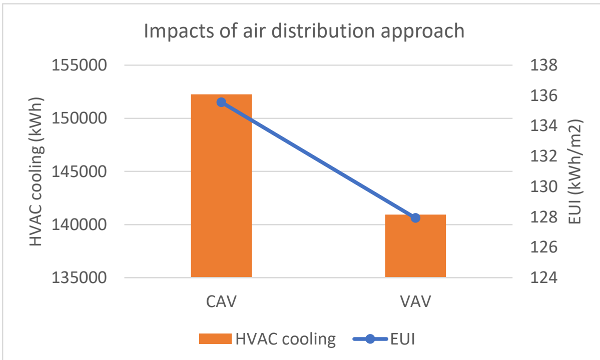

Fig.7. Impacts of air distribution approach on the EUI and HVAC cooling of the sample building in Ho Chi Minh City.

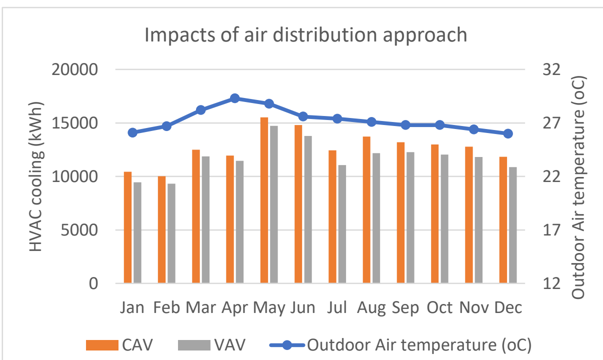

Fig.8. The monthly energy consumption for HVAC cooling of the primary school depends on the load distribution scheme of the chiller system in Ho Chi Minh, Vietnam.

3.5. Impacts of outdoor air temperature on the energy consumption of the sample primary school

The outdoor air temperature is a key factors that influence the performance of air conditioner systems and the energy consumption for providing cooling [37]. As shown in Fig.2-8, the monthly HVAC cooling energy consumption ranged from 8270.22 kWh to 24846.56 kWh. Generally, the higher the outdoor air temperature, the higher the energy the HVAC consumes for providing cooling. A previous study also illustrated the positive correlation between the outdoor air temperature and the power consumption of an HVAC system [38]. The higher power consumption of an HVAC system for cooling purposes during the higher outdoor air temperature could be attributed to the increase of indoor thermal load and the decrease of the COP of the air conditioner system [37].

4. Conclusions

In this study, we analyzed the power consumption of a primary school-installed chilled water system and the factors that influence the energy consumption of a primary school-installed water-cooled chiller system for providing cooling in Ho Chi Minh City in Vietnam. We consider the chillers' COP, the indoor air temperature, the air distribution approach, the load distribution scheme of the chiller system, and the outdoor air temperature that influence the energy consumption in our investigations. The EUI values of the sample building, which installed a water-cooled chiller system, ranged from 115.25 kWh/m^2 to 155.55 kWh/m^2. The total annual power consumption of the chiller system ranged from 123474.19 kWh to 260788.75 kWh. The monthly power consumption of the chiller system varied along with the outdoor temperature, ranging from 8270.22 kWh to 24846.56 kWh. While the energy consumption of the water-cooled chiller system increases along with the increase of outdoor air temperature, it expresses a negative relationship with the indoor air temperature, the chiller's COP. Generally, the VAV system consumes less power than the CAV system. Additionally, the chiller system under the optimal load distribution scheme saved 41.62 % compared with the uniform load distribution scheme. The total annual energy-saving of the chiller system depends on the choice of chillers' COP, load distribution scheme, air distribution approach, and the set point of indoor air temperature, ranging from 7.43 % to 41.62 %.

References

[1]. N. Đ. L. Nguyễn Công Thịnh, "Giải pháp phát triển công trình cân bằng năng lượng ở một số quốc gia trên thế giới và khuyến nghị cho Việt Nam," *Tạp chí khoa học công nghệ xây dựng, Đại học Xây dựng Hà Nội*, vol. 1, no. 17, pp. 91–100, 2023.

[2]. B. T. Hieu, "Nghiên cứu các mô hình mô phỏng năng lượng: phân loại, ứng dụng kỹ thuật, xu hướng nghiên cứu và phát triển," *Tạp chí Vật liệu và xây dựng*, vol. 2, no. 14, pp. 125–133, 2024.

[3]. O. Ahmed and T. Al-Zubaydi, "Building Models Design And Energy Simulation With Google Sketchup And," *J. Adv. Sci. Eng. Res.*, vol. 3, no. 4, pp. 318–333, 2013.

[4]. A. A. Chowdhury, M. G. Rasul, and M. M. K. Khan, "Modelling and simulation of building energy consumption: A case study on an institutional building in central queensland, australia," *IBPSA 2007 - Int. Build. Perform. Simul. Assoc. 2007*, no. Krarti 2000, pp. 1916–1923, 2007.

[5]. S. A. Klein, W. A. Beckman, and J. A. Duffie, "Trnysys - a Transient Simulation Program.," *ASHRAE Trans.*, vol. 82, no. pt 1, pp. 623–633, 1976.

[6]. D. Yan, J. Xia, W. Tang, F. Song, X. Zhang, and Y. Jiang, "DeST — An integrated building simulation toolkit Part I: Fundamentals," *Build. Simul.*, vol. 1, no. 2, pp. 95–110, 2008, doi: 10.1007/s12273-008-8118-8.

[7]. M. Wetter, "A modelica-based model library for building energy and control systems," *IBPSA 2009 - Int. Build. Perform. Simul. Assoc. 2009*, no. June, pp. 652–659, 2009.

[8]. C. Fan *et al.*, "Open-source Modelica models for the control performance simulation of chiller plants with water-side economizer," *Appl. Energy*, vol. 299, p. 117337, Oct. 2021, doi: 10.1016/j.apenergy.2021.117337.

[9]. K. F. Fong, V. I. Hanby, and T. T. Chow, "HVAC system optimization for energy management by evolutionary programming," *Energy Build.*, vol. 38, no. 3, pp. 220–231, Mar. 2006, doi: 10.1016/j.enbuild.2005.05.008.

[10]. M. Ali, V. Vukovic, M. H. Sahir, and G. Fontanella, "Energy analysis of chilled water system configurations using simulation-based optimization," *Energy Build.*, vol. 59, pp. 111–122, Apr. 2013, doi: 10.1016/j.enbuild.2012.12.011.

[11]. A. Hasan, M. Vuolle, and K. Sirén, "Minimisation of life cycle cost of a

detached house using combined simulation and optimisation," *Build. Environ.*, vol. 43, no. 12, pp. 2022–2034, Dec. 2008, doi: 10.1016/j.buildenv.2007.12.003.

[12]. Y. Pan *et al.*, "Advances in Applied Energy Building energy simulation and its application for building performance optimization : A review of methods , tools , and case studies," *Adv. Appl. Energy*, vol. 10, no. March, p. 100135, 2023, doi: 10.1016/j.adapen.2023.100135.

[13]. J. Yang, M. Santamouris, S. E. Lee, and C. Deb, "Energy performance model development and occupancy number identification of institutional buildings," *Energy Build.*, vol. 123, pp. 192–204, 2016, doi: 10.1016/j.enbuild.2015.12.018.

[14]. J. Li, W. Xu, P. Cui, B. Qiao, S. Wu, and C. Zhao, "Research on a Systematical Design Method for Nearly Zero-Energy Buildings," *Sustainability*, vol. 11, no. 24, p. 7032, Dec. 2019, doi: 10.3390/su11247032.

[15]. F. Nocera, A. Lo Faro, V. Costanzo, and C. Raciti, "Daylight Performance of Classrooms in a Mediterranean School Heritage Building," *Sustainability*, vol. 10, no. 10, p. 3705, Oct. 2018, doi: 10.3390/su10103705.

[16]. C. Tam, Y. Zhao, Z. Liao, and L. Zhao, "Mitigation Strategies for Overheating and High Carbon Dioxide Concentration within Institutional Buildings: A Case Study in Toronto, Canada," *Buildings*, vol. 10, no. 7, p. 124, Jul. 2020, doi: 10.3390/buildings10070124.

[17]. R. Kalaimani, M. Jain, S. Keshav, and C. Rosenberg, "On the interaction between personal comfort systems and centralized HVAC systems in office buildings," *Adv. Build. Energy Res.*, vol. 14, no. 1, pp. 129–157, 2020, doi: 10.1080/17512549.2018.1505654.

[18]. D. Kim, S. J. Cox, H. Cho, and P. Im, "Model calibration of a variable refrigerant flow system with a dedicated outdoor air system: A case study," *Energy Build.*, vol. 158, pp. 884–896, Jan. 2018, doi: 10.1016/j.enbuild.2017.10.049.

[19]. Y. M. Li and J. Y. Wu, "Energy simulation and analysis of the heat recovery variable refrigerant flow system in winter," *Energy Build.*, vol. 42, no. 7, pp. 1093–1099, Jul. 2010, doi: 10.1016/j.enbuild.2010.01.023.

[20]. D. Y. Park, G. Yun, and K. S. Kim, "Experimental evaluation and simulation of a variable refrigerant- flow (VRF) air-conditioning system with outdoor air processing unit," *Energy Build.*, vol. 146, pp. 122–140, Jul. 2017, doi: 10.1016/j.enbuild.2017.04.026.

[21]. T. E. Jiru, "Combining HVAC energy conservation measures to achieve energy savings over standard requirements," *Energy Build.*, vol. 73, pp. 171–175, 2014, doi: 10.1016/j.enbuild.2014.01.009.

[22]. F. W. Yu, K. T. Chan, R. K. Y. Sit, and J. Yang, "Energy simulation of sustainable air-cooled chiller system for commercial buildings under climate change," *Energy Build.*, vol. 64, pp. 162–171, Sep. 2013, doi: 10.1016/j.enbuild.2013.04.027.

[23]. T. A. T. Nguyen Anh Tuan, "The impact of climate change on the design of commercial and office building envelope in Vietnam in the period 2050-2080," *J. Sci. Technol. Univ. Da Nang*, vol. 19, no. 5.2, pp. 6–10, 2021.

[24]. P. A. D. Ngo ngoc Tri, Nguyen Huu Quang Minh, Nguyen Thanh Lam, Huynh Tien Luc, "PHÂN TÍCH NĂNG LƯỢNG TRONG TÒA NHÀ SỬ DỤNG MÔ HÌNH THÔNG TIN CÔNG TRÌNH HƯỚNG TỚI SỰ BỀN VỮNG.," *J. Sci. Technol. Univ. Da Nang*, vol. 18, no. 9, pp. 37–40, 2020.

[25]. B. T. Hieu, "Investigating the impacts of passive design solutions on building energy consumption using OpenStudio: Case study of a primary school, Hanoi, Vietnam," *J. Sci. Technol. Civ. Eng. - HUCE*, vol. 18, no. 4, pp. 123–131, Dec. 2024, doi: 10.31814/stce.huce2024-18(4)-10.

[26]. B. T. Hiếu, "Integration of variable refrigerant flow system and energy recovery ventilator in different construction climate zones in Vietnam: Case study of a primary school," *J. Sci. Technol. Civ. Eng. - HUCE*, vol. 19, no. 1, pp. 109–119, 2025.

[27]. J. C. Lam, "Energy analysis of commercial buildings in subtropical climates," *Build. Environ.*, vol. 35, no. 1, pp. 19–26, Jan. 2000, doi: 10.1016/S0360-1323(98)00067-5.

[28]. R. Saidur, M. Hasanuzzaman, T. M. I. Mahlia, N. A. Rahim, and H. A. Mohammed, "Chillers energy consumption, energy savings and emission analysis in an institutional buildings," *Energy*, vol. 36, no. 8, pp. 5233–5238, Aug. 2011, doi: 10.1016/j.energy.2011.06.027.

[29]. R. Saidur, "Energy consumption, energy savings, and emission analysis in Malaysian office buildings," *Energy Policy*, vol. 37, no. 10, pp. 4104–4113, Oct. 2009, doi: 10.1016/j.enpol.2009.04.052.

[30]. H.-M. S. of Vietnam, "World Weather Information Service."

[31]. AHSRAE, "ANSI/ASHRAE/IES standard 90.1-2010," 2010.

[32]. BocaPCM, "Discover probably the BEST chiller system energy efficiency." [Online]. Available: https://pcm-tes.com/chiller-system-energy-efficiency/

[33]. Y. Lin, T. Huang, W. Yang, X. Hu, and C. Li, "A Review on the Impact of Outdoor Environment on Indoor Thermal Environment," *Buildings*, vol. 13, no. 10, pp. 1–26, 2023, doi: 10.3390/buildings13102600.

[34]. Y. Wang, J. Kuckelkorn, F.-Y. Zhao, D. Liu, A. Kirschbaum, and J.-L. Zhang, "Evaluation on classroom thermal comfort and energy performance of passive school building by optimizing HVAC control systems," *Build. Environ.*, vol. 89, pp. 86–106, Jul. 2015, doi: 10.1016/j.buildenv.2015.02.023.

[35]. Z. Arifin, F. Fachruroji, and M. Huda, "Increasing performance of chiller systems in high-rise buildings by load optimization," *Int. J. Appl. Power Eng.*, vol. 13, no. 1, p. 113, Mar. 2024, doi: 10.11591/ijape.v13.i1.pp113-122.

[36]. L. Brackney, A. Parker, D. Macumber, and K. Benne, *Building Energy Modeling with OpenStudio*. Cham: Springer International Publishing, 2018. doi: 10.1007/978-3-319-77809-9.

[37]. M. H. Yusof, S. M. Muslim, M. F. Suhaimi, and M. F. Basrawi, "The Effect of Outdoor Temperature on the Performance of a Split-Unit Type Air Conditioner Using R22 Refrigerant," *MATEC Web Conf.*, vol. 225, p. 02012, Nov. 2018, doi: 10.1051/matecconf/201822502012.

[38]. C.-M. Lin, H.-Y. Liu, K.-Y. Tseng, and S.-F. Lin, "Heating, Ventilation, and Air Conditioning System Optimization Control Strategy Involving Fan Coil Unit Temperature Control," *Appl. Sci.*, vol. 9, no. 11, p. 2391, Jun. 2019, doi: 10.3390/app9112391.