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Energy Evaluation and Energy Savings Analysis with the 2 Selection of AC Systems in an Educational Building

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Abstract: This paper presents an energy performance assessment on an educational building in Barranquilla, Colombia. The electricity consumption performance was assessed using the software DesignBuilder for two different Air Conditioning (AC) systems. The current electricity intensity is 215.3 kWh/m^2-year and centralized AC systems with individual fan coils and a water chiller share 66% of the total consumption and lighting at 16%. The simulation of the AC technology change to Variable Refrigerant Flow (VRF) resulted in an improvement of 38% in AC energy intensity with 88 kWh/m^2-year and significant savings in electricity consumption and life-cycle cost of AC systems in buildings.

Keywords: energy efficiency indicators; HVAC systems; energy savings; life-cycle cost; building energy

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1. Introduction

Buildings have a significant 40% share of thetotal energy use worldwide. Since the buildings' internal environment must be conditioned to human comfort, a considerable amount of its energy consumption, approximately 55%, is spent on heating, ventilation, AC, and refrigeration systems [1–3]. In Colombia the energy consumption of buildings is an estimated 22.8% of the total [4] but there is a significant energy saving potential estimated at approximately 25% by The Mining and Energy Planning Unit (UPME) [5]. Owing to the population and economic growth in Colombia, a significantly increasing demand for services (health, education, culture, leisure, etc.) and energy consumption can be forecasted [6]; therefore, the continued improvement of energy performance in buildings is needed.

The performance of the building in the use of energy is usually assessed as Energy Efficiency Performance index (EEPi), called energy intensity, which is calculated as the yearly energy consumption by useful area unit and expressed in kWh/m^2-year [7]. The main rule to building energy efficiency (EE) improvement is to reduce energy consumption without reducing people's comfort or business activity level [8]. In new buildings, the main actions taken to reach a proper energy performance can be implemented during the design stage. For buildings already using these methods, the energy-saving potential is between 5% and 15% [9]; the EE measures are focused on updating technological systems mainly charged with the thermal comfort and lighting, improving the building façade, thermal isolation, and operational practices [10–12]. Therefore, managing energy in buildings can reduce end-use energy consumption, operating costs, and provide a comfortable and healthy indoor environment. However, without incorporating efficient technologies and analyzing the performance results, it is not possible to provide effective control over the energy performance and quality of the indoor environment [13,14].

The implementation of EE measures in AC systems can generate average energy savings of 2% to 6% depending on the size of the building, construction, and weather [15]. The energy demand that buildings currently have, and the global need to implement energy efficiency measures highlight the importance of selecting the appropriate AC technology in the early design stages [16,17]. Comparative analysis conducted between VAV and VRF technologies in existing buildings shows the energy advantages of the VRF system with energy savings from 15% to 42% and for HVAC systems between 18% to 37% [18–21]. Chiller demand has increased in recent years due to its high efficiency compared with other AC systems. [1].

These systems are mainly used in commercial buildings, large buildings with large central AC systems, and district cooling. However, the use of VRF systems is being considered as a replacement option for conventional HVAC systems in the market in response to recent efforts to decrease the energy consumption of HVAC systems in buildings. VRF systems have advantages over other conventional HVAC systems in the market, such as improved building design, reduced installation costs, low energy dissipation, excellent part-load efficiency, quiet operation, and flexible temperature, among others that reaffirm it as a good choice of high-tech product [2,3].

Energy management in the building trought with effective EEPi is difficult because of the need to properly monitor the occupancy levels and energy consumption in the building; usually, the administration only has invoices of energy consumption data and the data about occupancy is approximate [22,23]. One of the main environmental impacts of university campuses is the energy consumption of their buildings. For example, the electricity bill is a significant expense because the improvement of buildings is an attractive opportunity to enhance the university's social recognition for environmental protection and improve its economy [24].

Simulation is the main tool used to assess the potential energy saving in buildings because it can forecast the energy consumption for several values of influential variables and therefore estimate the energy saved from each EE measure [25]. It is useful to consider the building's energy performance during a building project, building renovation, building environmental certification seals, and energy audits [26]. Selecting a simulation program for building energy analysis depends on its application, the number of times it will be used, the user experience, and the hardware available to run it [27]. This kind of software uses precise physical functions and thermal dynamics theory to calculate detailed energy consumption from information about the characteristics of the building and the weather, operation performance, program or rate of use, AC systems, lighting, etc. [28,29].

In this research, the performance of the EEPi in a university building was analyzed by applying consumption prediction methods with DesignBuilder simulation software and the energy performance of the building for two AC systems, the installed Chiller system, and the change to a VRF system. The life-cycle cost for these technologies in the building was analyzed as well. The results indicated the importance and impact of selecting the best technology when the building is designed.

2. Materials and Methods

The educational building studied was built six years ago and is located in Barranquilla, Colombia (Figure 1), in a hot-humid climate. The building has eight floors that are thermally structured in 74 zones and its total useful area is 2695 m^2. The height of the ground floor is 5 m. The length/height ratio is 1.4 with 6.7% of glazing. The building is mainly used for classrooms but contains several offices on the first floor and two auditoriums.

Figure 1. Case-study Building.

The building usually operates at full capacity from 6:30 a.m. to 8:00 p.m. on a weekday, except from 12:30 p.m. to 1:30 p.m. when the occupation level decreases by 80%. On Saturday, it is fully occupied from 6:30 a.m. to 3:30 p.m. Due to poor design that does not take advantage of natural light, the lighting system in the classrooms remains fully on when the building is operating and is approximately 80% of the lighting load. The lighting in the corridors, which is the remaining 20%, remains on from 6:30 p.m. to 6:00 a.m. Computers in the classrooms and auxiliary electrical equipment operate within similar hours of the building. The specific lighting electrical load in use is 12 W/m^2, and the computers and auxiliary equipment are 10 W/m^2. The AC system also has a similar operating schedule to the building but its electricity consumption varies according to weather. The AC system installed corresponds to a water condensation chiller, with an average performance coefficient (COP) of 3.0 and a screw type compressor. A total of 41 fan coil type terminal units were used for the same number of climate zones. The water temperature was set to 7 °C and returned to 12 °C. The characteristics of the façade are shown in Table 1.

Table 1. Materials used in the building envelope.

Item	Material	Transmittance [U] (W/m^2-K)
Walls	0.025 mm stucco, 200 mm brick, and 0.019 mm plaster	2.886
Windows	Standard glass—6 mm	5.778

The electricity consumption of a building in a tropical area is mainly influenced by the envelope design, AC system technology, and ant occupation [25]. The performance with which the building uses electricity is usually assessed through the EEPi in a typical operation year [7]. The generalized EEPi for many types of buildings is the intensity of energy use [kWh/m^2]. For AC systems, the global efficiency index used by [30,31] was the AC used in this study. Equation (1) is as follows:

$$EEPi_{AC} = \frac{HVAC\ annual\ energy\ use}{conditioned\ area}\left[\mathrm{KWh/m^2 - year}\right] \quad (1)$$

Likewise, to evaluate the energy performance, a detailed analysis of the Chiller type AC system was conducted with individual fan coils of simple configuration at constant primary, centralized installation in the building. A market-available VRF system available was also used to forecast the performance of both technologies according to the thermal load conditions in which the building operates and cold demand profiles [32]; this can be applied in design or use stages of them [3,33]. The DesignBuilder software has a module that includes the most detailed HVAC systems from EnergyPlus, as well as those referenced in the ASHRAE 90.1 standard. The VRF system was selected from the DesignBuilder HVAC module, loaded into the building model, and customized according to the system parameters.

The methods for estimating energy consumption in buildings depend on how the data is acquired and the scope and depth of the performance evaluation to be applied [3]. For this research, the DesignBuilder software was used for building energy simulation, which is frequently used by researchers and designers in evaluating the energy performance of buildings; this is because DesignBuilder uses EnergyPlus as a calculation engine, with a conduction transfer function (CTF) [28,34–36] which allows the EEPi to be obtained and analyzed in indoor environment conditions.

This research first evaluated the energy performance of the building with the installed AC system, which consists of a water chiller (Chiller) with a COP 3 screw compressor where cold water is distributed through a pump to the terminal equipment in different building areas (administrative offices, classrooms, auditoriums, and study rooms) and fans that cause air circulation by passing through air diffusers located on the roof of each area being air-conditioned. In this type of system, within certain limits, the user can control the degree of comfort by acting on the speed of the fans and the water flow [37]; however, since the building analyzed does not currently have temperature control in each air-conditioned area, conditions of thermal comfort are not guaranteed and causes inefficiencies in the use of AC.

Secondly, we assessed energy performance if the AC technology of the building was instead a VRF direct expansion system, which eliminates the use of water as an intermediate heat transfer fluid and has a condensing unit (compressor and condenser) that simultaneously serves several evaporating units according to their capacity [37]. It uses a variable speed compressor and electronic expansion valve to independently vary the flow rate to each terminal unit to meet the thermal load. For this study, a VRF heat pump air conditioning system in cooling operation mode was simulated. Comparing the building's energy performance with both AC systems helps evaluate the economic impact of not properly selecting AC technology for the building.

The economic feasibility of changing AC technology was analyzed by comparing the long-term economic performance of different HVAC alternatives. This study used the net present value (NPV) method to find the Life Cycle-Cost (LCC), which considers the operating cost, the maintenance cost, and the investment cost. Estimates of energy consumption and annual costs of HVAC systems were added over a 20-year design life to determine the total energy consumption of the analyzed HVAC systems, considering the current operating conditions of the building. For the NPV analysis, Equation (2) [38] is applied:

$$NPV_n = \frac{\Delta C_n}{(1+d)^n} \tag{2}$$

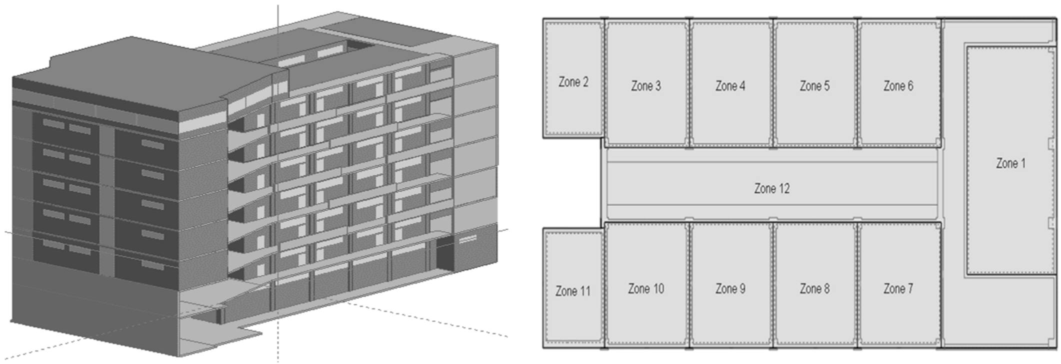
where, ΔC_n is the difference in the annual energy cost of the conditioning of the building between the Chiller system and the VRF system in the analysis year n with d representing the discount rate. The total NPV over a 20-year life cycle was estimated according to Equation (3):

$$NPV_{lifecycle} = \sum_{i=0}^{20} \frac{\Delta C_n}{(1+d)^n} \tag{3}$$

where, $NPV_{lifecycle}$ is the sum of the NPV_n for each of the 20 years of the project life cycle, including the investment cost of the AC systems in year 0. In this method, the NPV_{total} assesses whether investing in the VRF system was beneficial or costly over its life of use compared with the referenced Chiller system.

3. Results and Discussion

The building model is shown in Figure 2a,b. Through the analysis of physical functions and thermal dynamics, the annual energy consumption was calculated, step by step, from the external and internal climatic conditions, the construction characteristics, operation, building use rate, schedule, AC system, lighting, and electrical equipment.



(**a**) 3D model (**b**) First floor map

Figure 2. Three-dimensional model and first floor map of the building.

The performance of the indoor climate is established in Figure 3 according to an evaluation of the thermal comfort sensation by users of the building [39,40]. It was established that 84% of the students had the best thermal sensation of comfort in the range of 21.1–24 °C depending on the class schedule and time of year. These preferences are considered standard thermal conditions for the interior environment that must be guaranteed with the AC system to satisfy the occupants.

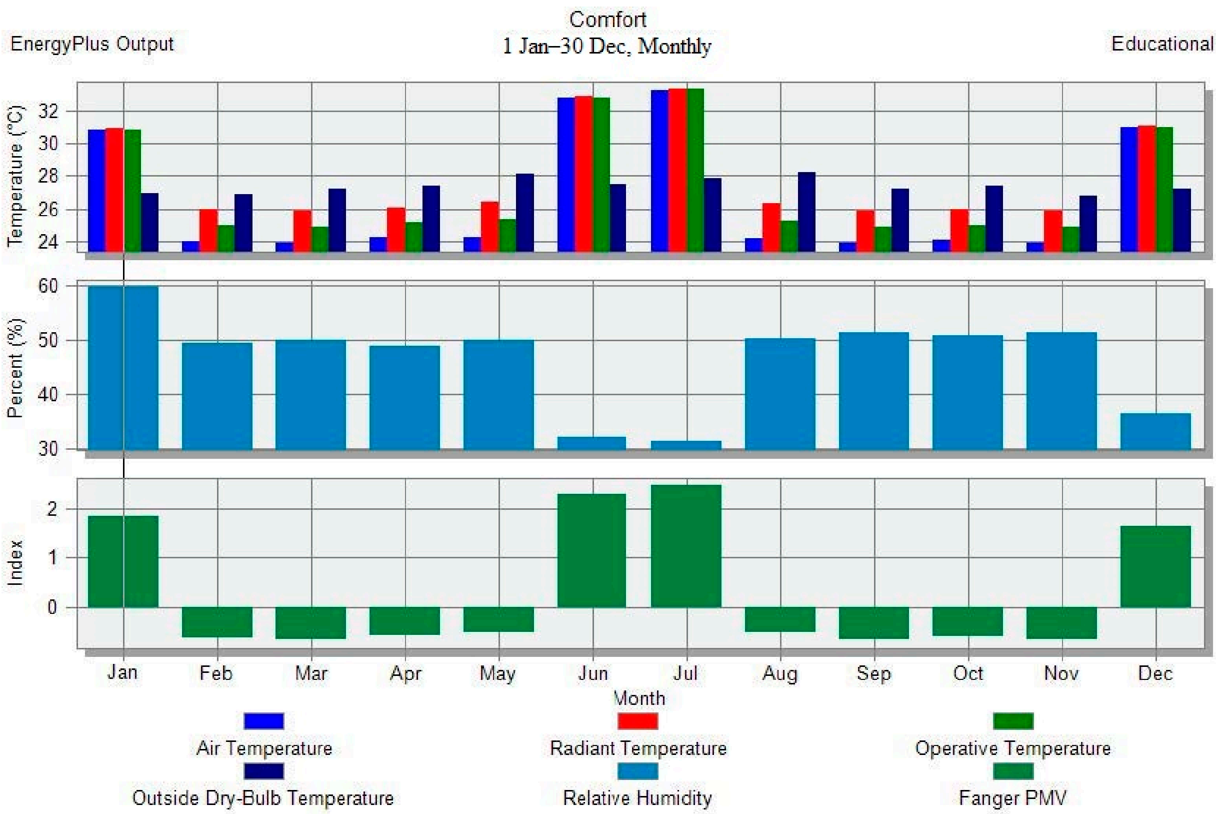


Figure 3. Thermal comfort conditions (temperature, relative humidity and Fanger PMV) in the air-conditioned area of the building.

In Figure 3, the performance of the temperatures affecting the interior of the building, the interior relative humidity and the Predicted Mean Vote (PMV) obtained from the simulation are shown. It was concluded that the average operating temperature is 24 °C, the result of the arithmetic mean between air temperature at 23 °C and radiant temperature at 25 °C. Relative humidity had an average performance of 50%, and the daily thermal comfort measured by the PMV performance was between 0.45 and −0.92, being within the zone of thermal acceptability and satisfaction for the interior environment, manifested by the occupants of the building. The building operates with a periodicity of two academic semesters per year, which last 4 months each. The months of January, June, July, and December correspond with school vacation; thus the building is not in operation during this time, because 100% of the spaces are used as classrooms.

The operation of the building was simulated to estimate the annual electricity consumption for year, discriminating between AC, lighting, and auxiliary equipment. The results are shown in Figure 4.

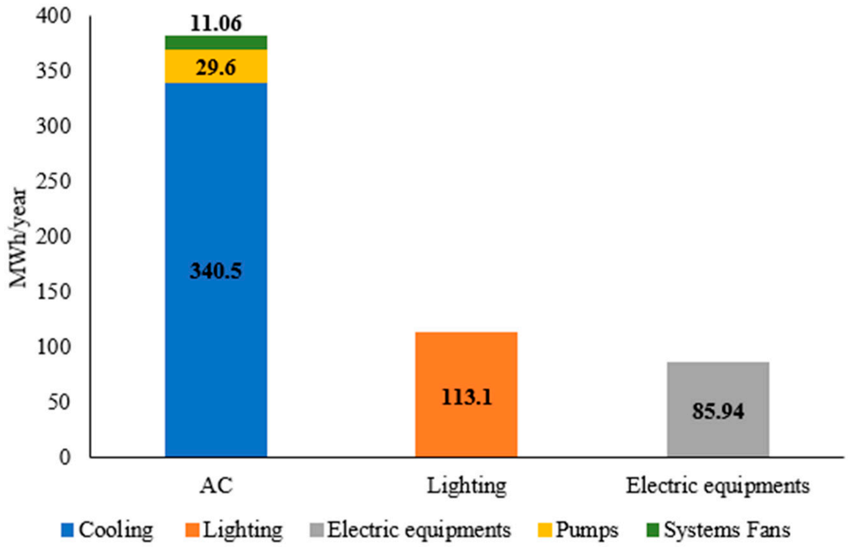


Figure 4. Distribution of the electrical energy consumption of the building Chiller technology.

In Figure 4, it can be seen that the total annual electricity consumption in the building was 580.2 MWh, with a consumption of 381.2 MWh in the AC system (compressors, pumps, and fans) and 199.04 MWh in lighting and electric equipment. As the climate in the region is not seasonal and has little variability throughout the year, the same analysis was conducted for a typical day (Figure 5). The total electricity consumption obtained for the building was 2028.7 kWh/day, with 69% of the consumption from the AC system and 31% to lighting and electric equipment.

Of the total electrical energy consumed by the Chiller, the compressors can consume approximately 61% and the water pumps between 7% and 11%. Air Handling Units (AHUs) and cooling towers consume 13% and 3%, respectively [27], and the remaining amount of energy is consumed by fan coil units. The analyzed building obtained 381.2 MWh/year of electricity consumption for air conditioning; 88% was for compressors, 8% for water pumping, and 4% for ventilation. The installed system does not have AHUs or cooling towers.

The VRF system, which supplies air to multiple zones with a COP of 3.3, was configured to operate at a conduction temperature of approximately 14 °C. For both cases, the ventilation air was 10 L/person. The thermostat control was independent in each conditioned area at 25 °C. During the different simulations, the specific characteristics of the building envelope and internal loads remained constant.

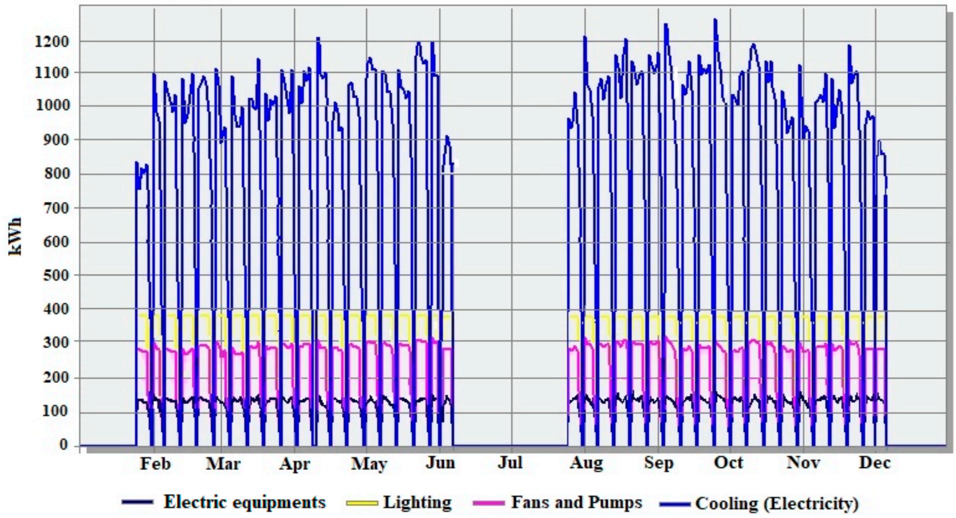


Figure 5. Performance of energy consumption (kWh/day) in the building.

The forecasted annual electricity consumption of both AC systems (Figures 4 and 6), with the replacement of the AC system with the water chiller (Chiller) and fan coil terminal units with the VRF type AC system, reached 237.4 MWh/year of energy consumption in AC, distributed in 227.7 MWh for cooling and 9682 MWh for ventilation, where a decrease of approximately 38% in annual energy consumption in the AC system could be achieved. Also, 29.6 MWh/year was saved in water pumping with the installation of a VRF system.

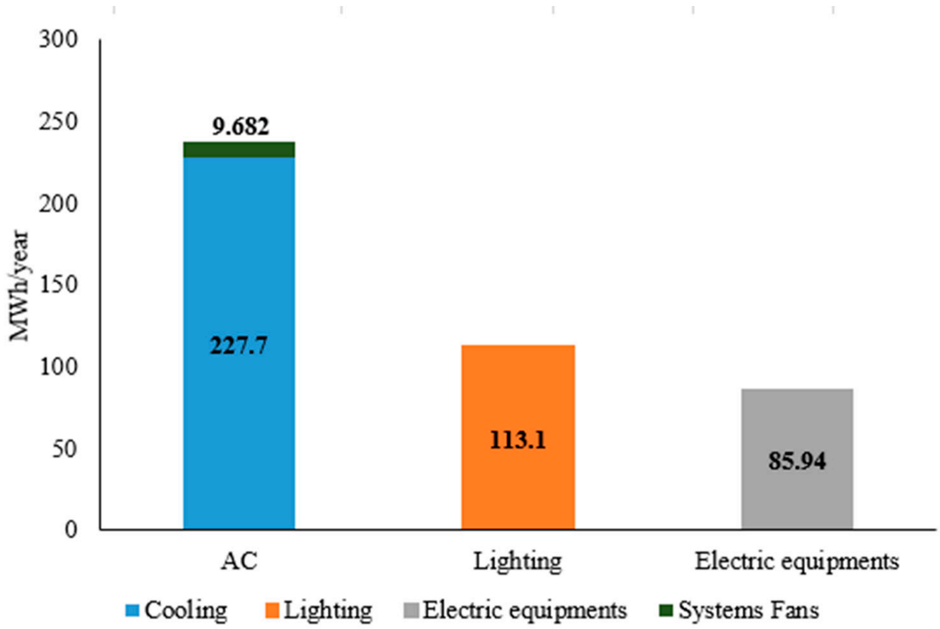


Figure 6. Energy consumption (MWh/year) of the building with VRF.

The performance of the EEPi according to the results of the simulation are shown in Table 2 for the energy consumption of the building with the existing AC system (Chiller) and the energy consumption of the VRF system.

The EEPi is higher for the current conditions of the building where the Chiller was used; therefore, it could go from 215.3 kWh/m^2-year to 161.9 kWh/m^2-year if it is replaced by a VRF system. For the EEPi of the AC system, it was obtained that the EEPi AC would change from 141.4 kWh/m^2-year with Chiller to 88.1 kWh/m^2-year with VRF; therefore, it would be possible to use less energy per m^2 of heated area in the building. According to [27,41], the annual total of EEPi currently in commercial buildings is usually above 200 kWh/m^2, mainly due to the use of AC and lighting.

Table 2. EEPi performance for the AC system and the building as a whole, for each technology analyzed.

AC Systems	kWh/m^2-Year	
	EEPi AC	**EEPi Building**
Chiller	141.4	215.3
VRF	88.1	161.9

The cost analysis considered the AC systems required for the thermal load of the building, a capacity between 120 and 130 TR of the AC, the investment cost, and the maintenance cost corresponding to a year, as shown in Table 2. For the LCC analysis (Table 3), the NPVs associated with energy consumption are compared with the two AC systems, assuming a 20-year life scenario for both technologies. Electricity costs are established at an average of 640 $/kWh considering the values provided by energy marketers in Colombia for the commercial sector, with an average annual growth rate of 5.6% based on the performance of 2021 compared with 2020 [42]. The discount rate (n) established for the project is 3.5% [38,43]. Also, the initial costs of the major HVAC systems for each alternative are estimated based on recent cost benchmarks.

Table 3. Investment costs, maintenance cost and LCC of AC systems.

AC System	Investment Cost	Maintenance Cost	LCC
Chiller	$1,043,867,160	$14,256,000	$4,699,414,150
VRF	$510,801,950	$9,828,000	$3,066,046,630

From Table 3, it can be concluded that the investment costs of the VRF system are approximately 50% of the investment cost of the chiller, and also a maintenance cost of 31%. This investment indicates that the installation of a VRF system represents 50% savings in costs. From the analysis, a NPV is obtained from 20 years of using the Chiller system of $4,699,414,155 and the VRF system at $3,066,046,631. Therefore, the savings obtained according to the result of the LCC are worth $1,633,367,524, representing a 35% savings in the LCC cost for the building's AC system if the VRF system had been selected.

4. Conclusions

The methodology applied in this study helped analyze the performance of the EEPi, and the savings achieved when a correct selection or application of active measures of technology using AC systems in educational buildings located in tropical climates was conducted. Based on our evaluation of the energy performance for the studied building, it is possible to determine in detail that the building's EEPi is 215.3 kWh/m^2-year, with an energy consumption of 2028.7 kWh on a typical day of operation from 6:30 a.m. to 10:00 p.m. AC has the highest energy consumption, representing approximately 66%, followed by lighting with 19% and auxiliary electrical equipment with 15%. The simulation, obtained 381.2 MWh/year of electrical energy consumption from air conditioning, 86% for compressors, 7% for water pumping, and 3% for ventilation for an EEPi AC of 141.4 kWh/m^2-year. These results help define saving measures for the building, conferring priority to the air conditioning system. Hence, the results show a potential saving of 38% in electricity consumption in the building's AC system if a VRF was selected, obtaining lower energy consumption per m^2 of heated area, passing the total EEPi to 161.9 kWh/m^2-year and 88.1 kWh/m^2-year in AC. In addition, the installation of a VRF would have generated savings of approximately 50% in investment, 30% in maintenance, and 35% in the LCC. The advantage of this system lies in the possibility that this technology presents an adjustment of the system load to the instantaneous thermal demand and the elimination of the pumping system. However, contemplating the analysis of technical parameters in future studies can provide more information about deciding on the best technology since it will depend on the characteristics of each project.

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References

1. De Gastines, M.; Correa, E.; Pattini, A. Heat Transfer Through Window Frames in Energyplus: Model Evaluation and Improvement. *Adv. Build. Energy Res.* **2019**, *13*, 138–155. [CrossRef]
2. Shahrestani, M.; Yao, R.; Cook, G.K. A Fuzzy Multiple Attribute Decision Making Tool For Hvac&R Systems Selection with Considering the Future Probabilistic Climate Changes And Electricity Decarbonisation Plans in The Uk. *Energy Build.* **2018**, *159*, 398–418. [CrossRef]
3. Wang, S.; Yan, C.; Xiao, F. Quantitative Energy Performance Assessment Methods for Existing Buildings. *Energy Build.* **2012**, *55*, 873–888. [CrossRef]
4. Indicative Energy Efficiency Action Plan 2017–2022. Available online: http://extwprlegs1.fao.org/docs/pdf/col181199.pdf (accessed on 30 June 2021). (In Spanish).
5. Unidad De Planeación Minero Energética. *Plan Energético Nacional Colombia: Ideario Energético 2050, Unidad Planeación Min. Energética*; Upme: Bogotá, Colombia, 2015. Available online: https://www1.upme.gov.co/documents/pen_idearioenergetico2050.pdf (accessed on 12 February 2021). (In Spanish)
6. Pérez-Lombard, L.; Ortiz, J.; Pout, C. A Review on Buildings Energy Consumption Information. *Energy Build.* **2008**, *40*, 394–398. [CrossRef]
7. Poel, B.; Van Cruchten, G.; Balaras, C.A. Energy Performance Assessment of Existing Dwellings. *Energy Build.* **2007**, *39*, 393–403. [CrossRef]
8. Nikolaou, T.; Kolokotsa, D.; Stavrakakis, G. Review on Methodologies for Energy Benchmarking, Rating and Classification of Buildings. *Adv. Build. Energy Res.* **2011**, *5*, 53–70. [CrossRef]
9. Brambley, M.R.; Hansen, D.; Haves, P.; Holmberg, D.R.; Mcdonald, S.C.; Roth, K.W.; Torcellini, P. Advanced Sensors and Controls For Building Applications: Market Assessment and Potential R&D Pathways. *Pac. Northwest Natl. Lab.* **2005**, 162. [CrossRef]
10. Luo, R.; Han, Y.; Zhou, X. Characteristics of Campus Energy Consumption in North China of Science and Technology Ruijiang. *Procedia Eng.* **2017**, *205*, 3816–3823. [CrossRef]
11. Alajmi, A. Energy Audit of An Educational Building in A Hot Summer Climate. *Energy Build.* **2012**, *47*, 122–130. [CrossRef]
12. Xia, J.; Hong, T.; Shen, Q.; Feng, W.; Yang, L.; Im, P.; Lu, A.; Bhandari, M. Comparison of Building Energy Use Data between the United States and China. *Energy Build.* **2014**, *78*, 165–175. [CrossRef]
13. Afroz, Z.; Higgins, G.; Urmee, T.; Shafiullah, G. Technological Advancement of Energy Management Facility of Institutional Buildings: A Case Study. *Energy Procedia* **2017**, *142*, 3088–3095. [CrossRef]
14. Madrigal, J.A.; Cabello, J.J.; Sagastume, A.; Balbis, M. Evaluation of Air Conditioning in Commercial Buildings, Integrating Thermography Techniques, Simulation and Modeling. *Inf. Tecnol.* **2018**, *29*, 179–188. [CrossRef]
15. Aryal, A.; Becerik-Gerber, B. Energy Consequences of Comfort-Driven Temperature Setpoints in Office Buildings. *Energy Build.* **2018**, *177*, 33–46. [CrossRef]
16. Shahrestani, M.; Yao, R.; Cook, G.K.; Clements-Croome, D. Decision-Making on Hvac & R Systems Selection: A Critical Review. *Intell. Build. Int.* **2017**, *10*, 133–153. [CrossRef]

17. Balbis-Morejon, M.; Tovar-Ospino, I.; Castro-Peña, J.J.; Cárdenas-Escorcia, Y.D.C. Energy assessment of the system pumping a climate control scheme with water coolers for an educational building using dynamic simulation. *Espacios* **2017**, *38*, 19–32.
18. Kim, D.; Cox, S.J.; Cho, H.; Im, P. Evaluation of Energy Savings Potential of Variable Refrigerant Flow (Vrf) from Variable Air Volume (Vav) in the U.S. Climate Locations. *Energy Rep.* **2017**, *3*, 85–93. [CrossRef]
19. Aynur, T.N.; Hwang, Y.; Radermacher, R. Simulation Comparison of Vav and Vrf Air Conditioning Systems in an Existing Building for The Cooling Season. *Energy Build.* **2009**, *41*, 1143–1150. [CrossRef]
20. Barros-Alvarez, M.; Balbis-Morejon, M.; Tovar-Ospino, I.; Castro-Peña, J.J.; De Leon-Siado, L.; Silva-Ortega, J.I.; Rosales Villa, D.E. Energy Consumption Comparison Between Air Conditioning System Mini-Split and Variable Refrigerant Flow in an Educational Building. *Espacios* **2017**, *38*, 19–32.
21. Zhu, Y.; Jin, X.; Fang, X.; Du, Z. Optimal Control of Combined Air Conditioning System with Variable Refrigerant Flow and Variable Air Volume for Energy Saving. *Int. J. Refrig.* **2014**, *42*, 14–25. [CrossRef]
22. Sekki, T.; Airaksinen, M.; Saari, A. Impact of Building Usage and Occupancy on Energy Consumption in Finnish Daycare and School Buildings. *Energy Build.* **2015**, *105*, 247–257. [CrossRef]
23. Montoya, P.; Morejón, J.L.; Inga, E. Maximum Coverage of Wireless Sensor Networks for an Energy Management System in Smart Homes. *INGE CUC* **2016**, *12*, 68–78. [CrossRef]
24. Kolokotsa, D.; Gobakis, K.; Papantoniou, S.; Georgatou, C.; Kampelis, N.; Kalaitzakis, K.; Vasilakopoulou, K.; Santamouris, M. Development of A Web Based Energy Management System for University Campuses: The Camp-It Platform. *Energy Build.* **2016**, *123*, 119–135. [CrossRef]
25. Rey Martínez, J.M.; Fancisco, J.; Velazco Gómez, E.; Hernández, R. *Eficiencia Energética De Los Edificios*, 1st ed.; Paraninfo Sa: Madrid, España, 2018. (In Spanish)
26. Gavilán, A. Análisis Comparativo De La Eficiencia Energética En Edificios Existentes Con Diferentes Herramientas De Simulación Energética. Doctoral Thesis, University of Valladolid, Valladolid, Spain, 2015.
27. Harish, V.; Kumar, A. A Review on Modeling and Simulation of Building Energy Systems. *Renew. Sustain. Energy Rev.* **2016**, *56*, 1272–1292. [CrossRef]
28. Zhao, H.X.; Magoulès, F. A Review on the Prediction of Building Energy Consumption. *Renew. Sustain. Energy Rev.* **2012**, *16*, 3586–3592. [CrossRef]
29. Strack, J.L.; Siárez, J.A.; Di Mauro, G.F.; Jacob, S.B. Impacto De La Iluminación Residencial Eficiente En La Calidad De La Energía De Una Red De Distribución. *Inge Cuc* **2014**, *10*, 9–19. (In Spanish)
30. Pérez-Lombard, L.; Ortiz, J.; Coronel, J.F.; Maestre, I.R. A Review of Hvac Systems Requirements in Building Energy Regulations. *Energy Build.* **2011**, *43*, 255–268. [CrossRef]
31. Pérez-Lombard, L.; Ortiz, J.; Maestre, I.R.; Coronel, J.F. Constructing Hvac Energy Efficiency Indicators. *Energy Build.* **2012**, *47*, 619–629. [CrossRef]
32. Fumo, N.; Mago, P.; Luck, R. Methodology to Estimate Building Energy Consumption Using Energyplus Benchmark Models. *Energy Build.* **2010**, *42*, 2331–2337. [CrossRef]
33. Papakostas, K.T.; Michopoulos, A.K.; Kyriakis, N.A. Equivalent Full-Load Hours for Estimating Heating and Cooling Energy Requirements in Buildings: Greece Case Study. *Appl. Energy* **2009**, *86*, 757–761. [CrossRef]
34. Li, Q.; Meng, Q.; Cai, J.; Yoshino, H.; Mochida, A. Applying Support Vector Machine to Predict Hourly Cooling Load in the Building. *Appl. Energy* **2009**, *86*, 2249–2256. [CrossRef]
35. Mui, K.W.; Wong, L.T.; Wai, M.K. Cooling Load Calculations in Subtropical Climate. *Build. Environ.* **2007**, *42*, 2498–2504. [CrossRef]
36. Al-Rabghi, O.M.A.; Al-Johani, K.M. Utilizing transfer function method for hourly cooling load calculations. *Energy Convers. Manag.* **1997**, *38*, 319–332. [CrossRef]
37. Victorio, D.; Raúl, B. *Acondicionamiento Térmico De Edificios*, 1st ed.; Juan O'Gorman Librerias: Buenos Aires, Argentina, 2005. (In Spanish)
38. Stephens, B. The Impacts of Duct Design on Life Cycle Costs of Central Residential Heating and Air-Conditioning Systems. *Energy Build.* **2014**, *82*, 563–579. (In Spanish) [CrossRef]
39. Balbis-Morejón, M.; Rey-Hernández, J.M.; Amaris-Castilla, C.; Velasco-Gómez, E.; San José-Alonso, J.F.; Rey-Martínez, F.J. Experimental Study and Analysis of Thermal Comfort in a University Campus Building in Tropical Climate. *Sustainability* **2020**, *12*, 8886. [CrossRef]
40. Balbis-Morejón, M.; Noya-Sambrano, A. Thermal Comfort Evaluation in an Educational Building with Air Conditioning Located in the Warm Tropical Climate of Colombia. *IOP Conf. Ser. Mater. Sci. Eng.* **2020**, *844*, 844. [CrossRef]
41. Ma, H.; Lai, J.; Li, C.; Yang, F.; Lai, J.; Li, C. Analysis Of School Building Energy Consumption in Tianjin, China. *Energy Procedia* **2019**, *158*, 3476–3481. [CrossRef]
42. Unidad De Planeacion Minero Energetica. *Inflación De Energía En Colombia*; Upme: Bogotá, Colombia, 2021. Available online: http://www1.upme.gov.co/demandaenergetica/informe_inflacion_energia_dic_2020.pdf (accessed on 12 April 2021). (In Spanish)
43. Shahrestani, M.; Yao, R.; Cook, G.K. Decision Making for Hvac&R System Selection for a Typical Office Building in the UK. *Ashrae Trans.* **2012**, *118*, 222–229.