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Comparative study of Variable Air Volume and Variable Refrigerant Volume for Automotive Workshop

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Abstract

The purpose of this study is to compare Variable Air Volume (VAV) with Variable Refrigerant Volume (VRV) air conditioning systems, as well as to determine the thermal comfort conditions in a Tyre Retreading Center. The air conditioning systems (AC) are created with OpenStudio software and simulated to determine overall energy usage under various load scenarios. It was found out that VRV system was the most efficient in comparision to VAV system with regards to energy saving. The most suitable system for tyre retreading center was examined, and it was discovered that the VRV system was the most energy efficient. The most suitable system for tyre retreading center was discovered to be the ceiling cassette type VRV system.

Keywords

Air-conditioning, Refrigerants, Automotive, Workshop, Variable Air Volume, Variable Refrigerant Volume

1. Introduction

Heating and cooling of residential and commercial buildings, and various systems that transfer air between indoor and outdoor spaces are all handled by Heating, Ventilation, and Air Conditioning (HVAC) system. It maintains temperature by warming the air in winter, and cooling it in summer. It is also a system that filters and purifies the indoor air to create a healthy environment and keep the humidity level at an acceptable level.The Variable Air Volume (VAV) system uses dampers inside the VAV box to control the flow of air supply, adapt to fluctuations in the cooling load of the space, and keep the zone temperature at the set temperature. The Variable Refrigerant Volume (VRV) system is a refrigeration system that uses a variable speed compressor and an electronic expansion valve to match the flow rate of the refrigerant to the cooling load of the space, and keep the zone temperature at a specified temperature. With the growing number of AC systems installed across the world, their high energy consumption is a challenge that must be addressed sooner rather than later.It is estimated that there will be a rise of 20% of energy usage in buildings. [1]. In the midst of the modern world's energy crisis, an energy-efficient air conditioning system is a must.Some important ratings are calculated before the installation of any HVAC system, such as Energy Efficiency Ratio (EER) and Season Energy Efficiency ratio (SEER). These ratings help to indicate how efficient any conditioning system is. Higher values of these ratings indicate a more efficient system and vice-versa. This study is done to compare two different systems of HVAC and recommend the efficient system of in a small-scale workshop. The site is currently located in the Pokhara Industrial Estate area at a latitude of 28.2044°N, 84.0108°E. The workshop consists of various heat generating machines that are used for the retreading process of tires.The sole objective of any AC system within the workshop is to maintain comfort inside the working environment for the workers.The effectiveness of the workers is directly dependent upon the working environment.Studies show that the optimal comfort is best achieved between the temperature range of 22-25 °C and Carbon dioxide(CO_2) concentration less than 650 ppm. [2] There is no provision of proper air conditioning in the tire retreading workshop. The machines used in the workshop produce a lot of heat and emit harmful gases, so it directly affects the comfort and health of all the staff of the workshop and their productivity. Due to the heat generated by the machines and other sources, the environment inside the workshop is suffocating and a proper air conditioning system is necessary in the workshop. The selected air conditioning system should be effective and energy efficient. Software packages like AutoCAD, SketchUp, OpenStudio and EnergyPlus are used in modelling and simulation of air-flow and energy consumption for determination of thermal comfort zones and energy usage patterns.

2. Related Works

A simulation based study for energy analysis using different conditioning systems was conducted in Ref[3]. The performance in terms of comfort was found to be best in VAV system in comparison to other traditional systems.Zhou et al. [4] conducted a simulation study of VRV system under cold climate. The author found the VRV system was more energy efficient compared to VAV system and the Fan coil Plus Fresh Air (FPFA) system. The study concluded that the VRV system can yield approximately 22.2% and 11.7% energy saving potentials in comparison to VAV and FPFA systems respectively.

Yao et al. [5] carried out an energy performance of three different kinds of AC system namely VAV, Constant Air Volume (CAV) and Fan-Coil System. The authors found that the VAV system was more energy efficient among all three systems. The study showed that the VAV system was approximately 17.0%-37.6% and 4.6%-10.2% more efficient than CAV and Fan-Coil System respectively.

Zhou et al. [6]. conducted a simulation and experimental based study of VRV system using simulation software, Energy Plus. The results showed that the difference between simulated and observed data for the energy and power consumption was found to be within 25.19% and 28.31% respectively.

Tiwari et al. carried out design and estimation of a HVAC system with thermal storage inside the proposed building.The final report including the piping and ducting system designs for the HVAC system with suitable indoor units and chilling equipment was submitted to the Institute of Engineering. The authors concluded that the annual operational cost of the HVAC system could be lowered by about 400 thousands to 1 million Nepali Rupees when integrated with Thermal Energy Storage(TES) in Nepal.Similarly, Bista et al. designed water cooled chiller with heat recovery system for a proposed hospital building. The final report was submitted to the Institute of Engineering with detailed design of HVAC system with heat recovery system. The main purpose of a heat recovery system is to utilize the heat rejected as waste, to be used in various heating applications which ultimately leads to energy saving. As discussed earlier, there are various studies performed on different types of AC systems, but the ones in automotive workshops are limited. In this paper, a simulation study of two different types of AC systems: VAV and VRV is carried out in an automotive workshop. After analyzing the simulation results, the most suitable system of HVAC is recommended.

3. Methodology

This section includes the procedural steps carried out in this study. The selection of site is done for the installment of HVAC system. For this study a Tyre retreading center is selected located in Pokhara. The primary purpose of HVAC system within a workshop is to make the workers comfortable. The selected building will be re-conditioned with the both VAV and VRV systems.

Load calculation, energy consumption patterns and detailed study of thermal zones is carried out for the selected building. After the selection of building various characteristics of the working site like heat loads, space types, spaces, sub subspaces, thermal zones and output variables are defined.

The workshop consists of various heat generating machines that are used for the retreading process of tires. Due to the heat generated by the machines and other sources, the environment inside the workshop is suffocating and a proper air conditioning system is necessary in the workshop. There are numerous heat-generating sources inside the workshop. The major heat generating sources are the machines used during the retreading process of the tires. The different machines used in the workshop are mainly buffer machine, builder machine, thermal chamber and air compressor. For this study, heating loads from various machines, other electrical appliances as well as from human body is taken into consideration. On site measurement of the workshop was done. The obtained dimensions are as follows: Various software packages are used in modelling and simulation of energy consumption for determination of energy usage patterns. The software packages used in this project are AutoCAD, SketchUp, Open Studio and EnergyPlus. The simulation steps for evaluating energy performance of both systems is based on building modeling that includes the information about construction materials, schedule of the people, selection of AC equipment. This can be better understood from the flowchart shown in fig 1.

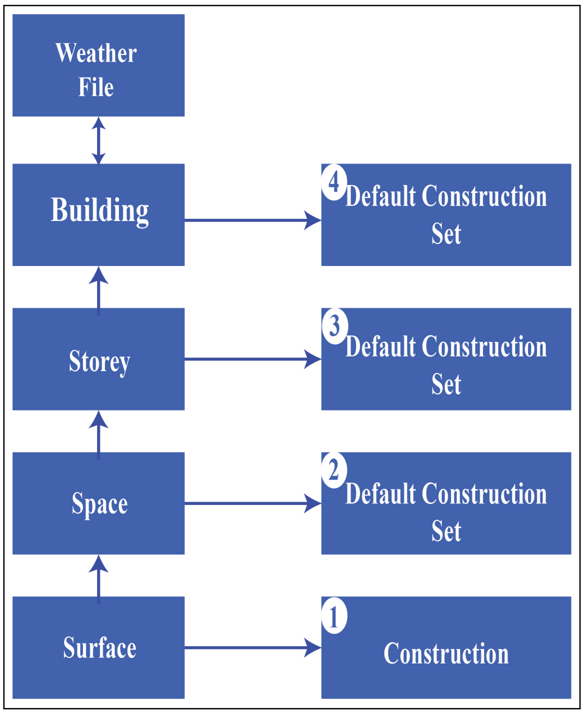
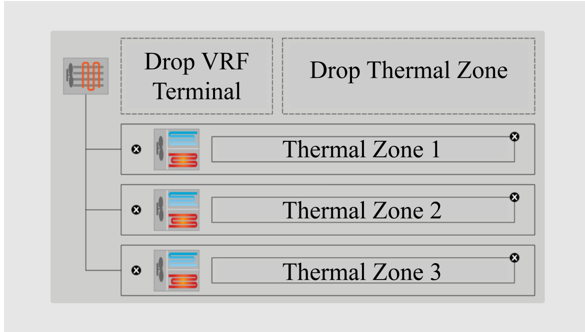
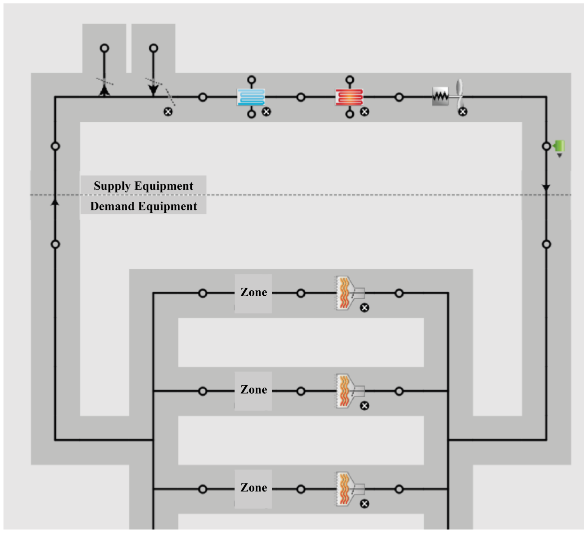


Figure 1: Representation of simulation steps for evaluation of energy performance of VAV and VRV system

The real-time simulation work based on above modeling provides detailed information instead of ideal ones. This analysis provides insights of energy performance of building in actual scenarios rather than ideal ones. These works assess the proper strategy to reduce the thermal loads. The simulated study guides whether the conditioning system can actually meet the energy usage inside the building. There is always a chance of some inaccuracies in the building modeling, as real time data is difficult to gather. However, simulation studies are found to be one of the efficient tools for final decision. Though, the modelling may carry certain inaccuracies depending on the available information about the building, and it's varying with actual case, but the simulation results are considered very useful to decide the final design decisions.



(a)



(b)

Figure 2: System Design in OpenStudio **(a)** VRV system **(b)** VAV system

AutoCAD is used to draw the CAD floor plan and elevation drawings that are used to build a model in this project.The building layout design in AutoCAD is shown in figure 3. SketchUp is used in this project to create geometry and assign thermal zones after importing the CAD drawings from AutoCAD. OpenStudio is used in this project to create materials or assign building construction materials to calculate loads and display results.The design of VAV and VRV system is done in OpenStudio as shown in figure 2. And then simulated using EnergyPlus engine. Mostly used simulation software for energy modeling inside a building is EnergyPlus. This software is widely used by energy analysts, research, studies, and other professionals. It gives information about energy usage and patterns.The energy simulation work was carried after the geometrical modeling and inputs of construction material of the building.

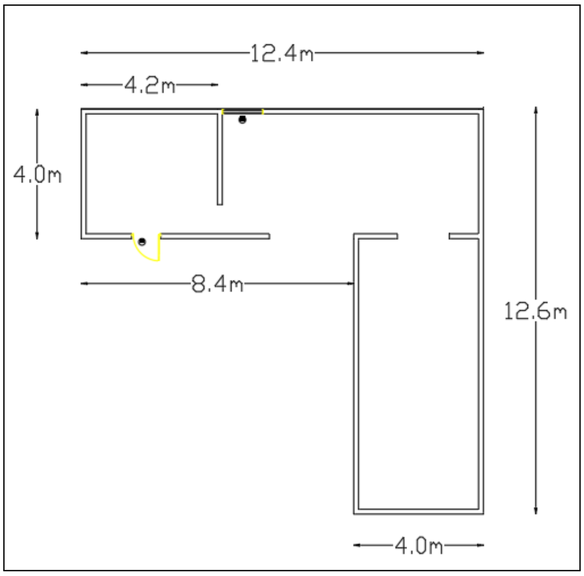


Figure 3: Building layout design in AutoCAD

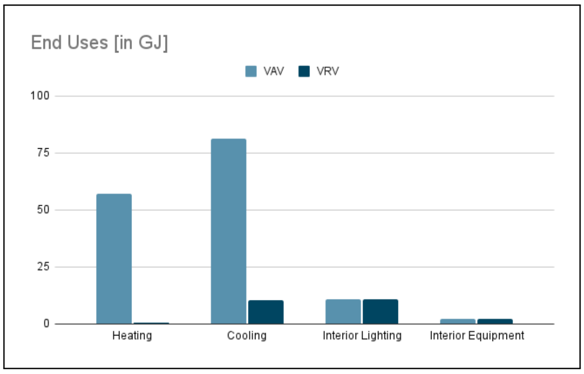
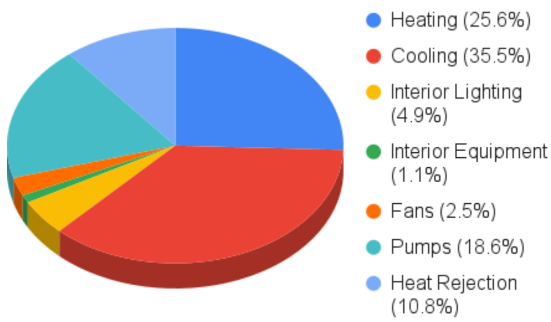
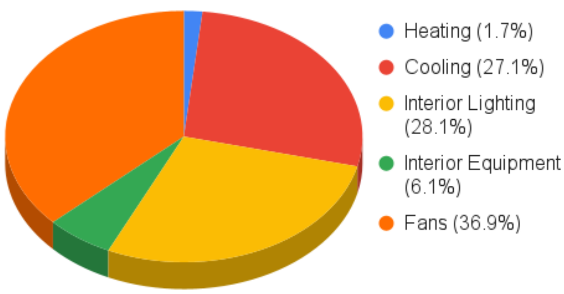


Figure 4: End Uses Comparison of VAV and VRV

The pie charts below, shown in figure 5 is a breakdown of the yearly end uses of both VAV and VRV systems.



(a)



(b)

Figure 5: Annual End Uses
(a) VAV system **(b)** VRV system

One of the major inputs in the simulation process is the weather file of site location. It was obtained from the official website of EnergyPlus in .epw format. The format is simple, text-based with comma-separated data. All EnergyPlus weather(epw) data is in International System of Units (SI) units. It is even possible to view and/or edit the .epw weather data in a text editor. For this project the data of Kathmandu, Nepal was taken, and later the weather file was edited with information obtained from Meteorological Forecasting Division Office, Pokhara. Afterwards, simulation was carried out.

4. Result and Discussion

After running the simulation study in OpenStudio software, end uses of VAV and VRV systems were acquired.While comparing the simulation results, the end uses of the VAV system were found to be much greater than those of the VRV system, as shown in figure 4. The heating and cooling loads of VAV and VRV were substantially different, although the interior lighting and interior equipment used by both systems were the same

The total site energy and total source energy of both VAV and VRV systems are in the figure 6. It is visible that the energy for the VAV system is greater. For both VAV and VRV systems, the source-site ratio is approximately 3.1.

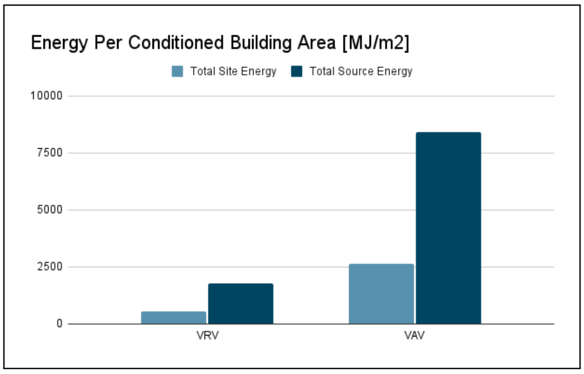
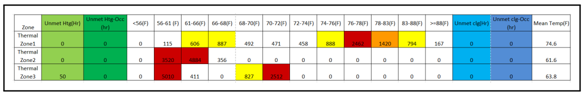


Figure 6: Site-source energy of VAV and VRV systems

The decision parameters used to choose between VAV and VRV systems include energy consumption and yearly end uses. The yearly energy usage and energy consumption of the building demonstrates that VRV is more energy efficient than VAV. One of the reasons for VAV systems being more energy-consuming devices is that the quantity of energy required for water heating is more than that necessary for air heating, since water has a higher specific heat capacity than air. Thus, to adjust the temperature by 1 degree celsius, water requires 4200 J per kilogram of heat, whereas air requires only 1000 J per kg. As a result, it is advised to use a VRV unit rather than a VAV unit for the current building. The total hours of multiple zones lying beyond the set point of the temperature sensor within the throttling range of temperature control is defined as Unmet hours. This hour is expected to be within 300 hours either during the heating or cooling period as in Ref [7]. It can be seen from the figure 7, that the total unmet hours in cooling and heating period were 0 and 50 hours respectively, which is well-defined within the criteria stated. The site to source energy conversion factor of VAV and VRV system was found to be 3.1669 that is on par with the conversion factor defined in ABUPS [8]. The total energy consumption ratio of VRV to VAV system was found to be 0.17. This ratio in the published work of Lawrence Berkeley National Laboratory was found to be 0.16 [9]. For the validation purpose, the difference between the ratio of our work and published work is 0.1 and the error percentage against the published work is approximately 6%, so this ratio is well within the acceptance criteria. Based on this study, a complete layout of VRV unit with their indoor units, outdoor units and refrigerant kits is designed as shown in fig 8.



Zone	Unmet Htg(Hr)	Unmet Htg-Occ (hr)	<56(F)	56-61 (F)	61-66(F)	66-68(F)	68-70(F)	70-72(F)	72-74(F)	74-76(F)	76-78(F)	78-83(F)	83-88(F)	>=88(F)	Unmet clg(Hr)	Unmet clg-Occ (hr)	Mean Temp(F)
Thermal Zone1	0	0	0	115	606	887	492	471	458	888	2462	1420	794	167	0	0	74.6
Thermal Zone2	0	0	0	3520	4884	356	0	0	0	0	0	0	0	0	0	0	61.6
Thermal Zone3	50	0	0	5010	411	0	827	2512	0	0	0	0	0	0	0	0	63.8

Figure 7: Representation of hours spent in each temperature range to obtain total unmet hours

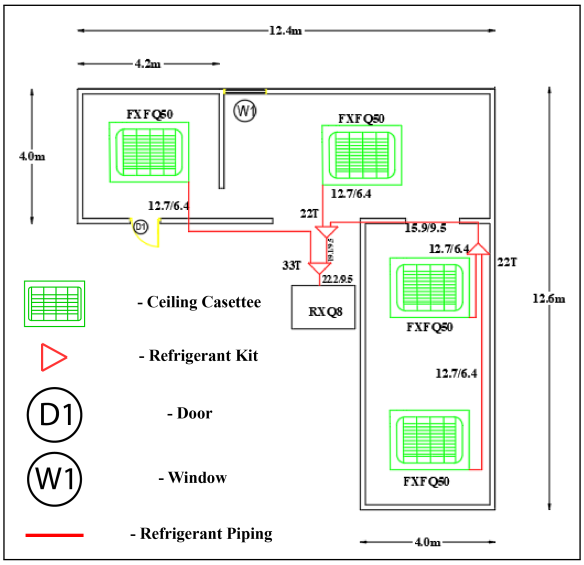


Figure 8: Design of VRV Ceiling Cassette Units and pipes in AutoCAD

5. Conclusion

OpenStudio software was used to design VAV and VRV systems, whereas EnergyPlus software was used for carrying out the simulation.In the OpenStudio software, the various heating and cooling sources, as well as other boundary conditions, were assigned, and the overall heating and cooling load, as well as the end uses of both VAV and VRV systems, were calculated. The simulation revealed that both the annual consumption and end uses for the VAV system were greater. For the automobile workshop, a comparison of simulation results revealed that VRV is more energy efficient and acceptable for the workshop.

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