Office Area Air Conditioning Optimization using Variable Refrigerant Volume System

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Abstract *— An office area located in a food industry manufacturing plant of Puerto Rico was analyzed, and a variable refrigerant volume system (VRV) was proposed. Calculations showed an expected energy consumption reduction of around 45%, while optimizing the cooling system in general. Temperature and humidity levels could be better controlled, providing better comfort at each space. Also, the VRV proposed design can individually operate the areas, allowing turning on and off smaller equipments while providing more operation flexibility to the site and users.*

Key Terms *— Energy consumption, inverter systems, temperature and humidity levels, variable refrigerant volume.*

INTRODUCTION

Air conditioning systems in general are a need in most commercial buildings. Even though there are several energy efficient technologies, there are still many that are not. These systems account for a considerable proportion of total energy consumption in a building; typically it ranges from around 50% to 75% of total energy use. By optimizing the air conditioning system, not only can economic benefits be obtained, health benefits can also be obtained and the environment can be helped. Nowadays, inverter types of systems are a rule of thumb in terms of energy efficiency.

The staff of a food industry manufacturing plant indicated that they are spending a lot of money in electricity. Because of this reason, several target projects were proposed in order to gradually reduce their electricity consumption. The air conditioning system of the office area of this plant was selected as one of the target projects.

The main system consists of a water cooled chiller, three 20-tons air handlers, one 30-tons air handler, two pumps and a cooling tower. The secondary system consists of three separate direct expansion splits. These two were treated as one "global" system. The main electricity consumption corresponds to the chiller; however, the other equipments also request a lot of energy to operate.

MAIN OBJECTIVE

The main objective of this project is the optimization of the A/C system of the office area while introducing the energy saving concept as the main parameter.

VRV SYSTEM

When analyzing different possible systems to recommend, the Variable Refrigerant Volume (VRV) was the best option. VRV is a split system where one or many units (typically up to 64) can be connected to a single circuit. It has an inverter compressor that operates as a variable frequency drive. It varies its frequency, which it's also proportional to the velocity of the compressor. With electronic expansion valves on each of the indoor units and the velocity of the compressor being varied, the refrigerant can also be varied. By first analyzing the cooling demand on each of the areas, and varying the refrigerant as required, this system provides better energy savings and performance in general.

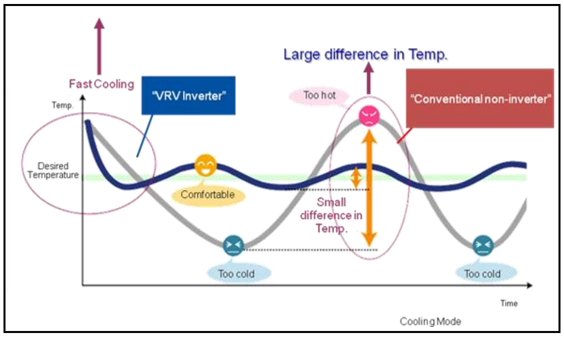

Figure 1
VRV Benefits

In Figure 1, the main benefits of better control in terms of temperature and humidity can be observed. The conventional non-inverter system typically turns the compressor on and off as the desired temperature is reached, representing large temperature and humidity level differences each time this cycle occurs. Instead, the VRV system continually maintains the compressor on, and varies it's velocity in order to maintain the desired temperature level. Parameters of temperature and humidity translate into more or less comfort on the space being acclimatized if they are controlled within a small range, so this is a another advantage for the VRV system. Also, by analyzing the graph as if the variables were current and time, it would also be established that the VRV system does not have any considerable peak current, meaning more energy savings.

METHODOLOGY

Mechanical and electrical conditions analysis for the air conditioning system was made. Electrical consumption was measured with ammeters. No data logging device was available, so current measure was made and calculations were completed. It is important to mention that measuring the amperage is a good technique, but it lacks exactitude. With data logging systems, energy consumption calculations will be more precise because it takes more parameters into consideration such as peak currents, compressor off time and exact hours of operation.

Measured amps were used for calculating single or three phase power. Then, operation hours were provided by plant staff and energy consumption was established. This type of calculation is useful, but again, it lacks exactitude, so this is a limitation for this study. Typical energy savings for VRV systems have an average of 40%, for that reason, expected results are similar to this percentage.

After consumption was established, design recommendations were made, and final design established. A simple economic analysis was required in order to establish the viability of the project; main pro parameter being energy saving and main con parameter being initial cost. Also, an energy awareness education program was part of the project proposal.

SYSTEM DESCRIPTION

The present A/C system consists of a total of 90 tons, while the new design consists of 94.85 tons. This confirms that original cooling capacity design was correct. The small variance is mainly because of the fact that instead of using big main ducts connected to the four air handlers, now the system is designed with many individual evaporators which do not have an exact calculated capacity per room. These types of indoor units provide the user with more flexibility in terms of temperature, velocity, air distribution and on-or-off capability. It also translates into more energy savings.

Figure 2 shows one of the metal ducts from one of the air handlers. It is observed that the condition is not good, and rust and humidity are present. Figure 3 shows the common return air duct to the air handler's room. Typically, these common return ducts are not recommended since adequate pressure balance is not achieved. Also, in this specific case, temperature going to the air handlers varies considerably from the one at the rooms being served by these air devices. This happens because there is a long distance between the offices and the air handler's room, and no insulation is present on the ductwork. Temperature losses occur because of this factor and energy efficiency decreases.

Figure 2
Actual ductwork

Figure 3
Actual common return air

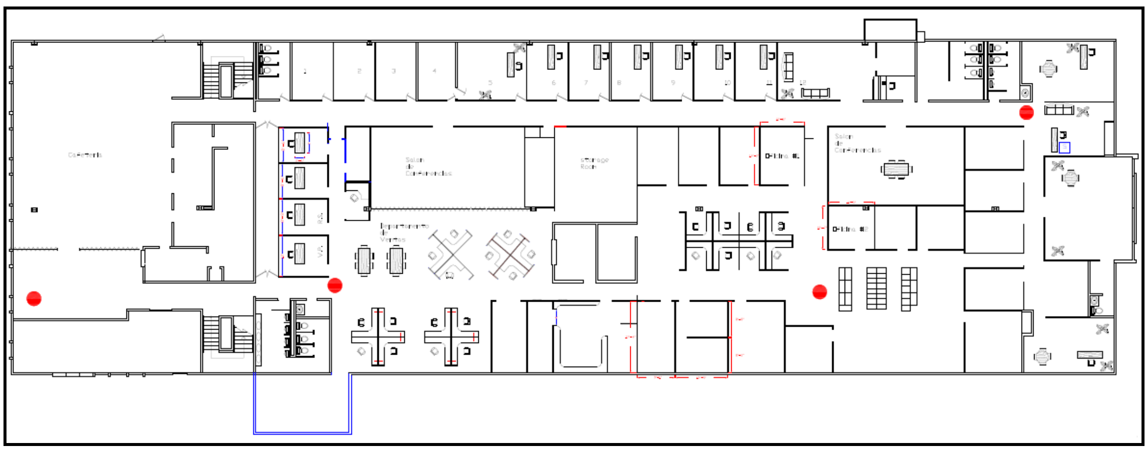

Figure 4
Office layout

Figure 4 shows the actual office layout. Separate offices are mainly on the sides of the space, while common and "open" style offices are mainly at the center. Staff did not require the cafeteria (top left space) as part of this project since other projects are being analyzed for that area.

Five main A/C circuits were designed, the smallest one with 10 evaporators and the largest with 14. Cassettes and ducted vertical/horizontal air handlers were selected. Figure 5 shows the piping layouts for CU-1.0. The other four circuits are similar, so this layout is typical. Communication layout is presented in Figure 6 and is also typical.

ANALYSIS AND CALCULATIONS

Table 1 shows calculations for power input on each of the present equipments. Current and voltage measurements were made, and power input was calculated for single and three phase electrical configurations. 127.23 KW was the total calculated power used by the 90 tons A/C system. For simplicity purposes in the analysis, exact voltage values of 480 and/or 208 are presented, but measured voltages reflected a variance of around ± 4.5V.

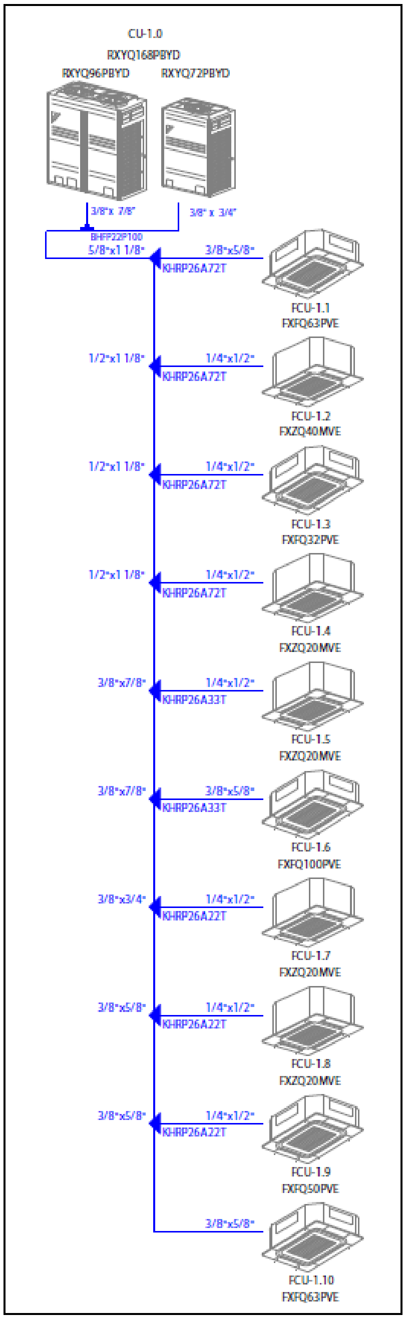

Figure 5
CU-1.0 A/C circuit layout

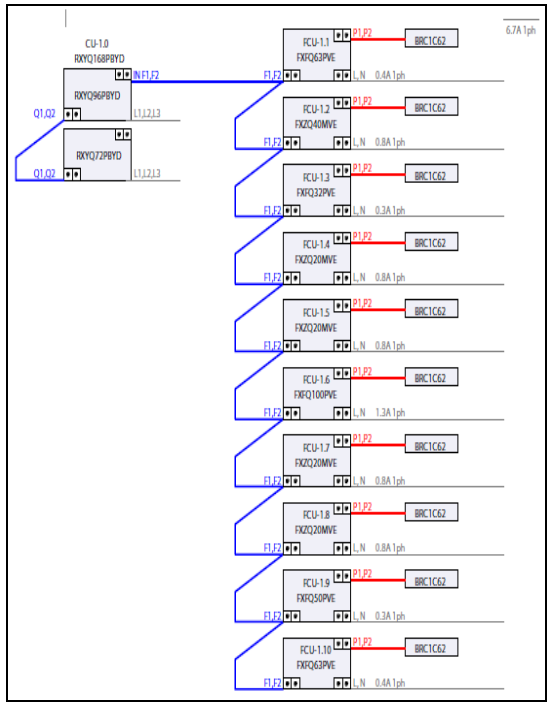

Figure 6
CU-1.0 Communication layout

Table 1
Actual equipments energy consumption

Type	Current (A)	Voltage (V)	Phases	Input (KW)
Chiller	50.0	480	3	41.57
Chiller Pump	23.5	480	3	19.54
Cooling Tower Pump	25.4	480	3	21.13
Cooling Tower Fan	14.9	480	3	12.39
AHU #1	12.0	208	3	4.32
AHU #2	10.5	208	3	3.78
AHU #3	11.0	208	3	3.96
AHU #4	16.0	208	3	5.76
Conference Room CU	31.4	208	1	6.53
RD 17 Conf. Room AHU	5.4	208	1	1.12
Office 1 CU	18.1	208	1	3.76
Office 1 AHU	2.0	208	1	0.42
Office 2 CU	12.6	208	1	2.62
			Total	**127.23**

Table 2
Proposed condensing units energy consumption

CU	Model	IEER (Btu/Wh)	Cap. (Btu/hr)	Input (KW)
1.0	RXYQ168PBYD	19.00	168,000	8.8
2.0	RXYQ240PBYD	16.00	240,000	15.0
3.0	RXYQ240PBYD	16.00	240,000	15.0
4.0	RXYQ240PBYD	16.00	240,000	15.0
5.0	RXYQ192PBYD	17.75	192,000	10.8

As shown in Table 2, IEER (Integrated Energy Efficiency Ratio) was used to calculate power input. It is an efficiency parameter created specifically for VRV/VRF systems [1]. VRF refers to variable refrigerant flow, which is another name for VRV. Daikin, the selected equipment manufacturer for this proposed project, patented the name when they invented this technology back in year 1982 [2]. IEER calculation is a useful tool, and it is a parameter certified by AHRI Standard 1230.

Since these evaporators are able to operate (on or off) per area, a usage factor of 70% was selected. Visual inspection of the office was made and several spaces with no people or need of cooling were noticed. For that reason, the selected factor was used, but from experience, it is still very conservative.

$$FCU's\ Power\ Input_{usage\ factor} = (0.70) * 6.37\ KW = 4.459\ KW \quad (1)$$

$$CU's\ Power\ Input = \frac{Cooling\ Capacity}{IEER} \quad (2)$$

Equation 1 corresponds to the power input calculation for the indoor units. 6.37 KW is the full load power. Since there is no inverter system on the evaporators, full load power can be used for calculations. Again, usage factor of 0.70 can be observed in the formula. Equation 2 corresponds to the condensing unit power input. As explained, since IEER is a parameter already adjusted to the inverter operation on a VRV system, this equation is typically used in the Air Conditioning Industry, consequently it can also be used on this project.

TOTAL ENERGY CONSUMPTION

In order to calculate the total energy consumption for present and proposed systems, plant staff provided certain information. Some assumptions were also considered. These points are presented below:

- Daily schedule: 10 hrs: (7:30AM – 5:30PM)
- 22 days per month
- Rate of $0.26/Kwh (Autoridad de Energía Eléctrica de PR – AEE)
- Full load operation for actual system
- Variable load operation for VRV proposed system
- Usage factor of 70% for indoor units
- IEER takes into consideration the consumption variation at different operation load ranges. For this reason, usage factor is not used.

With all these parameters considered, the calculated total energy consumption for present equipment was 27,991 KWh/month, while for the proposed equipment it was 15,635 KWh/month. This consumption reduction corresponds to around $3,200 monthly savings. Around 45% less energy will be required.

With a total project cost of around $265,000, a payback period of 6.9 years is expected. It is important to mention that this factor does not take into consideration the fact of increasing petroleum cost.

EDUCATION PROGRAM

It is very important to educate people in terms of energy savings. Electrical and mechanical equipments could be changed by more efficient systems, but based on experience, savings could be a lot more if users change their mentality of using more energy than the one really needed.

Because of this reason, an energy awareness program is also proposed. It includes quarterly conferences from qualified professionals, directed to protect the environment while implementing techniques and manners at the job site, at home and in different places that people visit. With this in mind, the project initiative will tackle the "waste of energy culture" at the plant and the individual's way to use this energy in general. This program will also include monthly metrics that will be available to every employee. Electronic messages will transmit this information, and also tables and graphics will be shown at walls from common areas such as hallways, conference rooms and break rooms.

Conclusion and Recommendations

Calculations showed a considerable amount of savings that can be achieved with the VRV system. Not only the monetary savings need to be considered here, mechanical and electrical conditions of the chiller system also showed that A/C system must be replaced or modified soon. If more energy efficient technologies are present today, residential, commercial and industrial sites must consider these options. Home owners, tenants and companies in general can save important amounts of money if they implement these inverter systems.

They will be also helping the environment, while reducing air pollutants. Carbon dioxide, nitrogen oxide, ozone, nitrogen dioxide and hydrocarbons are just some of them [3].

With around 45% less energy used in the A/C proportion of this office building, it is technically recommended to proceed with the project. However, financially speaking, total payback of 6.9 years is not an attractive number to proceed with the project; manufacturing plants typically seek a period of less than 2.5 years. Payback period is also high mainly because of installation cost. Since this is an area in operation, installation is complicated and more costly.

Just one mechanical contractor and one manufacturer were used for design, quoting and payback calculation. Main recommendation will be to analyze the possibility of using another contractor and another equipment manufacturer. Costs could be again established and payback period compared.

References

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