Outdoor Air, Heat Wheels and JCPenney: A New Approach To Retail Ventilation

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Abstract

JCPenney Construction Services department is responsible for the construction of new stores, take-over of existing facilities to create a new store, repairs to existing JCPenney facilities and the expansion and modernization of stores across the nation and the world. Each year, JCPenney Construction Services handles approximately 50 projects along these lines. After the implementation of ASHRAE 62-1989 by JCPenney and many major building codes, including BOCA, mechanical engineers at JCPenney noticed a sharp increase in the percentage of cooling capacity required to cool the outdoor ventilation air. In an effort to limit this impact, both in first cost and in operational costs, JCPenney is beginning to make an effort to use enthalpy heat wheels in the hot and humid climate areas where it is economically feasible. This paper discusses the efforts of JCPenney to implement this option to the treatment of outdoor air in a store in Baton Rouge, LA while maintaining indoor air quality requirements as stated in ASHRAE Standard 62-1989 and maintaining energy efficiency. This paper also discusses the projected energy savings and operations of this alternative to the standard treatment of outdoor air.

Construction In The Retail World

JCPenney is a nationally- and internationally-known clothing and soft line retailer with over 1,300 stores worldwide. The company, which started in 1902, maintains a Construction Services department which manages and oversees the construction of stores and service facilities throughout the nation and the world. Construction Services consists of approximately 100 project managers, engineers, architectural project coordinators and interior planners located in the Home Office located in Plano, Texas. The projects managed by Construction Services routinely include new stores, take-overs of existing facilities, new service facilities, modernizations and expansions of existing JCPenney stores and service facilities. During 1996, Construction Services was involved in managing and overseeing approximately 50 different projects.

The Construction Services department includes several mechanical engineers as part of the engineering staff. Each mechanical engineer at JCPenney is responsible for the HVAC, plumbing and fire protection components of each project he oversees. This responsibility includes developing the conceptual design of systems, particularly HVAC systems, used in the project, developing cost estimates and verifying the accuracy of mechanical construction costs and reviewing the detailed design of the projects as developed by either the contractor or a consulting engineer for adherence to JCPenney specifications and requirements. Once the project has completed the design phase, JCPenney mechanical engineers' responsibility expands to include reviewing the construction progress and adherence to the plans and specifications of each project, solving problems and answering questions that arise during construction, reviewing change order costs and credits and verifying the completion and commissioning of the projects.

One of the items that fall under the responsibility of mechanical engineers at JCPenney is adherence to the retail ventilation requirements of ASHRAE Standard 62-1989, Ventilation for Acceptable Indoor Air Quality. While indoor air quality has become one of the more important issues in the building construction and maintenance industry, the actual indoor air quality of JCPenney facilities is not the focus of this paper. The impact of the increase in outdoor air quantities needed to satisfy the requirements of ASHRAE 62-1989 on the HVAC systems is the direct reasoning for exploring alternatives to the standard treatment of outdoor air.

With the formal adoption of ASHRAE 62-1989 by several major building codes and, subsequently, JCPenney, outdoor air began to play a larger role in determining the HVAC systems and the loading of the stores and other facilities. Among the effects of implementation of ASHRAE 62-1989, JCPenney noticed a sharp increase in the percentage of outdoor air required to be supplied to the space, increasing from approximately 15% of the total air flow to approximately 40%. With an increase in untreated outdoor air, a corresponding increase in the amount of cooling and heating capacity was soon evident. In hot and humid climates, such as the Gulf Coast region and including states such as Texas, Louisiana, Alabama, Mississippi, Georgia and Florida, this increase was even more noticeable. As one would expect, as the HVAC equipment increased to handle the outdoor air requirements, the construction or "first" costs and the corresponding operational costs rose.

Load/Design Profile of a JCPenney Store

In order to maintain the necessary comfort levels for both employees and customers, JCPenney has developed criteria regarding the temperature and humidity levels that should be maintained in the store. Additionally, JCPenney electrical and mechanical engineers have performed studies to determine what the approximate electrical loading is in the various store areas. The electrical loading, in terms of watts per square foot, the per person sensible and latent loading which is based on an average store occupancy rate, the interior design conditions, the ambient conditions and the outdoor air requirements are the major factors used to determine the heating, cooling and airflow capacities required for a store or service facility. A listing of the design conditions for the store in Baton Rouge, Louisiana, is shown in Chart 1. (1,2,3)

The store listed here, in Baton Rouge, is in the hot and humid climate region that was mentioned above. The buildings in this area require cooling for the majority of the year. In this case, as there is a relatively consistent people and electrical load present in the store during all portions of the year, cooling is the mode of HVAC operations that is the most concern for this store. Additionally, due to the high humidity and warm temperatures during the majority of the year, economizer operations are not usually feasible. In Table 1 (6) below, note the cooling requirements of this store. Please note that this information is based on the sales floor area of the store only. Other areas such as stockrooms, office areas and the Styling Salon are not included here as they have individual, contained HVAC systems.

Chart 1. Indoor and Ambient Design Conditions

JCPenney Interior Design Conditions

Summer

75 °F Dry Bulb

50% Relative Humidity (66 grains/lb_{air})

Winter

70°F Dry Bulb

Ventilation Rates

0.3 cfm/SF for the 1st Floor

0.2 cfm/SF for the 2nd Floor

Design Electrical Loading

2.3 W/SF average over the sales area

Ambient Design Conditions

Summer

95°F Design Dry Bulb

77°F Mean Coincident Wet Bulb (111 grains/lb_{air})

80°F Design Wet Bulb

Winter

25°F Design Dry Bulb

Table 1. Sales Area Loading

System	Standard VAV System	VAV System with Enthalpy Heat Wheel
Total Cooling Capacity (MBH)	3,430	2,830
Supply Airflow (CFM)	64,000	64,000
Outside Air Requirement (CFM)	21,800	21,800

As discussed earlier, the outdoor air accounts for a sizable percentage of the total air flow, approximately 34%. The amount of capacity required to condition this load in the cooling season at peak temperatures and loading is approximately 1,200 MBH, or 100 tons. This amount of capacity is approximately 35% of the total cooling capacity required to condition the sales floor of this store at peak conditions. Any savings or reduction in the amount of capacity required for the treatment of outdoor air would have an immediate, favorable impact on operational costs.

A New Approach to Ventilation

In an effort to reduce the amount of capacity that the outdoor air requires for stores in the hot and humid climates such as Baton Rouge, JCPenney engineers have turned to alternative methods of conditioning the outdoor air. While the standard approach to outdoor air is to increase the cooling capacity of the unit in question to handle the outdoor air load, it is the most costly in terms of operational costs. Due to this, JCPenney has attempted to use more efficient equipment on new construction.

In order to compare all alternatives equally when determining the most cost effective and efficient systems for new construction, JCPenney has made a system using standard VAV rooftop units as the base system for the sales area. The VAV rooftop unit system consists of four VAV rooftop units with variable frequency drives and VAV and fan-powered VAV terminal boxes to serve the sales area, several constant volume DX rooftop units to serve the offices, main stockroom and Styling Salon and a building energy management system. In addition to the base VAV system, JCPenney routinely investigates the use and cost-effectiveness of several other systems including a single, self-contained, evaporative condensing DX rooftop unit to serve the sales area. This type of system consists of the same type of equipment as the VAV rooftop system with the exception of the use of a single evaporative condensing DX rooftop unit for the sales area.

The evaporative condensing DX rooftop system consists of the equipment standard to a self-contained DX rooftop unit with variable air volume capability. However, this type of system is water-cooled with a forced airflow, evaporative cooling tower located at the end of the unit. This tower is a part of the unit and is not required to be on a separate support structure. As this unit is water-cooled, the efficiency available in this unit is approximately 0.70 kW/ton as compared to an average 1.05 kW/ton for standard, air-cooled DX rooftop units.

In an additional simulation on this project, an enthalpy heat wheel was added to the DX evaporative condensing unit. An enthalpy heat wheel is design to pre-condition the outdoor air that is brought into the unit by means of heat transfer between the outdoor air and the return/exhaust air from the space. The process of using a heat wheel to treat the outdoor air begins with the minimum amount of outdoor air determined for the building per ASHRAE 62-1989 being drawn through the wheel by either a process air fan or, as in this case where the static pressure drop is sufficiently low, the pull of the supply air fans. The wheel that the outdoor air passes through is slowly rotating in a clockwise motion as shown in Figure 1, (5)

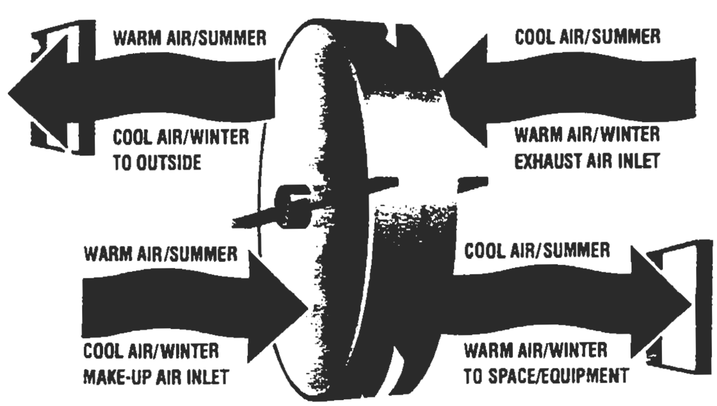

Figure 1. Heat Wheel Process Flows

The heat wheel that the outdoor air is passing through is basically an air-to-air heat exchanger that is in continuous motion. The wheel, which consists of a heat-absorbing, moisture-absorbing matrix surrounded by an aluminum and steel casing with a motor to drive the rotation, removes moisture and heat from the outdoor air in summer operation and, through rotation, transfers it to the cooler, drier exhaust air from the store. This serves the purpose of preconditioning the outdoor air by the reuse of the energy expended on the return air from the space when it was originally cooled at the unit prior to introduction to the space. Once the outdoor air is pre-cooled and dehumidified to some extent through this transfer of latent and sensible heat, the outdoor air mixes with the return air from the store in the unit's mixed air section and proceeds to the cooling coils and then through the supply ductwork to the store. Also, at this point, the portion of the return air that is being exhausted through the wheel receives the transferred heat and moisture and is exhausted from the unit with the help of an exhaust fan. Figure 2 shows the positioning of the heat wheel and the exhaust fan with respect to the remainder of the unit.

In many HVAC systems, it is common to have temperature and humidity sensors in the return air and outside air streams. Knowing the enthalpy heat wheel's rated effectiveness as determined by the manufacturer in addition to these values, one may use the following equation (X) to determine the supply air and exhaust air temperatures and humidity ratios. Additionally, by using this equation and temperature and/or humidity sensors in either of the exhaust or supply air streams leaving the wheel, the effectiveness may also be verified.

$$\varepsilon = \frac{\dot{m}_{\sup}}{\dot{m}_{\min}}\left(\frac{X_{OA}-X_{SA}}{X_{OA}-X_{RA}}\right)$$

or

$$\varepsilon = \frac{\dot{m}_{exh}}{\dot{m}_{\min}}\left(\frac{X_{EA}-X_{RA}}{X_{OA}-X_{RA}}\right)$$

where ε is the sensible, latent or total heat effectiveness of the unit,

$\dot{m}_{\min}$ is the mass flow rate of the supply air stream,

$\dot{m}_{\min}$ is the mass flow rate of the exhaust air stream,

$\dot{m}_{\min}$ is the minimum value of either the exhaust or supply air mass flow rate,

X_{OA} is the dry bulb temperature, humidity ratio or total enthalpy of the outside air,

X_{RA} is the dry bulb temperature, humidity ratio or total enthalpy of the return air,

X_{SA} is the dry bulb temperature, humidity ratio or total enthalpy of the supply air,

X_{EA} is the dry bulb temperature, humidity ratio or total enthalpy of the exhaust air.

For example, on a design day for the Baton Rouge project, the above equation (5) will show the potential decrease in dry bulb temperature of the supply air from the outside air. Using the temperature and humidity levels mentioned as the design conditions in Chart 1 and the flow rate of the supply air as given in Chart 2 along with the sensible effectiveness given by the manufacturer (ε=81.1%) (4), the reduction in temperature is given by:

$$T_{SA} = \frac{\dot{m}_{\min}}{\dot{m}_{\sup}}\cdot\varepsilon\cdot\left(T_{RA}-T_{OA}\right)+T_{OA}$$

$$T_{SA} = \frac{13{,}600cfm}{13{,}600cfm}\cdot 0.811\cdot\left(75^\circ F-95^\circ F\right)+95^\circ F$$

$$T_{SA} = 78.8^\circ F$$

and the reduction in humidity is given by:

$$W_{SA} = \frac{\dot{m}_{\min}}{\dot{m}_{\sup}}\cdot\varepsilon\cdot\left(W_{RA}-W_{OA}\right)+W_{OA}$$

$$W_{SA} = \frac{13{,}600cfm}{13{,}600cfm}\cdot 0.811\cdot\left(66grains-111grains\right)$$
$$+111grains$$
$$W_{SA} = 74.5grains$$

Thus, as this equation shows, the outside air temperature can be reduced by approximately 17% and the humidity can be reduced by approximately 33% on a design day before the outside air and the remainder of the return air mix prior to entering the cooling coils. This effect is repeated with the humidity ratio of the air. With these reductions in the temperature and humidity of the entering ventilation air, the capacity of the unit required to meet the building design requirements is reduced as shown in Chart 2.

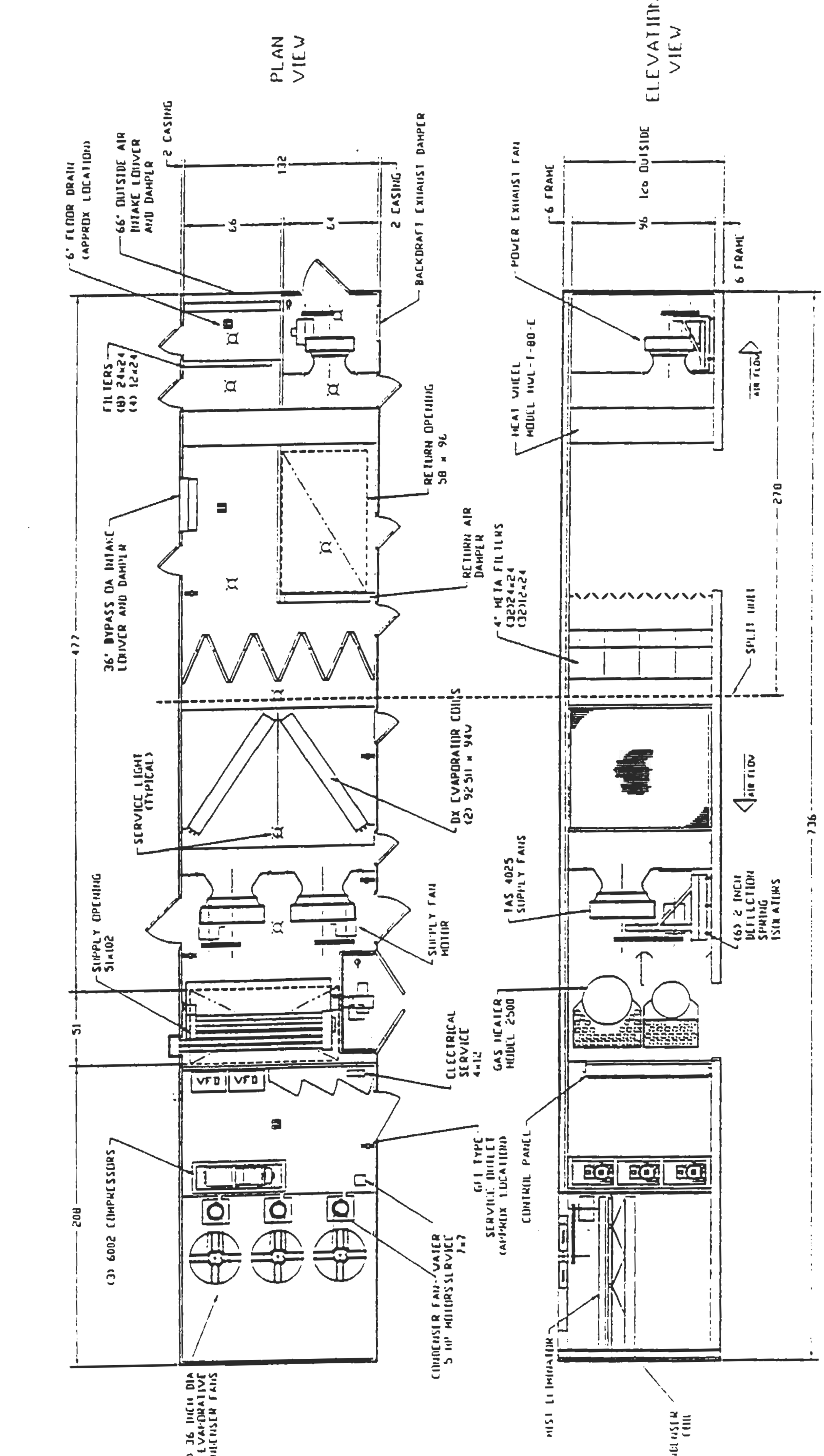

Figure 2. Baton Rouge Unit Schematic

As non-design days must also be considered, the energy management system controlling the operation of the unit and the building is designed to address the times when conditions are not as clear cut as those for design days as listed previously. In an effort to maintain the proper use of this equipment in all conditions, the building energy management system examines the enthalpy of the return air from the space and the enthalpy of the outside air and compares them. If the return air enthalpy should prove to be more useful and economical for cooling, then the heat wheel rotation shall be stopped until such a time that the enthalpy comparison shall favor the use of the wheel again.

There are also several important factors that should be noted in addition to the latent and sensible heat transfer between the air streams. It is important to note that the exhaust air and the outdoor air do not mix at any time during this process. Additionally, another benefit of this equipment is that the process above is reversed in during the winter months, although they are few in number in the hot and humid climates such as the one studied here. Though the primary benefit comes in the removal of some of the heat and moisture from the ventilation air in this climate, the winter benefits can provide an additional source of energy savings.

The economic benefits of the wheel extend farther that just the energy savings from the heat transfer. The unit also benefits from a reduction in the required cooling and heating capacities. While in this application and environment, the heating impact was negligible, the cooling impact was significant. As shown in Chart 2, the impact of the treating the outdoor air on the unit capacity during the peak summer months is extreme, approximately 35% of the unit's total capacity. Through the use of a heat wheel, the capacity of the unit was reduced by approximately 50 tons, or 50% used to treat the outdoor air. (6)

It should be noted that the potential to reduce more capacity in the unit exists through the flow of the entire amount of outdoor air required through the heat wheel. However, the total outdoor air requirement was not able to be passed through the heat wheel due the necessity of matching the exhaust and outdoor air flows for optimum effectiveness and the size of the heat wheel with respect to the unit cabinet. The reduction in exhaust air through the unit is due to the use of auxiliary exhaust fans in toilet rooms and the negative pressure requirement for the Styling Salon. Despite this, the capacity saved by the wheel as noted above remains significant.

ENERGY EFFICIENCY... THE TRUE TEST

While the scope of the HVAC system equipment is extremely important to the construction costs of the project and any capacity that can be reduced is money that is saved, the true savings for a project lie in the energy costs. Using the rate structure that was predominant for the area the store was constructed in at the time of design, the energy analysis plays the largest factor in determining whether a system is viable. As shown earlier, the use of the heat wheel reduces the impact of the outdoor air on the cooling system in the summer and the heating system in the winter. These savings are reflected in Table 2 which illustrates a 12-month estimate of the energy consumed by each system as calculated by a simulation using an common industry standard load and equipment estimation program.

THE PRICE WE PAY...

While the base system that is used for JCPenney stores is variable air volume (VAV) rooftop units with variable frequency drives as mentioned above, other systems may be selected provided that system meets the selection criteria which includes an 11% internal rate of return (IRR). In the case of the store in Baton Rouge, LA, economic data, including utility rate analysis and estimated annual utility and maintenance costs showed that a single, large DX evaporative condensing unit would not have an IRR greater than the 11% hurdle. (6)

However, the DX evaporative condensing system with a heat wheel added showed an IRR greater than the 11% hurdle over the base VAV rooftop system. The heat wheel option did not add an extreme amount of "first" costs even though the unit was lengthened and the heat wheel and exhaust fan were added. The amount of additional costs were minimized through the compressor capacity savings as mentioned earlier. As shown in Table 3, the additional "first' costs did not impact the IRR when compared with the additional utility savings.

Chart 2. Impact of Outdoor Air and a Heat Wheel

Impact of Outside Air on Loading

- Outside Air portion of Total Airflow: 21,800 CFM (34% of total airflow)
- Capacity used to Treat Outside Air: 1,200 MBH or 100 tons (35%)

Impact of Heat Wheel on Loading

- Flow Through Heat Wheel: 13,600 CFM (64% of outside air requirement)
- Est. Effectiveness of Heat Wheel: 81% (both latent and sensible)
- Capacity Saved by Heat Wheel: 600 MBH or 50 tons

Table 2. System Energy Consumption Comparison for Baton Rouge Project

Month	VAV Rooftop Units (kWh/kW)	Single, Large Evaporative Condensing Unit (kWh/kW)	Single, Large Evaporative Condensing Unit with Heat Wheel (kWh/kW)
January	144,539 / 478	148,164 / 495	146,682 / 488
February	131,866 / 501	135,429 / 510	134,102 / 504
March	169,531 / 571	169,400 / 544	167,494 / 540
April	182,759 / 632	175,844 / 580	171,380 / 572
May	203,150 / 683	190,860 / 606	185,662 / 588
June	215,687 / 728	198,171 / 635	189,212 / 604
July	222,457 / 734	204,831 / 647	192,229 / 610
August	230,341 / 737	211,845 / 649	199,001 / 611
September	201,733 / 693	188,655 / 618	181,549 / 592
October	173,968 / 598	171,169 / 556	169,419 / 556
November	162,890 / 573	162,410 / 546	160,500 / 542
December	151,089 / 530	153,844 / 526	152,241 / 521
Total kWh/Peak kW	**2,190,030 / 737**	**2,110,622 / 649**	**2,049,471 / 611**

Table 3. System Costs and Evaluation for Baton Rouge Project

System Type	VAV Rooftop Units	Single, Large Evaporative Condensing Unit	Single, Large Evaporative Condensing Unit with Heat Wheel
Est. Annual Utility Costs ($)	142,000	135,000	131,000
Est. Annual Maintenance ($)	---	4,000	4,000
Total Est. Annual Costs ($)	142,000	139,000	135,000
"First" Cost Differential* ($)	---	30,000	40,000
Internal Rate of Return (%)	---	6.8	11.8
Simple Payback (yrs)	---	10.0	5.7

Although the projected utility savings for the simulation using the evaporative condensing unit with the heat wheel were significant at approximately $11,000, they were limited by the low utility rate of this location. Neither the energy charge nor the electrical demand charge were significantly high. This lower utility rate lengthened the simple payback time and lowered the IRR of both evaporative condensing scenarios. Higher utility rates would support the expense of more efficient equipment and their higher costs through additional savings over the same energy savings.

The study shown here was based on a 30-year life cycle without replacement of the rooftop units which would occur earlier than any replacement of the main unit would be required. Other analysis based on 20-year life cycles with replacement costs for the rooftop units figured at year 15 due to the hot, humid and salty environment of this area showed similar results. The analysis based on a 20-year life cycle and without replacement costs showed the heat wheel option to with 0.3% of the IRR hurdle. Some other factors to note include that the "first" costs include the equipment, ductwork, terminal devices, control systems and installation. Finally, the maintenance costs listed for the evaporative condensing options was costs over and above the costs for maintenance with rooftop systems. (6)

Conclusion

In conclusion, as shown in the tables above, the outdoor air requirements as determined by ASHRAE 62-1989 significantly impact the costs of equipment and operations for retail stores. The increase of the outdoor air requirements to include 34% of the total airflow for a store as well as 35% of the cooling capacity have forced JCPenney to continually seek to reduce this impact through "first" and operation cost reductions. This has led to the exploration of alternatives in the main HVAC system for the store other that VAV rooftop units. These alternatives have included the use of a single, large evaporative cooling DX rooftop unit with an enthalpy heat wheel to serve the sales floor area of the Baton Rouge project. Through the use of this system, JCPenney has realized savings of approximately 50 tons of cooling capacity and will constant realize utility savings through the pre-treatment of the outdoor air through the heat wheel, which has both latent and sensible heat transfer capabilities. The savings in annual utility costs and a minimal "first" cost increase make the heat wheel an attractive and economical alternative to the treatment of outdoor air for retail ventilation.

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