ABSTRACT

High equipment first cost and high operating costs, if electricity is used to drive such a system, have prohibited the application of active humidity control equipment in comfort conditioning in the past. Instead, passive techniques have been applied. A comparison of passive control methods to control humidity shows that only the combined face and bypass and variable air volume systems show improved performance with respect to space humidity control, dew point depression, and response to perturbations.

A gas-fired desiccant humidity pump will provide economical humidity control in existing and new construction using VAV or constant volume air distribution systems. The humidity pump is designed as a packaged make-up air module. It is coupled to new or existing conventional air-conditioning systems via a duct. It consists of a triple integrated heat exchanger combining (liquid) desiccant dehumidification with indirect evaporative cooling, a brine interchanger, and a gas-fired brine heater to regenerate the desiccant. Field experiments of two humidity pumps on existing commercial buildings have been initiated. Each system dehumidifies 5000 acfm of makeup air to meet all the latent loads, which is short fed to conventional, electric-driven HVAC equipment which meet all the sensible loads.

INTRODUCTION

Desiccants exhibit a strong affinity for moisture. This process is driven by the vapor pressure differential between the moist air to be dehumidified and the desiccant. By applying heat, this differential can be reversed; thus, allowing regeneration of the desiccant material on a continuous basis. Desiccants are placed in desiccators that have been traditionally used in tandem with mechanical refrigeration in specialty air conditioning systems. These combined systems have been commonly applied to critical air conditioning situations with large dehumidification load fractions, which often arise with dehumidified air conditioning (5). Employee salaries equal approximately $2.25 ft² (5). Annual energy costs for medium to large commercial buildings are in the range between $1.50/ft² to $2.50/ft² (5). The advent of abundant and inexpensive electricity and mass production manufacturing resulted in the electrified, mechanical refrigeration becoming the market choice for energy-effective commercial and residential air conditioning systems.

This paper presents the results of the conceot phase of an effort to develop a gas-fired, liquid desiccant, make-up air module for low rise commercial buildings, referred to in the following as humidity pump. It can cost-effectively provide increased amounts of outside air and help overcome some of the VAV system deficiencies. The National Institute for Occupational Safety and Health (NIOSH) investigated from 1971 to December 1986 446 commercially used buildings (2). In a sample of 73 buildings, the NIOSH teams linked stuffiness (ventilation deficiency) as the most commonly occurring problem requiring correction. VAV which was haled to a cost-effective air conditioning/distribution system is not without problems (3.4), which may prove it be more costly than previously thought. Annual energy costs for medium to large commercial buildings are in the range between $1.50/$² to $2.50/$² (5). Employee salaries equal approximately $2.00/$²/year. A one percent reduction in productivity more than offsets any potential savings in HVAC operating costs.

In the meantime, we have come to realize, however, that we can not reduce the amount of outside air without negatively impacting the comfort of space occupants and ultimately reducing their productivity. The National Institute for Occupational Safety and Health (NIOSH) investigated from 1971 to December 1986 446 commercially used buildings (2). In a sample of 73 buildings, the NIOSH teams linked stuffiness (ventilation deficiency) as the most commonly occurring problem requiring correction. VAV which was hailed to a cost-effective air conditioning/distribution system is not without problems (3-4), which may prove it be more costly than previously thought. Annual energy costs for medium to large commercial buildings are in the range between $1.50/$² to $2.50/$² (5). Employee salaries equal approximately $2.00/$²/year. A one percent reduction in productivity more than offsets any potential savings in HVAC operating costs.

This paper presents the results of the concept phase of an effort to develop a gas-fired, liquid desiccant, make-up air module for low rise commercial buildings, referred to in the following as humidity pump. It can cost-effectively provide increased amounts of outside air and help overcome some of the VAV system deficiencies. The bacteriostatic nature of liquid desiccants, combined with the elimination of wet cooling coils in the refrigeration/humidity control equipment. The resultant decrease in product rejection coupled with increase in product quality and the parallel increase in the profitability of the product yields a quick payback on the initial investment in the desiccant humidification equipment. Now, interest is being revived in thermal driven desiccant dehumidification for general space conditioning applications. Desiccant dehumidifiers when combined with existing or new electric-driven air conditioners can greatly enhance comfort conditions while at the same time reduce operating costs. The explosion of energy costs in the 19706 led to numerous energy conservation approaches in commercial building design. The foremost one was the reduction of the amount of outside air introduced to the buildings. This approach was adopted by ASHRAE in its standard 62-1981. Parallel to reducing the ventilation air rates, the variable air volume system established itself as a more cost-effective air distribution system when compared to constant air volume equipment.

In the meantime, we have come to realize, however, that we can not reduce the amount of outside air without negatively impacting the comfort of space occupants and ultimately reducing their productivity. The National Institute for Occupational Safety and Health (NIOSH) investigated from 1971 to December 1986 446 commercially used buildings (2). In a sample of 73 buildings, the NIOSH teams linked stuffiness (ventilation deficiency) as the most commonly occurring problem requiring correction. VAV which was hailed to a cost-effective air conditioning/distribution system is not without problems (3-4), which may prove it be more costly than previously thought. Annual energy costs for medium to large commercial buildings are in the range between $1.50/$² to $2.50/$² (5). Employee salaries equal approximately $2.00/$²/year. A one percent reduction in productivity more than offsets any potential savings in HVAC operating costs.

This paper presents the results of the concept phase of an effort to develop a gas-fired, liquid desiccant, make-up air module for low rise commercial buildings, referred to in the following as humidity pump. It can cost-effectively provide increased amounts of outside air and help overcome some of the VAV system deficiencies. The bacteriostatic nature of liquid desiccants, combined with the elimination of wet cooling coils in the refrigeration/humidity control equipment. The resultant decrease in product rejection coupled with increase in product quality and the parallel increase in the profitability of the product yields a quick payback on the initial investment in the desiccant humidification equipment. Now, interest is being revived in thermal driven desiccant dehumidification for general space conditioning applications. Desiccant dehumidifiers when combined with existing or new electric-driven air conditioners can greatly enhance comfort conditions while at the same time reduce operating costs. The explosion of energy costs in the 19706 led to numerous energy conservation approaches in commercial building design. The foremost one was the reduction of the amount of outside air introduced to the buildings. This approach was adopted by ASHRAE in its standard 62-1981. Parallel to reducing the ventilation air rates, the variable air volume system established itself as a more cost-effective air distribution system when compared to constant air volume equipment.

In the meantime, we have come to realize, however, that we can not reduce the amount of outside air without negatively impacting the comfort of space occupants and ultimately reducing their productivity. The National Institute for Occupational Safety and Health (NIOSH) investigated from 1971 to December 1986 446 commercially used buildings (2). In a sample of 73 buildings, the NIOSH teams linked stuffiness (ventilation deficiency) as the most commonly occurring problem requiring correction. VAV which was hailed to a cost-effective air conditioning/distribution system is not without problems (3-4), which may prove it be more costly than previously thought. Annual energy costs for medium to large commercial buildings are in the range between $1.50/$² to $2.50/$² (5). Employee salaries equal approximately $2.00/$²/year. A one percent reduction in productivity more than offsets any potential savings in HVAC operating costs.

This paper presents the results of the concept phase of an effort to develop a gas-fired, liquid desiccant, make-up air module for low rise commercial buildings, referred to in the following as humidity pump. It can cost-effectively provide increased amounts of outside air and help overcome some of the VAV system deficiencies. The bacteriostatic nature of liquid desiccants, combined with the elimination of wet cooling coils in the refrigeration/humidity control equipment. The resultant decrease in product rejection coupled with increase in product quality and the parallel increase in the profitability of the product yields a quick payback on the initial investment in the desiccant humidification equipment. Now, interest is being revived in thermal driven desiccant dehumidification for general space conditioning applications. Desiccant dehumidifiers when combined with existing or new electric-driven air conditioners can greatly enhance comfort conditions while at the same time reduce operating costs. The explosion of energy costs in the 19706 led to numerous energy conservation approaches in commercial building design. The foremost one was the reduction of the amount of outside air introduced to the buildings. This approach was adopted by ASHRAE in its standard 62-1981. Parallel to reducing the ventilation air rates, the variable air volume system established itself as a more cost-effective air distribution system when compared to constant air volume equipment.
The objective of this R&D effort is to develop a gas-fired, liquid desiccant make-up desiccant module applicable to low rise commercial buildings. The module (humidity pump) should have:
1. low first cost,
2. acceptable economics,
3. installation costs which are at par with electric-driven rooftop equipment, and
4. be applicable to retrofit as well as new construction.

This set of objectives requires careful analysis of the cost and benefits associated with each configuration option. The approach taken here was to perform system simulation of different configuration options. The baseline system, shown in Figure 1, incorporates all the options studied:
1. a brine-to-brine interchanger,
2. an air-to-air heat exchanger to recover heat of regeneration,
3. use of condenser air to preheat regeneration air, and
4. dual firing rate of the regeneration burner for part load operation.

A desuperheater to preheat the regeneration air was another option considered. It was discarded because it doesn't meet the refrigeration circuit requirements. A detailed integrated system model was used to determine annual costs for any configuration option. This analysis of the costs/benefits associated with each option. The DOE 2.1C software package was used to generate hourly loads for the entire year. The building modeled was a 50,000 ft², three story office building with six 30 ton packaged rooftop units. The loads output was sorted by ambient temperature and humidity into bins that included only relevant hours, i.e. hours that the office building would be actually used, and calculated the average internal latent and sensible loads for each bin. The ORNL heat pump model was modified to simulate the vapor compression rooftop (VCR) packages. This model was checked against the manufacturers' published performance data which yielded an agreement within 5 percent. The detailed VCR model generated performance data for each selected bin to establish baseline annual operating costs.

The results of this component cost/benefit analysis are depicted in Figures 2 through 4. Our criterion was that a component option has to pay back itself within three years, i.e. the component cost must not be higher than potential savings realized within three years of operation. This approach also makes it possible to determine a minimal efficiency level of the heat exchangers. In the case of the interchanger it was determined that it has to be at least a 60% efficient to be an economically viable option; the same being true for the air-to-air heat exchanger. The savings realized with condenser preheat, on the other hand, are too low to make it a viable option. The system simulation also indicated that the brine heater should be approximately 85% efficient based on the gas input. The desired cost/benefit requirements made the development of a new brine heater and interchanger necessary. The final brine heater design incorporates several of the conventional regenerator functions into one unit, resulting in a significantly lower cost and more compact package. The specific interchanger objectives, such as compact design, low cost, low pressure drop, and long life expectancy in a corrosive environment were also met in a new design, which currently is patent pending.

The second major task was to determine the performance of the humidity pump by a computer simulation based on the performance maps of the individual components. The specifications of the humidity pump baseline design are listed in Table 1. The projected cooling capacity, coefficient of performance, regeneration gas input,
Performance Specifications

- Cooling Capacity: 17.8 tons
- Gas Input: 300 MBtuh
- Electrical Input: 4.8 kW
- COP: 0.71
- EER: 46
- Process Air Flow Rate: 6000 scfm
- Process Inlet Conditions:
  - Temperature: 95.0°F
  - Humidity: 0.014 lb/lb
- Process Outlet Conditions:
  - Temperature: 88.7°F
  - Humidity: 0.007 lb/lb

Table 1. Humidity Pump Baseline Design

- Permeate Inlet Conditions:
  - Temperature: 86.0°F
  - Humidity: 0.014 lb/lb
- Permeate Outlet Conditions:
  - Temperature: 88.7°F
  - Humidity: 0.007 lb/lb

and electrical input as a function of ambient conditions are shown in Figures 5 through 8.

Unlike that of electric-driven air conditioning equipment, the cooling capacity of the humidity pump increases with ambient humidity and temperature (Figure 5). The cooling capacity is here defined as the enthalpy difference between the entering and leaving process air (make-up air) stream multiplied by the process air mass flow rate. The firing rate of the regenerator is the limiting factor of cooling capacity. Alternatively, higher than design capacities can be easily achieved by higher firing rates.

Since the desiccation process is driven by the vapor pressure differential between the moist air and the desiccant, the higher this potential is the lower is the required regeneration input (Figure 7). Consequently, the coefficient of performance increases with higher dry bulb temperatures and decreases with higher ambient humidity (Figure 6). The required electrical input shows analogous behavior to the regeneration input (Figure 8).
The humidity pump supplements electric-driven rooftop equipment. This syneresis offers unique opportunities. By splitting the latent and sensible loads and controlling each individually, tight and cost-effective control of humidity and dry bulb temperature is possible. The currently recommended comfort standard, ASHRAE 55-74, suggests that the building comfort zones lie between 72°F (22°C) and 77°F (25°C) dry bulb temperature and 20 to 60 percent relative humidity. ASHRAE has also established an effective temperature scale that allows for direct comparison of comfort conditions, since both temperature and humidity are considered. It is this relationship, not a fixed maintained wet/dry bulb temperature condition that should dictate design performance and response for desiccant systems. The growing concerns about indoor air quality led ASHRAE to revise its standard for 1981. This revised standard requires a more thorough evaluation of the HVAC system and its impact on the indoor environment. It is anticipated that liquid desiccant systems will become a part of many future HVAC installations due to their system-inherent capability to provide enhanced comfort conditions and positively impact the indoor air quality via the bacteriostatic effect of the liquid desiccant and elimination of wet cooling coils.

The integration with existing or new electric rooftop air-conditioners is straightforward. The two systems are connected via a duct. One 5000 acfm humidity pump can serve up to three 30 ton rooftop packages. This integration offers unique advantages. Both systems can operate independently with the electric air-conditioner operating at a sensible heat ratio of one. This allows either an increase in the capacity of the electric equipment if the temperature lift is held constant or a higher performance level if the temperature lift is reduced. The ventilation air rates can be substantially increased at reduced operating cost (when compared to electric-driven alternatives). The economizer season can be prolonged, thus further reducing the operating cost. By substituting gas for electricity the owner/operator will benefit from reduced operating costs and reduced electric demand charges.

The humidity pump can overcome part load ventilation deficiencies of VAV systems. This can be accomplished by holding the amount of ventilation air constant, which the humidity pump will do inherently, and varying only the amount of return air. This approach leads to the unique effect that at part load conditions the percentage of ventilation air is higher than at design point. When adding a humidity pump to a constant volume system with reheat, the subcooling and reheat requirements can be substantially decreased. The operating costs can be dramatically reduced while maintaining the same air distribution system.

In new construction, HVAC systems with unitary heat pump terminals have come forward as very cost-effective alternatives to VAV systems. The effectiveness with respect to cost and comfort of these systems can be greatly enhanced with the integration of a humidity pump. A similar system has been realized in 1979 (6). This installation also shows all the benefits when combining cogeneration with desiccant dehumidification. Similar synergistic benefits can be realized when a gas engine-driven chiller is integrated with a humidity pump, as shown in Figure 9. The integrated system cooling capacity can be increased by 50%, the overall system COP by more than 10%.
The findings of the concept phase and the results of the component development phase of an effort to develop a gas-fired, liquid-desiccant based make-up air module (humidity pump) for low rise commercial buildings indicate that such a system is feasible with today's technology while maintaining competitive first cost and operating economics. The humidity pump will allow for easy integration with electric-driven equipment in retrofit and new construction applications. The integrated system will tightly control humidity and provide enhanced comfort conditions. It can cost-effectively meet the need for higher ventilation air rates and/or cooling capacities without the need to change existing HVAC systems. The system is currently undergoing field experiments at two commercial office buildings. Results of these experiments will be available in fall of this year.

REFERENCES