VENTILATION CONTROL STRATEGIES FOR BUILDINGS WITH HYDRONIC RADIANT CONDITIONING IN HOT HUMID CLIMATES

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ABSTRACT

The paper describes the moisture control strategy used in the case of a multi-story office building located in a hot humid climate and estimates the energy consumed to dehumidify the ventilation air to avoid condensation. The results show that, in order to achieve a comfortable and stable environment from both thermal and humidity perspectives, the ventilation (and dehumidification) system of the building should be operated 24 h/day. If high variations in the relative humidity are acceptable, important energy savings can be achieved by switching off the ventilation system at night. When compared to an all-air system, the use of the hydronic radiant system for conditioning in a hot humid climate provides similar indoor comfort conditions and requires less energy and peak power to operate.

INTRODUCTION

Conditioning of non-residential buildings contributes significantly to electricity consumption and peak power demand. Most of the building conditioning systems are all-air systems which operate based on convection only. The separation of the cooling and ventilation tasks of a conditioning system, as achieved by air-and-water systems, reduces transport energy and peak-power requirements. The elimination of recirculation by air-and-water systems reduces air velocity and therefore improves thermal comfort (Feustel et al. 1995). On the downside, air-and-water systems require well-tuned control strategies to maintain the indoor moisture levels in tolerable range and to avoid surface condensation during the cooling season.

In buildings conditioned by radiant systems humidity control is essential not only for the time the building is occupied but also for the time of pre-cooling the space and for some time after hours. This additional use of the ventilation system increases the energy consumption of the conditioning system and reduces the energy savings achieved through the use of hydronic

radiant cooling. The scope of this paper is to investigate the effects of using the stringent dehumidification required by a radiant conditioning system on the energy consumption and peak power demand of the system.

The results of the paper are based on RADCOOL (Stetiu et al. 1995) and DOE-2 (Simulation Research Group, LBNL 1991) simulations. The program RADCOOL was designed to simulate the dynamic thermal performance of hydronic radiant systems in a numerical test room. The latest addition to RADCOOL is a routine that simulates the moisture balance in a room and evaluates the potential risks of condensation during cooling mode. The moisture balance takes into account the influences of ventilation, infiltration, occupancy patterns and humidity sorption on the room surfaces. The sorption model is based on the concept of effective penetration depth.

METHODOLOGY

Two control strategies for the ventilation system were simulated in RADCOOL for one office space in a basecase office building (Stetiu et al. 1995). The same office building was afterwards modeled in DOE-2 as conditioned by a variable air volume (VAV) system during occupancy hours and a constant volume system (CV) at night. The VAV system was designed in such a way that, during occupancy hours, the indoor conditions match those provided by the air-and-water system as closely as possible. Estimates were made for the indoor comfort conditions and the conditioning energy and then compared for the air-and water and the all-air systems.

Basecase building and office space

The basecase building selected for this study has rectangular shape and is oriented with its longer facade 45° east of north (LBNL et al. 1995). For the purpose of this paper, we simulated the building in the hot humid climate of New Orleans, Louisiana (30° north, 90° west) using typical meteorological year (TMY) weather data.

The basecase office space is situated in the middle of the facade and has one exterior wall oriented 45° west of south. The office is rectangular with an area of 22.5 m^2. The window area of the facade represents 20% of the floor area.

The building structure corresponds to that of a well-insulated office building. The facade consists of a curtain-wall construction with the opaque part having a U-value of 0.45 W/m^2K, and the window a center-of-glass U-value of 1.31 W/m^2K. The ceiling of the office space is an aluminum panel system, made out of 20 cm wide panels with water pipes attached on the back. The panel system delimits a 10 cm plenum.

Loads

A variable occupancy pattern in the range of 1 to 2 persons was simulated in the office space, with a 9 - 17 h schedule during weekdays. No occupancy was simulated during the weekend. Each person was considered to generate 115 W heat, of which 75 W are sensible and 40 W latent. Of the sensible heat, 50% were simulated as convective and 50% as radiative.

275 W of equipment were modelled in the room, with a 9 - 17 h schedule on weekdays. 50% of the load was considered convective and 50% radiative.

The infiltration rate was modelled as 0.2 ACH (13.5 m^3/h) during the time when the ventilation system is off and the building is not pressurized.

Air-and-water system

Water is pumped through the radiant cooling panels a rate of 180 kg/h. The cooling water is supplied at 20 °C. For the purpose of the study, the on/off time of the water flow is controlled by a timer. On time coincides with occupancy time.

The ventilation is provided by a CV system functioning with outside air only. The inlet air temperature is constant at 20 °C, and the inlet air humidity ratio is constant at 9.5 g water/kg dry air (65% relative humidity). For the purpose of the study, two ventilation strategies were simulated (see Figure 1).

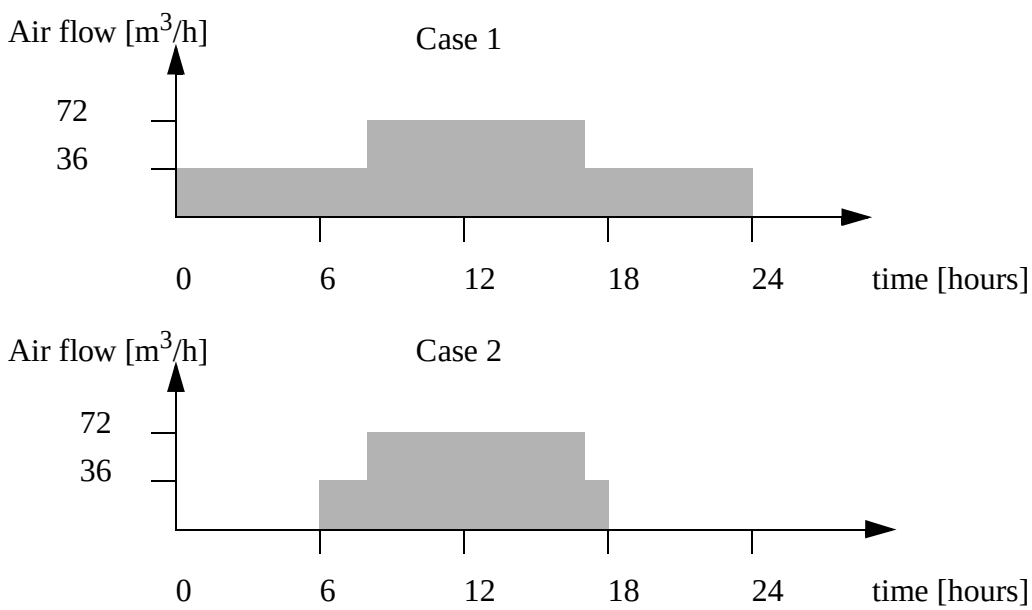

Figure 1. Ventilation strategies: schedules for weekday hours.

All-air system

The VAV system was modeled to match (1) the outside air fraction supplied by the air-and-water system, and (2) the indoor conditions during occupancy hours. The design volume flow and minimum cooling coil temperature of the VAV system are 400 m^3/h and 14.5 °C. The indoor air relative humidity is allowed to vary in the range of 40%-60%.

In the case when the fan is on 24 h/day, a CV system replaces the VAV system during the hours when the building is not occupied. The CV system supplies only outside air at a rate of 36 m^3/h. The supply air is dehumidified to 9.5 g water/kg dry air.

Simulation time and considerations about the climate

The simulation time was chosen to model summer conditions. A one-week period was modeled, between Friday, July 22 and Thursday, July 28. This period was chosen to include a

weekend, as well as the time of the peak load in the basecase office space.

The typical weather in New Orleans during the study period is hot and humid: the ambient temperature varies between 23 and 33 °C, and the humidity ratio between 16 and 22 g/kg. The 1% ASHRAE design values for the cooling system in New Orleans are 34°C dry bulb temperature and 26°C coincident wet bulb temperature (18 g/kg).

RESULTS & DISCUSSION

According to the calculations, the peak load for the space does not occur simultaneously for the two systems. However, the time of peak occurs when the ambient air temperature and the coincident wet-bulb temperature are very close. This indicates that dehumidification is an important factor in the energy balance of the conditioning system, regardless of its type.

A summary of the energy consumption and peak power load of the office space during the week of study is presented in Table 1. The first two columns contain RADCOOL and DOE-2 results for the case when the fan is on 24 h/day. The last two columns contain results for the case when the fan is off at night. The reported chiller energy was calculated by considering a COP of 3 for both the air-and-water and the all-air system. The comfort conditions were assessed in relation to comfort ranges of 23-27 °C for the indoor dry bulb temperature, 30-60% for the indoor relative humidity, and an indoor humidity ratio lower than 12.5 g/kg (ASHRAE 1992).

Figure 2 shows the indoor air temperature provided by the air-and-water system. The two ventilation strategies lead to essentially the same indoor air temperature, maintained inside the comfort range at all times. The air temperature is slightly higher when the ventilation system is turned off because no cooling occurs when the radiant system and ventilation system are off.

Figure 3 shows the indoor relative humidity for the air-and-water system. In the first case, the fan is on 24 h/day, and the continuous functioning of the ventilation system maintains the relative humidity within the comfort range. In the second case, dehumidification of the supply air during occupancy hours controls the indoor air humidity ratio, maintaining it inside the comfort range. At night, when the fan is off, the humidity rises due to infiltration of moist, almost saturated air. At the same time the indoor air temperature drops due to a lack of loads. This drives the relative humidity into the 90% range. Although the notion of comfort is not relevant when the office space is not occupied, relative humidity levels with averages of 65-70% and amplitudes of 30% can potentially affect the furniture and paper-based materials in the office.

The calculations show that the presence or absence of the sorption properties of the building materials is not important when the fan is on 24 h/day, but that the results for the case when the fan is off at night vary substantially with the presence or absence of sorption. The third curve in Figure 3 shows that, if sorption is neglected, RADCOOL predicts saturation when the fan is turned off at night. If the sorption properties of the building materials are considered, the program predicts that no saturation occurs.

The RADCOOL results imply that controlling the relative humidity during off time leads to a stable environment from the moisture perspective. However, if high moisture swings are acceptable, switching off the conditioning system at night is associated with energy savings in the order of 25%. An important factor in making such a decision is that switching off the system at night should not result in the formation of condensation on the cooling surface.

The results for the air-and-water system were compared with the results for the VAV system modeled in DOE-2. Figure 4 presents the indoor air temperature provided by the two sys-

tems in the case when the fan is turned off at night. As can be seen from Figure 1 and Table 1, the VAV system provides very similar temperature conditions in the office space during occu-

TABLE 1. Energy Consumption and Peak Power Components

	Air-and-water fan on at night	All-air fan on at night	Air-and-water fan off at night	All-air fan off at night
Comfort conditions	thermal yes moisture yes condens. no	thermal yes moisture yes condens. no	thermal yes moisture yes condens. no/yes	thermal yes moisture yes condens. yes
Air sensible energy [kWh]	20.5	72.7	14.4	69.7
Air latent energy [kWh]	59.8	60.2	35.3	37.5
Water sensible energy [kWh]	33.2	-	34.1	-
Chiller energy [kWh]	37.8	44.3	27.9	35.7
Fan energy [kWh]	1.3	6.3	1.0	8.2
Pump energy [kWh]	0.2	-	0.2	-
Total energy [kWh]	39.3	50.6	29.1	43.9
Relative difference to all-air case	-22.3%	-	-33.7%	-

TABLE 1. Energy Consumption and Peak Power Components

Peak load [kW_{el}]	0.62	0.84	0.63	0.86
Relative difference to air-and-water case	-26.1%	-	-26.7%	-
Peak load components [kW_{el}]				
Air sensible	0.10	0.48	0.11	0.46
Air latent	0.23	0.17	0.18	0.21
Water sensible	0.26	-	0.31	-
Fan and pump	0.03	0.19	0.03	0.19

pancy hours. Turning the VAV system off at night, however, leads to a temperature swing due to heat release from the building envelope. This temperature swing is missing in the case of the air-and-water system because the building structure is already cooled and does not release heat.

As DOE-2 does not consider sorption on building materials, a comparison of the humidity levels inside the office space by the air-and-water system and the all-air systems could only be made for the case when sorption is ignored (Figure 5). As in the temperature case, the results for the two systems are very close during occupancy hours, but differ over the time when there is no ventilation. Both DOE-2 and RADCOOL predict saturation of the indoor air when the fan is turned off. This translates into the occurrence of condensation on the building envelope.

An examination of the data in Table 1 shows that, while providing essentially the same indoor conditions, the air-and-water system consumes less energy and requires less peak power to operate. The energy savings are impressive mostly in the case when the fan is off at night.

CONCLUSIONS

1. Infiltration in an office building in a hot humid climate causes the indoor humidity level to have high amplitude swings. This might result in condensation on the building envelope.
2. An air-and-water system cannot provide stable indoor moisture conditions unless its ventilation system functions without interruption. Operating the ventilation system 24 h/day leads to an increase of 25% in energy consumption, mainly due to latent heat removal.
3. In order to maintain similar thermal and humidity comfort conditions inside an office space in a hot humid climate, an air-and-water system requires less energy and peak power than an all-air system. The savings are largest when the system only operates during the day.

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REFERENCES

ASHRAE. 1992. ASHRAE Standard 55-1992. Thermal Environmental Conditions for Human Occupancy. Atlanta: American Society of Heating Refrigerating and Air-Conditioning Engineers, Inc.

Feustel, H.E. and C. Stetiu. 1995. Hydronic Radiant Cooling - Preliminary Assessment, Energy and Buildings Vol. 22, Number 3, pp. 193-205.

LBNL, ETHZ and Intep AG. 1995. Environmental Assessment of Low-Energy Cooling for Buildings, Intep AG report, Zurich, Switzerland.

Simulation Research Group, LBNL. 1991. DOE-2 Basics, LBNL-29140.

Stetiu, C., H. E. Feustel, and F. C. Winkelmann. 1995. Development of a Simulation Tool to Evaluate the Performance of Radiant Cooling Ceilings, LBNL-37300.