

# OPERATIONAL STRATEGIES FOR REDUCING COIL LOADS

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## ABSTRACT

*In HVAC systems, the sensible reheat requirement may be reduced through recirculation of supply air that bypasses a cooling coil. An analysis and parametric study of this approach is presented. The results are applicable to constant-air-volume systems, which often require large amounts of reheat. Reheat is needed when the latent load requires a lower temperature supply air than that needed to meet the sensible load. Reheat can be reduced by processing only a fraction of the return air, and then mixing the remainder of the return air with this processed air. Since the airflow through the coil is reduced, the coil temperature must be lowered to meet the same sensible and latent loads. The air conditioner coefficient of performance (COP) is reduced since the coil temperature is lowered, but cooling energy is reduced since less flow is processed by the coil. The fraction of circulation flow that eliminates the reheat is a function of the space setpoint, the space load, the sensible heat ratio, and the circulation flow rate. A significant reduction in air conditioner coil size and power consumption could be realized through this approach.*

## INTRODUCTION

Conventional constant-air-volume (CAV) systems may require large amounts of reheat. In applications such as supermarkets, the latent load limits the maximum operating temperature of the air conditioner coil and there is a potential to exceed the sensible space load. Therefore, the outlet from the air conditioner coil is too cool and reheat must be added to bring the air up to the required supply temperature. Although reheat is usually considered free if the heat is taken from the condenser of the chiller, the cost of initially overcooling the air is significant. Ideally, the coil should cool the air directly to the desired supply temperature to minimize the load on the coil.

A typical CAV system is shown in Figure 1a. This system usually requires reheat because the supply temperature (state A) is lower than that required to meet the sensible load (e.g. Mitchell 1983). Heat is added in the reheat coil to bring the temperature at S to the desired value. Reheat can be minimized by using some of the warm return air. This is accomplished by dividing the return airflow into two flows. One flow mixes with the

fresh air and is cooled and dehumidified by the air conditioner coil. The other flow bypasses the coil and mixes with the other at the coil outlet. A reduction in coil load is achieved because the reheat is reduced.

The CAV system with variable flow through the coil (CAV-V) is shown in Figure 1b. A conventional variable-air-volume (VAV) system is controlled such that the airflow rate through the system is varied in order to exactly meet the sensible load (Mitchell 1983). The CAV system differs from the VAV system in that the total flow rate is constant, but the flow rate through the coil is controlled such that both the latent and sensible loads are met.

The process for a conventional CAV system is shown on a psychrometric chart in Figure 2. Outside air at state

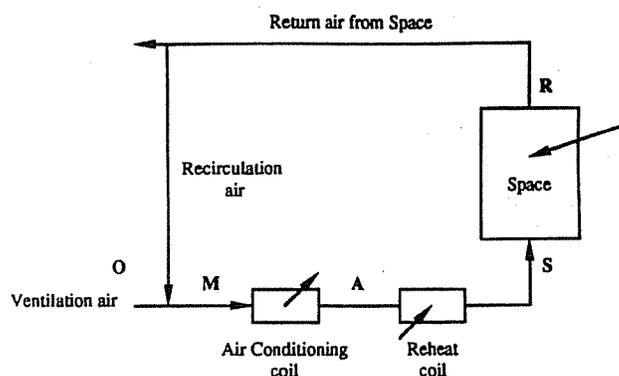


Figure 1a The conventional CAV air-conditioning system.

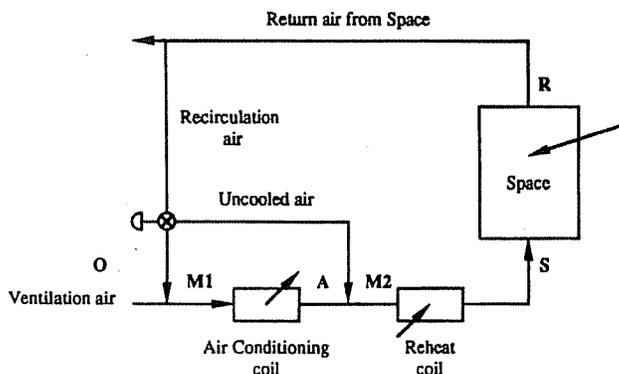


Figure 1b The variable-flow CAV air-conditioning system.

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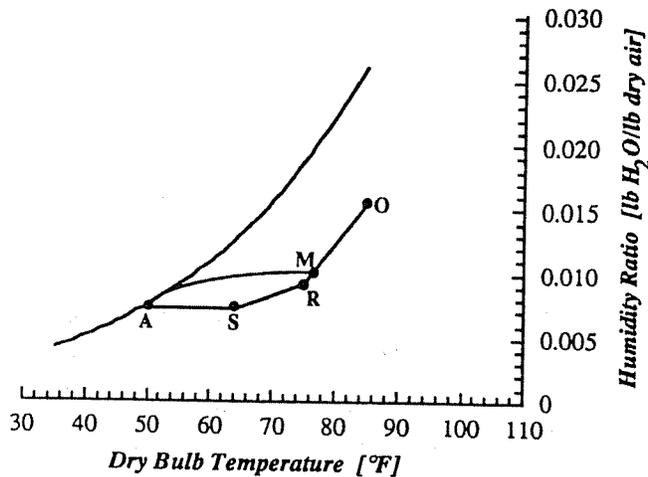


Figure 2 Psychrometrics of conventional system.

O mixes with return air at state R to produce state M entering the coil. The line M-A is the cooling and dehumidification of the airflow through the air conditioner coil. The line A-S is the sensible reheat of the air to the supply state. The line S-R is the load line for the space. An energy balance on the entire system results in the following equation for the coil load:

$$\dot{Q}_{A/C} = \dot{Q}_S + \dot{Q}_{RH} + \dot{m}_{vent}(i_o - i_i) \quad (1)$$

where  $\dot{Q}_S$  is the space latent and sensible load,  $\dot{Q}_{RH}$  is the reheat load, and  $\dot{m}_{vent}$  is the ventilation load. For a given space load, ventilation mass flow rate, and ambient conditions, the reheat  $\dot{Q}_{RH}$  is the only quantity that can be controlled to reduce the coil load.

The corresponding process diagram for the CAV-V system is shown in Figure 3a. State M1 is the result of mixing a portion of return air with outside air. The process line through the coil (M1-A) results in a lower coil outlet temperature than that for the conventional system because the same amount of moisture must be removed from a smaller flow of air. The remaining portion of return air (state R) mixes with the coil outlet state to produce state M2. Comparison of Figure 3a with Figure 2 shows that at the same humidity ratio, state M2 for the CAV-V system is at a higher temperature than state A for the CAV system. Thus, the amount of reheat is significantly reduced and, as shown by Equation 1, the coil load is correspondingly reduced.

Control of the amount of air that bypasses the coil will allow state M2 to be at the desired supply state S and totally eliminate reheat, as shown in Figure 3a. However, if the outlet temperature from the air conditioner coil is less than about 38°F, the coil surface begins to frost up and a defrost cycle must be incorporated into the coil operation. Defrosting the coil penalizes the coil performance and adds to the power consumption of the air conditioner. Therefore, two control scenarios will be considered. In the first, the space load allows total elimination of reheat with the outlet temperature greater

than 38°F (as shown in Figure 3a). In the second, if the space load requires the outlet temperature to be less than 38°F for elimination of reheat, the coil will be operated such that the outlet air temperature is 38°F and some reheat will be required (as shown in Figure 3b, process line M2-S).

## ANALYSIS AND PARAMETRIC STUDY

The systems were modeled with TRNSYS, a modular simulation program (Klein 1988). Both the conventional and variable-flow CAV systems were studied and a parametric study was done to determine the important factors in reducing the air conditioner coil load. The coil load was evaluated with specified volume flow rate, total space load, and space setpoint and ambient conditions.

A parametric study of the effect on the coil load of the fraction of the total flow sent through the coil was performed. The range of circulation flow rate was

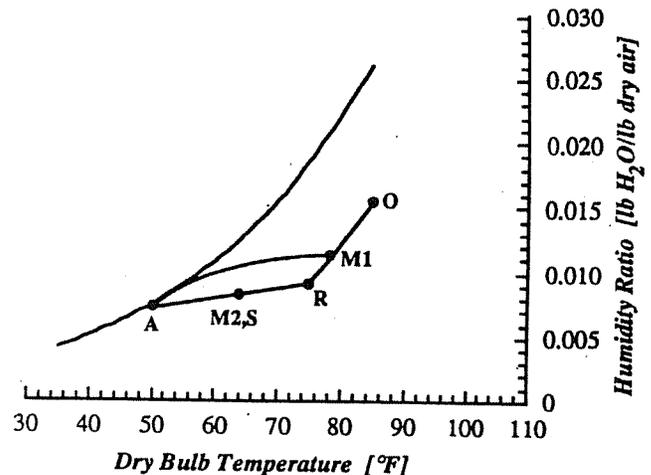


Figure 3a Variable flow through air conditioner coil with elimination of reheat.

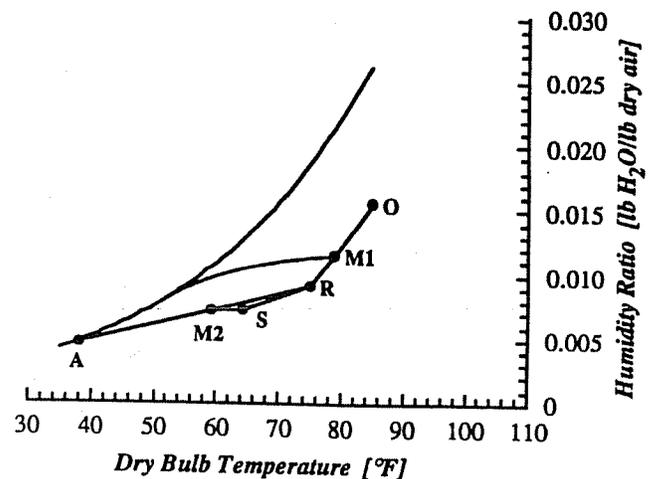


Figure 3b Variable flow through cooling coil with minimum coil outlet temperature.

between 4,000 and 10,000 cfm, with the total space load maintained at 100,000 Btu/h. The range of fresh air ventilation flow rate was between 5% and 25% of the total flow rate of air. The range of sensible heat ratio of the total load was varied between 0.4 and 0.9. The space setpoints considered were 75°F/40% RH and 72°F/50% RH. The nominal design of the system is shown in Table 1. The fraction of the total flow through the air conditioner coil was varied for a constant space load, ambient conditions, ventilation mass flow rate and setpoint.

The ratio of the total volume flow rate to the total space load is reflected by the length of the load line of the space. The length of the load line (R-S in Figure 3) is inversely proportional to the flow rate, as shown by an energy balance on the space

$$i_R - i_S = \frac{\dot{Q}_S}{\dot{m}}, \quad (2)$$

where  $i_R$  and  $i_S$  are the enthalpies of the room and supply states, respectively.

Figure 4 shows the load on the coil for several circulation flow rates with the load and ventilation flow rate at nominal conditions. The minimum load corresponds to no reheat. As the circulation flow rate increases, the load increases with flow through the coil, and reheat is required. At the nominal conditions, the minimum load is the same for all circulation flow rates and corresponds to the same flow through the coil. For example, for 8,000 cfm of circulation flow rate the fraction of the flow through the coil is 0.27, corresponding to 2,200 cfm through the coil. For 4,000 cfm, the 0.54 fraction also yields 2,200 cfm through the coil.

At the minimum coil load, reheat is eliminated and both the sensible and latent loads are exactly met. At higher rates of flow through the coil, the load is increased because the latent load limits the operating temperature of the coil and some sensible reheat is required in order to obtain the correct supply temperature. At lower rates of

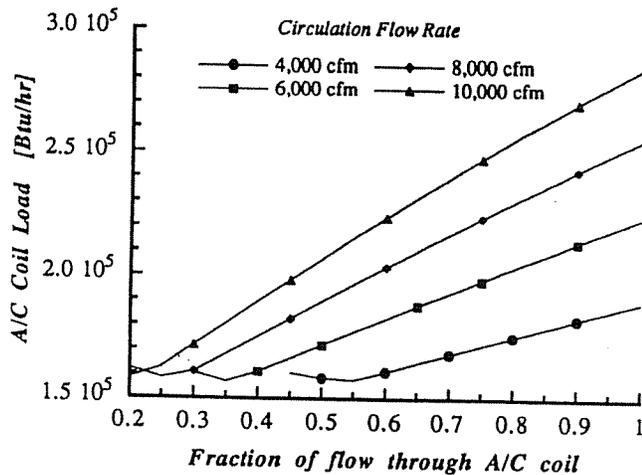


Figure 4 Load as a function of fraction of flow through coil and circulation flow rate.

TABLE 1  
Nominal Design for TRNSYS Model

Parameter Description	Value and Units
Space set-point (Dry bulb temp/Relative Humidity)	72° F/50% RH
Outdoor conditions (Dry bulb temp/Relative Humidity)	91° F/45% RH
Sensible Load	70,000 Btu/hr
Latent Load	30,000 Btu/hr
Circulation flow rate	8,000 cfm
Ventilation air fraction	0.15

flow, the load is increased because the sensible load limits the operating temperature of the coil and the supply state is drier than necessary (Figure 5b, point M2). In the latter case, it is assumed that the space humidity ratio stays constant despite the lower supply humidity; in reality, the humidity ratio would decrease slightly (Figure 5b, R2). This decrease has a small effect on load.

The amount of incoming ventilation air affects the state entering the coil and, consequently, the amount of dehumidification performed by the coil. The load as a

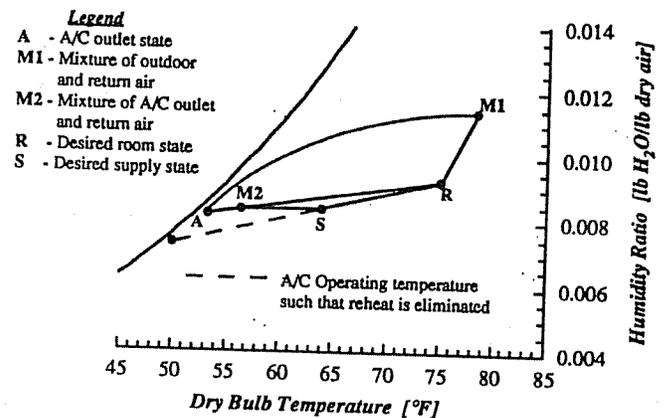


Figure 5a System operation with too much flow through air conditioner coil.

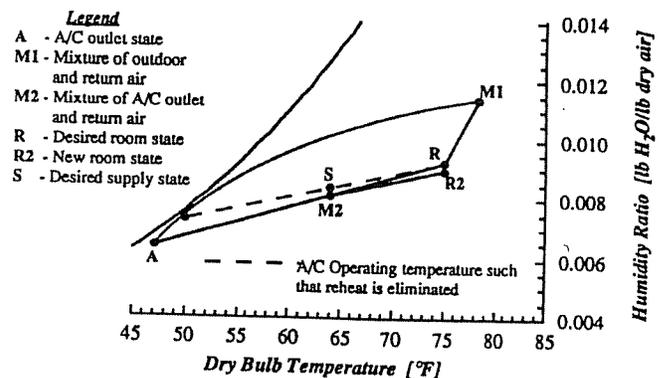


Figure 5b System operation with too little flow through air conditioner coil.

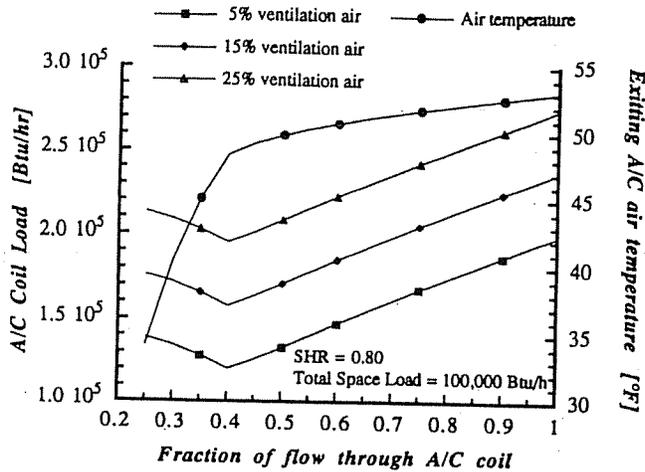


Figure 6 Load as a function of fraction of circulation flow through air conditioner coil and ventilation flow rate.

function of the ventilation flow rate is shown in Figure 6. The optimum fraction does not change since the air bypassing the coil is always at the return state, independent of the ventilation flow rate. The optimum fraction of airflow through the air conditioner coil is independent of the ventilation flow rate.

The sensible heat ratio (SHR) has a large effect on the optimum fraction of total flow through the coil. The SHR is the slope of the space load line at a given setpoint and determines the temperature at which the air conditioner coil should operate. It also determines whether or not the reheat can be totally eliminated or if the coil will have to be run at the lowest temperature without requiring defrost. The load as a function of flow fraction is shown in Figure 7. The total load is constant at 100,000 Btu/h, but the sensible and latent fractions change with the SHR. The optimal fraction decreases as the latent load fraction increases (SHR decreases). For SHR values less than 0.7, at a space setpoint of 75°F and 50% RH, the outlet air conditioner temperature would need to be less than 38°F

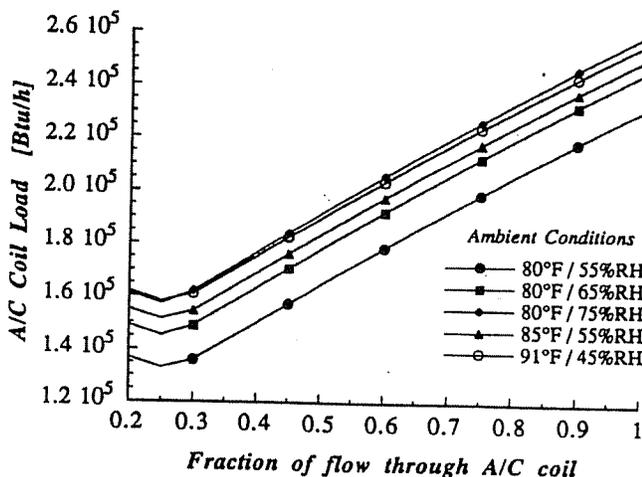


Figure 8 Load as a function of ambient conditions.

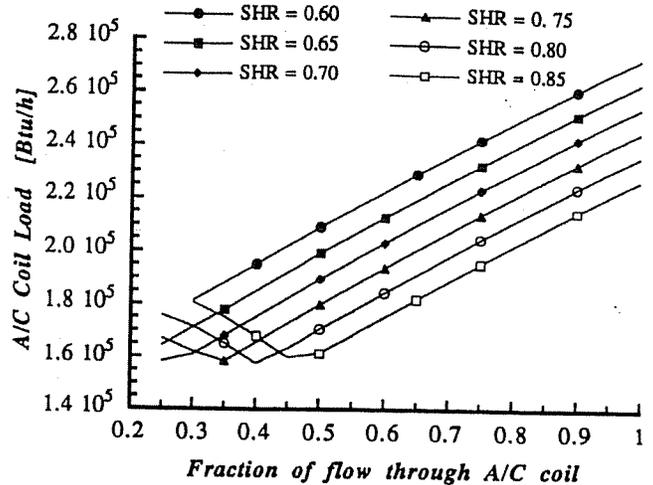


Figure 7 Load as a function of fraction of circulation air through air conditioner coil and SHR.

and reheat would be needed in order to obtain the desired supply state. Figure 7 also shows that the air conditioner load decreases with decreasing latent load (increasing SHR) for all flow rates through the coil greater than optimal. However, the minimum load stays the same because the total space and ventilation loads are the same and reheat is eliminated.

The ambient conditions were found to only affect the total load and not the optimum fraction through the coil, as shown in Figure 8. The space setpoint affects the load on the coil because both the ventilation load and the operating temperature of the air conditioner coil are affected by the setpoint. Figure 9 shows that the fraction of total flow that corresponds to the minimum load changes for different zone setpoints.

In summary, the fraction of the total flow through the coil that gives the minimum air conditioner load is dependent on the space setpoint, the total circulation flow, and the SHR of the space load. The ambient conditions and fraction of ventilation mass flow affect the coil load

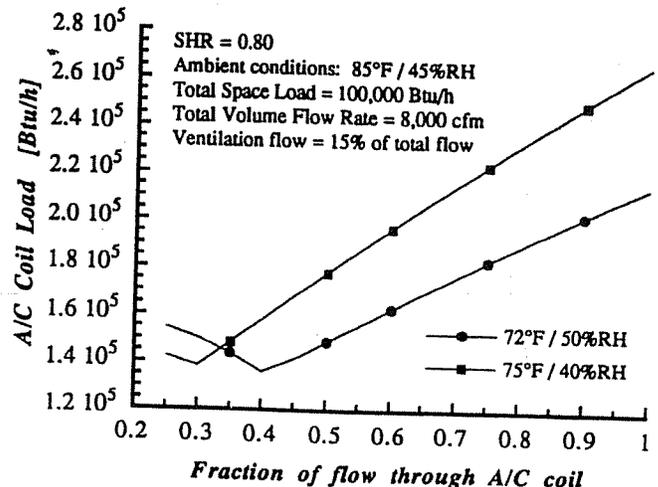


Figure 9 Load fraction of flow through air conditioner coil and space setpoints.

but do not affect the coil operating temperature or optimum fraction of total flow through the coil.

Control laws were developed to determine the optimal flow rate fraction through the coil. Figure 10 shows the optimum flow as a function of SHR and circulation flow rate at the nominal space setpoint and load descriptions. For the nominal design SHR of 0.7, the optimum fraction is approximately 0.25 and the coil temperature is approximately 40°F.

As the flow rate delivered to the space increases, the fraction through the coil decreases because the supply state moves toward the setpoint. The point on the line for 4,000 cfm when the optimum fraction equals 1 corresponds to a supply state at saturated conditions.

Readily programmable controller algorithms that determine either the optimum fraction of flow to be sent through the coil or the fraction given a constant coil outlet temperature when subject to changing loads were developed. A curve fit of the saturation line on the psychrometric chart (enthalpy and humidity ratio), the space setpoint temperature and humidity, and the SHR are used with Newton's method to predict the saturation temperature at which the load line intersects the saturation line. The flow chart for the algorithm is shown in Figure 11. The optimum fraction of flow rate through the coil is calculated using the saturation temperature and humidity ratio (coil outlet state), setpoint temperature and humidity ratio, and the circulation flow rate of air through the system.

The changes in temperature and humidity ratio as a result of changes in the sensible and latent loads are simplified as follows:

$$\Delta T = \Delta Q_s / c_p \quad (3)$$

$$\Delta \omega = \Delta Q_L / i_{fg} \quad (4)$$

where  $c_p$  is the specific heat of dry air and  $i_{fg}$  is the heat of vaporization of water.

The inputs to the controller algorithms are the space setpoint temperature, humidity ratio and enthalpy, the space load and sensible heat ratio, and the circulation flow rate. The outputs from the controller are the fraction of the total flow that should be sent through the coil and the temperature of the outlet air from the air conditioner coil.

### EXAMPLE OF FLOW CONTROL

An example of the load reductions through bypass control was conducted. An example space load for a design day is shown in Figure 12a. The latent load is assumed to be constant at 20,000 Btu/h and the outdoor and setpoint conditions are assumed to be constant at 91°F/45% RH and 72°F/50% RH, respectively. The constant outdoor conditions will not affect the optimum fraction of the total flow through the coil, but will affect the air conditioner load. The nominal design parameters given in Table 1 will be used.

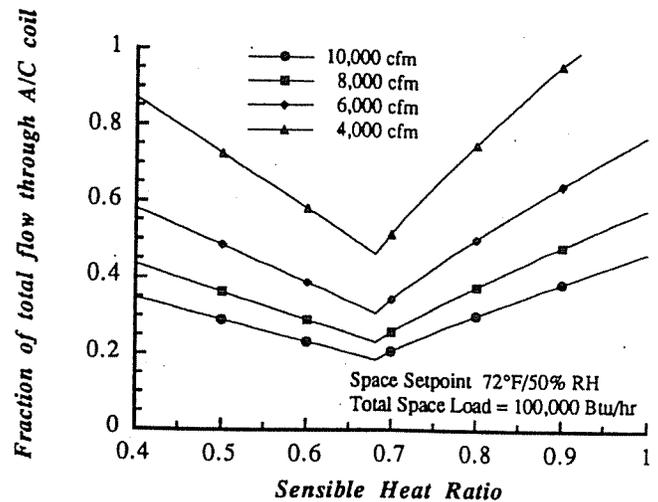


Figure 10 Optimum fraction through coil for several circulation flow rates at nominal space setpoint and load.

For the conventional CAV system, the latent load on the space determines the coil operating temperature. Since the ambient and setpoint conditions and the latent load are constant, the load on the coil will be constant because the outlet humidity level must be constant in order to meet the latent load. The reheat will change as the sensible space load changes increase with increased sensible reheat needed as its sensible space load decreases. Figure 12b shows that the coil load for the conventional system is constant over the course of the day.

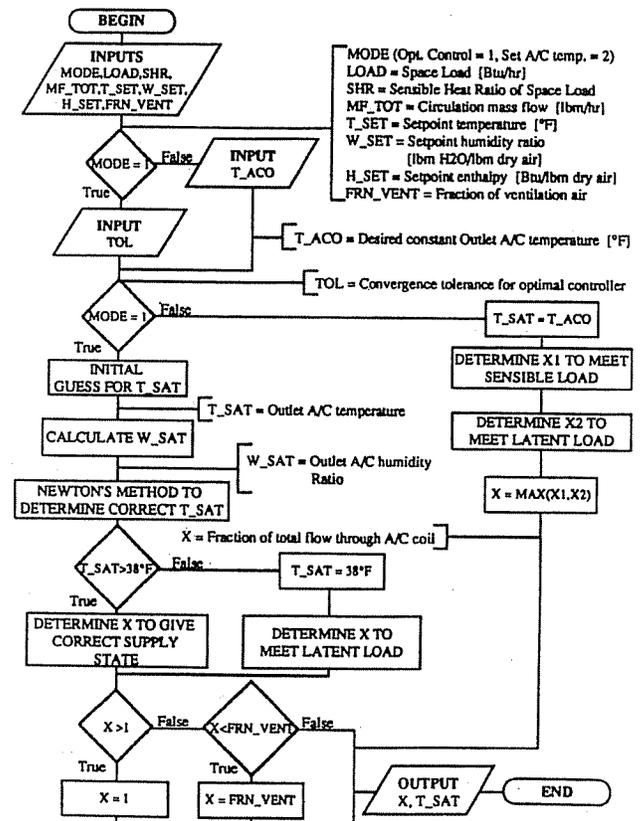


Figure 11 Control algorithm for optimization of coil load.

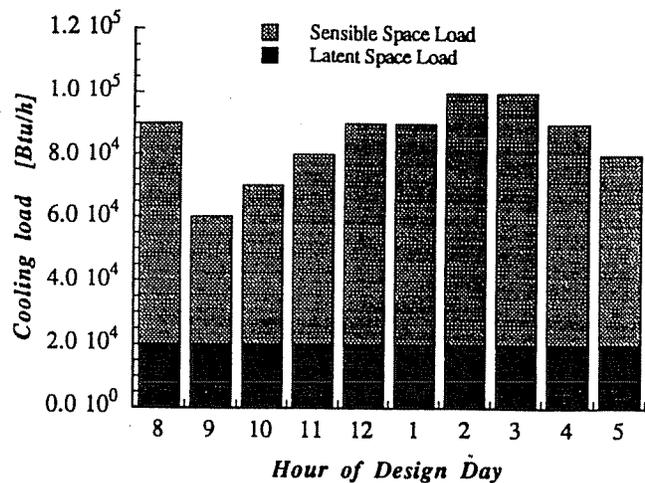


Figure 12a Design-day load schedule for variable-flow example.

The control algorithms were used to determine the optimal flow through the coil. The power for the variable-flow system varies with the space load because the reheat is eliminated or minimized. The example demonstrates a reduction in energy of about 50% and a maximum load reduction of 30%.

The design-day loads and ambient conditions determine the size of the air conditioner coil. The size of the air conditioner coil is smaller than for the conventional system because the amount of reheat is reduced. In the example in the previous section, the rated capacity of the air conditioner coil sized for the conventional system was 287,000 Btu/h based on the maximum air conditioner coil load of about 237,000 Btu/h. The maximum air conditioner coil load for the variable-flow system is decreased to about 161,000 Btu/h, which is approximately 30% less than the conventional system. Thus, the control strategy could reduce both equipment costs and operating energy costs.

## CONCLUSIONS

A variable-flow system that minimizes the air conditioner coil load while meeting both the sensible and latent space loads has been simulated. The amount of airflow that should be cooled by the air conditioner coil is a function of the value and SHR of the space load, the space setpoint conditions, and the total flow through the system. The ambient conditions and ventilation flow rate did not affect the amount of flow that should be cooled in order to minimize the air conditioner coil load. A variable-flow-rate controller was developed that determines the amount of airflow that should be cooled in order to minimize the air conditioner coil load. Although the air conditioner coil must operate at a lower temperature and thus a lower COP, the decrease in load could reduce power consumption.

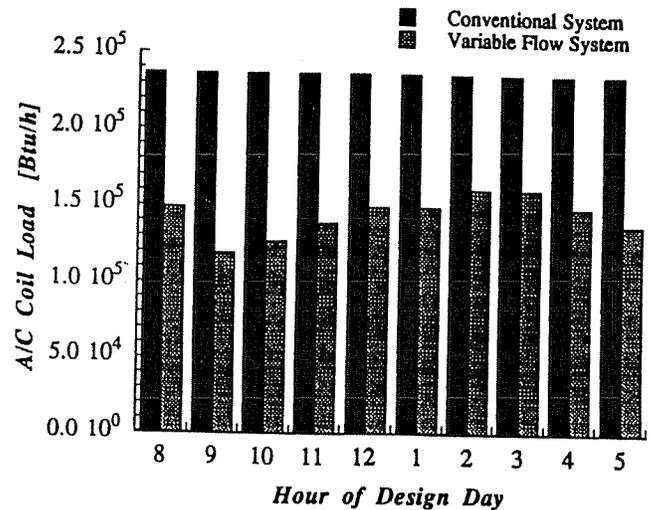


Figure 12b Load of conventional and variable-flow systems for variable space load.

## NOMENCLATURE

$c_p$	=	specific heat of air
$COP$	=	coefficient of performance
$i$	=	enthalpy
$\dot{m}$	=	mass flow rate
$Q$	=	energy
$\dot{Q}$	=	load
SHR	=	sensible heat ratio
$T$	=	temperature

## Greek Symbols

$\Delta$	=	difference
$\omega$	=	humidity ratio

## Subscripts

$A/C$	=	air conditioner
$fg$	=	heat of vaporization
$i$	=	inlet (ventilation)
$o$	=	outlet (exhaust)
$R$	=	return
$RH$	=	reheat
$S$	=	space
$sat$	=	saturated
$vent$	=	ventilation

## REFERENCES

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- Mitchell, J.W. 1983. *Energy engineering*. New York: John Wiley & Sons.
- Urban, R.E. 1988. The performance of conventional and humid-climate vapor-compression supermarket air-conditioning systems. M.S. thesis, University of Wisconsin-Madison.

## DISCUSSION

**Dick Hegberg, Engineer, Hegberg & Associates, Inc., Chicago, IL:** This paper brings up an interesting point—to reduce the load on the coil by bypassing the cooling coil with a portion of return air and to reduce the amount of reheat normally required. I think the reader needs some cautionary advice. The occupant comfort is a very important criterion, especially where “steep” room moisture ratio lines may occur due to high latent loads. In his text *Air Conditioning Analysis* (MacMillan Co. 1947, chapters 12 and 13), William Goodman developed an approach to minimize the amount of reheat required. Your Figures 5a and 5b seem to indicate that reheat can be eliminated, but I wonder if that’s feasible when steep ratio lines occur, as in loads due to human activity, such as dancing, exercising, and swimming, or high outdoor humidity conditions.

**J.W. Mitchell:** I agree that reheat may be needed when there are large latent loads (steep load lines). However,

using the strategy that we propose, it is possible to minimize the amount of reheat required and still provide comfort in the zones.

**Jan F. Kreider, University of Colorado, Boulder:** Your algorithm requires measurements of SHR and load. In practice, both are very difficult to measure in a real building. What surrogates do you suggest for load and SHR so that your control scheme can actually be implemented?

**Mitchell:** In an actual building system, measurements of temperature and humidity from the zones could be used to implement the control strategy we describe. These would be used with feedback control in an EMCS system to vary the bypass flow and temperature leaving the coil. This would be similar in concept to methods using a thermostat to vary the room airflow rates in a VAV system to always meet the sensible load.

