

REDUCING BUILDING ENERGY COSTS USING OPTIMIZED OPERATION STRATEGIES FOR CONSTANT VOLUME AIR HANDLING SYSTEMS

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ABSTRACT

Building energy consumption can be substantially reduced after implementing what we call Extended O&M Measures. The Extended O&M Measures are a scientific refinement of traditional O&M measures. Specifically, they involve resetting the cooling deck or heating deck temperature according to the ambient temperature such that maximum energy efficiency can be achieved without compromising indoor air quality and comfort. Extended O&M Measures optimize system performance as a whole rather than focusing on the malfunction of individual component. Our study involving five medical and institutional buildings at the University of Texas Medical Branch (UTMB), Galveston shows that Extended O&M Measures can reduce chilled water and condensate costs by \$517,800/yr, or 19% of the total building energy cost (\$2.7 million dollars). This potential percentage savings is comparable to the LoanSTAR measured thermal energy savings in 10 buildings at another University of Texas campus where constant air volume systems have been converted to variable volume systems. Though in the later case fan electricity consumption is also reduced but with some investment cost. On the other hand, Extended O&M Measures do not require any retrofit or investment cost. Extended O&M Measures have been implemented in one of the five buildings, and the measured savings are consistent with predicted savings. It seems that the Extended O&M Measures are an excellent alternative to converting constant volume systems to variable volume systems, especially if there are no retrofit funds available.

INTRODUCTION

The quality of operation and maintenance is a key factor in influencing a building's energy costs. Historically O&M energy conservation research has focused on: 1) fixing damaged parts; 2) reducing excessive operation hours; and 3) making appropriate nighttime setbacks [1]. These traditional O&M measures can substantially reduce building energy consumption in poorly operated and maintained

buildings and energy systems [2-8]. However, building energy consumption can be further reduced even after these traditional O&M measures are applied. This involves optimal adjusting of cold deck and hot deck settings according to the ambient temperature and organizing cold deck settings properly where more than one cold deck is present (Extended O&M Measures). The cold deck and hot deck settings can be adjusted continuously by the Energy Management and Control Systems without additional investment. The optimized cold deck settings can be implemented manually or by EMCS systems. These O&M measures reduce or even eliminate reheat by optimizing the whole system performance according to current weather conditions rather than focusing on the malfunction of individual components. Therefore, we call these measures or concepts Extended O&M Measures.

A study of potential savings due to the Extended O&M Measures has been performed on five different types of buildings at the University of Texas Medical Branch at Galveston (UTMB). These Extended O&M Measures can reduce the chilled water and condensate costs by \$517,800/yr, or 19% of the total building energy cost (\$2.7 million dollars). This potential percentage savings is comparable to the LoanSTAR measured thermal energy savings in 10 other buildings on another campus where constant air volume systems have been converted to variable volume systems. Though in the later case fan electricity consumption is also reduced but with some investment cost. On the other hand, Extended O&M Measures do not require any retrofit or investment cost. This paper discusses Extended O&M Measures and their applications to the five buildings at UTMB.

EXTENDED O&M MEASURES

Extended O&M Measures vary with the type of HVAC system. Although dual duct and single duct systems are frequently shown in textbooks and handbooks, real systems in buildings could be different. Three different systems are discussed below.

Dual-Duct Constant Air Volume System With Pretreated Outdoor Air Intake (DDCVP):

The schematic of this type of system is shown in Figure 1. The outdoor air is cooled by the pre-treatment cold deck during summer (ambient temperature higher than 60 °F), and heated up by the pre-heat coil in winter (ambient temperature lower than 46 °F). The rest of the time, both the pre-treatment cold deck and the pre-heat deck are shut down. The main system is a typical dual-duct constant air volume system, where a portion of the air is cooled and the other portion is heated.

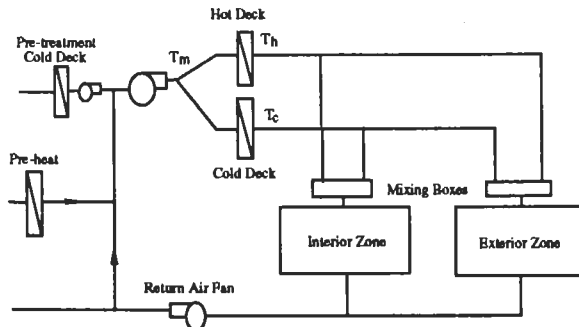


Figure 1: Schematic of Dual Duct Constant Air Volume System with Pretreated Outdoor Air Intake

It was found that the pre-treatment cold deck generally had a supply air temperature of 57 °F to 60 °F, while the main cold deck had a temperature of 52 °F to 55 °F. Under this cold deck setting structure, the main cold deck has to bear both sensible and latent loads. In this system, the following two Extended O&M Measures were seemed necessary:

1. *The deck setting structure needs to be optimized.* This measure requires decreasing the pre-treatment cold deck temperature to the lowest value according to the cold deck capacity, and increasing the main cold deck temperature to its highest value according to the sensible load. The pre-treatment cold deck would remove more moisture after its temperature is decreased. Consequently, the major task of the main cold deck is to control the sensible cooling load. Therefore, a substantial amount of re-heat can be avoided. A decreased hot deck temperature is often necessary in order to keep the cold deck flow rate within its capacity.

2. *The operation schedule needs to be optimized i.e. the cold deck temperature needs to increase as the ambient temperature decreases.* This measure adjusts the deck temperature according to the ambient temperature. Since heating and cooling loads vary with the ambient temperature, the cold deck temperature should be increased as the temperature

decreases during summer mode. The optimized operation schedule will eliminate the need for much of the reheat. Consequently, the thermal energy consumption will be similar to that of variable air volume systems, except for the fan power savings.

Single Duct Constant Air Volume System (SDCV):

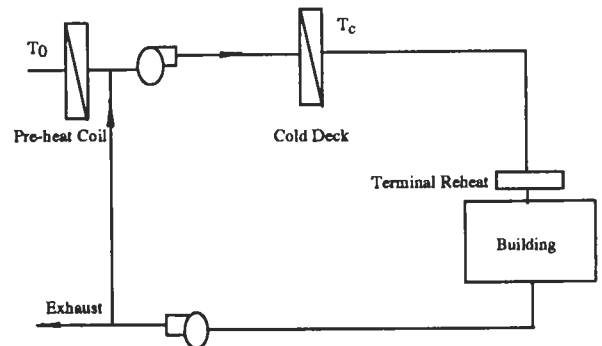


Figure 2: Schematic of Single Duct Constant Air Volume System

This is a typical single duct constant air volume system. Two Extended O&M measures are suggested for this type of system:

1. *The operation schedule needs to be optimized or the cold deck temperature needs to increase as the ambient temperature decreases* (discussed above). The cold deck temperature may be increased except for only a few very hot summer days. This cold deck temperature increase will reduce the reheat substantially. However, the increased cold deck temperature may increase room relative humidity levels. In some cases, the increased room relative humidity level, such as from 45% to 60%, can be accepted. In fact, there is now a tendency to extend room relative humidity levels from 30% to 70% [9]. If the increased room relative humidity level is not acceptable, another Extended O&M Measure is suggested below.

2. *The cold deck should be partially closed to maintain the dehumidification capacity of the coil.* In big buildings, the cold deck consists of more than one parallel coil (three or six coils are often connected in parallel). The increased cold deck temperature can be implemented by closing or partially closing one or more coils while keeping other coils open.

Figure 3 demonstrates the advantage of the partially closed cold deck using the psychrometric chart. The following conditions are assumed: outdoor air, 75 °F and 80% (RH) (point o); return air, 74 °F and 50% (RH) (point R); and the return air fraction, 0.7. The mixing air condition is marked as point m.

Under this ambient temperature condition, the supply air temperature can be set at 58 °F according to the sensible cooling load, while the base or current cold deck temperature is 50 °F. Point 1 is the current supply air condition, point 2 is the supply air condition obtained by increasing the cold deck temperature, and point 3 is the supply air condition where one of the coils is closed and the other two coils maintain 50 °F supply air temperature.

Figure 3 shows that no moisture will be removed if the cold deck temperature is simply increased to 58 °F. However, the partially closed cold-deck measure supplies 58 °F air to the building and removes 0.0021 lb/lb air moisture, or 70% of the moisture removed when cold deck is operated under 50 °F. Clearly, the partially closed cold deck can maintain room relative humidity at much lower levels than by increasing cold deck temperature. However, the partially closed cold deck will reduce the same amount of reheat.

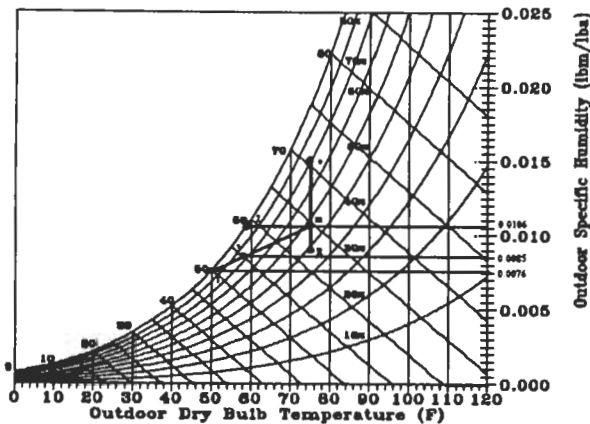


Figure 3: Working Processes Under Different Schedules of Air-Handling Units

Single Duct Constant Air Volume System with Partially Reheated Air (SDCVP):

The third type of system is the single duct constant air volume system with partial air reheat (Figure 4). The Extended O&M Measures are the same as in the single duct constant air volume system mentioned above.

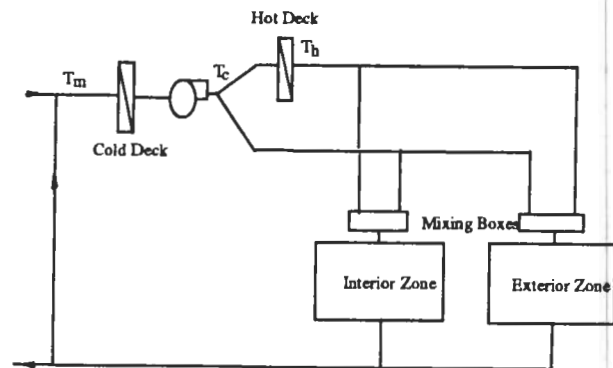


Figure 4: Schematic of Single Duct Constant Air Volume System

APPLICATIONS OF EXTENDED O&M MEASURES

Extended O&M Measures have been investigated at five UTMB buildings: 1) the John Sealy North Building (JSN); 2) the Clinical Science Building (CSB); 3) the Basic Science Building (BSB); 4) the Moody Library Building (MLB); and 5) the John Sealy South Building (JSS).

Building & HVAC System Information

The JSN building is a two-story structure with one DDCVP system and three SDCV systems. It houses the primary operating rooms on the second floor and associated facilities on the base floor. The CSB building is a six-story teaching building with two DDCVP systems. The BSB is a seven-story building which houses offices, classrooms, laboratories and storage. Two SDCV systems are used in this building. The MLB building is a six-story building with a core 1st floor, 5th and 6th floor. It includes a book collection, offices, conference rooms and necessary service facilities. Two SDCVP systems are used in the MLB. The JSS building is a 12-story in-patient care facility with four DDCVP systems.

These buildings range in size from 67,380 ft² to 373,000 ft² and have a total floor area of 778,768 ft² (see Table 1). The buildings' annual energy costs vary from \$195,000 to \$990,600, totaling over \$2.7 million dollars (including about \$2.1 million thermal energy costs and \$0.6 million electricity energy costs). The thermal energy cost is about 78% of the total energy cost. The energy cost varies from \$2.65/ft² to \$6.64/ft² with an average of \$3.48/ft². The detailed information is supplied in references [10-14].

Table 1: Information Summary of the five UTMB Buildings

Building Name	JSN	CSB	BSB	MLB	JSS	Total
Type/Usage	Hospital In-patient	Lab. & Class	Lab. & Class	Library	Hospital operation	
HVAC System Type	DDCVP SDCVP	DDCVP	SDCVP	SDCVP	DDCVP	
Floor area (ft ²)	75,662*	124,870	137,856	67,380	373,000	778,768
Thermal Energy Cost(\$/yr)	\$405,300	\$235,300	\$573,900	\$153,200	\$759,000	\$2,126,700
Electricity Cost (\$/yr)	\$96,800	\$115,200	\$97,000	\$41,800	\$231,600	\$582,400
Total Energy Cost (\$/yr)	\$502,100	\$350,500	\$670,900	\$195,000	\$990,600	\$2,709,100
Total Energy (\$/ft ² -yr)	\$6.64	\$2.81	\$4.87	\$2.89	\$2.65	\$3.48**

* Including a kitchen area (18,000 ft²) within another building

** Average cost of five buildings

The hourly energy consumption (chilled water, condensate and electricity) has been measured by both the LoanSTAR program and the EMCS (Energy Management & Control System) at UTMB.

Model Analysis:

A simplified model was developed to simulate the air side of the HVAC system and the building thermal performance for each building. This model simulated each building as two zones and calculated both thermal performance (such as chilled water, condensate consumption and room relative humidity levels) and mechanical performance (such as air flow rate through each duct). The model predicted chilled water and condensate energy consumption according to the ambient temperature and coincident dew point temperature, HVAC parameters (air flow rate, cold deck and hot deck settings etc.), and building internal gain and envelope information. These HVAC and envelope parameters were collected by a site visit. Katipamula & Claridge suggested that two zones are often adequate for building energy modeling [15].

The simplified model was calibrated by comparing the predicted daily average energy consumption with LoanSTAR measured daily average energy consumption. In most cases, the simplified model prediction was close to the measured consumption. However, in one case, the simplified model prediction using the EMCS measured cold deck setting as model input did not match the measured consumption. A site measurement proved that the temperature sensors used in the EMCS were erroneous with a constant bias. On correcting this parameter in the model, the match between simulated and measured energy use was satisfactory. Figures 5, 6, 7, 8, and 9 compare the simplified model prediction and the LoanSTAR

measured energy consumption for each building. The horizontal axis is the ambient temperature. The vertical axis is the average daily energy consumption in MMBtu/hr.

Figure 5 compares the predicted and measured energy consumption at the John Sealy North building from December 1992 to August 1993. The predicted average chilled water consumption is 12% less than the measured value while the predicted average condensate consumption is the same as the measured value. The root mean square errors of the predictions are 1.02 MMBtu/hr and 0.28 MMBtu/hr for chilled water and condensate, respectively, while the coefficients of variation are 19% and 20% for chilled water and condensate, respectively.

Figure 5 shows that the measured chilled water and condensate energy consumption are substantially higher than the predicted values when the daily average ambient temperature is lower than 60 °F. These differences can be explained as follows. When the daily average ambient temperature is lower than 60 °F, the daytime temperature may be higher than 50 °F and the nighttime temperature may be lower than 50 °F. Consequently, the pre-heat coil is off during the day and comes on at night. However, the model assumed that the pre-heat coil is off when the daily average ambient temperature is higher than 53 °F. Therefore, the predicted chilled water and condensate consumption are lower than measured values when the ambient temperature is lower than 60 °F. These differences can probably be reduced by performing hourly simulation. Since these differences have little impact on the savings estimate, the daily average ambient temperature is used in this analysis.

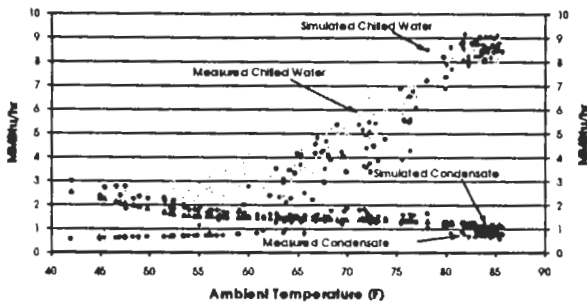


Figure 5: Comparison of Simulated and Measured Average Daily Energy Consumption (John Sealy North Building, December 1, 1992 to August 29, 1993)

The chilled water and condensate energy consumption was predicted using the measured daily average temperatures from August 1, 1992 to July 31, 1993 at the Clinical Science Building. Figure 6 compares measured energy consumption with model simulated energy consumption. The simulated average chilled water consumption is 0.5% lower than measured values while the simulated average condensate consumption is 1% higher than the measured values. The root mean square errors are 0.42 MMBtu/hr and 0.13 MMBtu/hr for chilled water and condensate, respectively, while the coefficients of variation are 15% and 7% for chilled water and condensate, respectively.

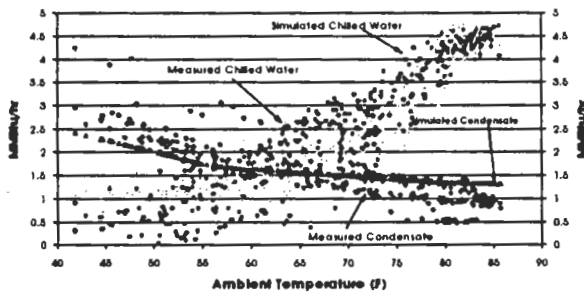


Figure 6: Comparison of Simulated and Measured Average Daily Energy Consumption (Clinical Science Building, August 1, 1992 to July 31, 1993)

Figure 7 compares measured energy consumption with model simulated energy consumption from December 1, 1992 to June 30, 1993 at the Basic Science Building. The predicted average chilled water consumption is 8% lower than the measured values while the simulated average condensate consumption is 3% lower than the measured values. The root mean square errors are 1.13 MMBtu/hr and 0.25 MMBtu/hr

for chilled water and condensate, respectively, while the coefficients of variation are 19% and 6% for chilled water and condensate, respectively.

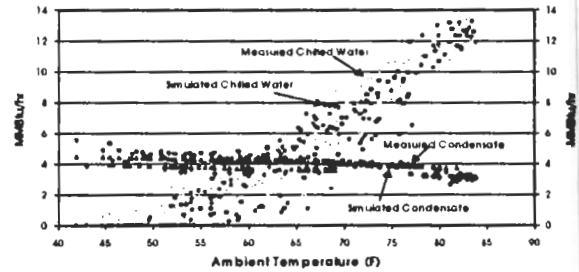


Figure 7: Comparison of Simulated and Measured Average Daily Energy Consumption (Basic Science Building, December 1, 1992 - June 30, 1993)

Figure 8 compares the measured and the model predicted energy consumption at the Moody Library Building from October 24, 1992 to June 29, 1993. The simulated average chilled water consumption is 2% higher than the measured value. The simulated average condensate consumption is 5% higher than the measured value. The root mean square errors are 0.10 MMBtu/hr and 0.14 MMBtu/hr for predicted chilled water and condensate energy consumption, respectively, while the coefficients of variation are 6% and 13% for chilled water and condensate consumption, respectively.

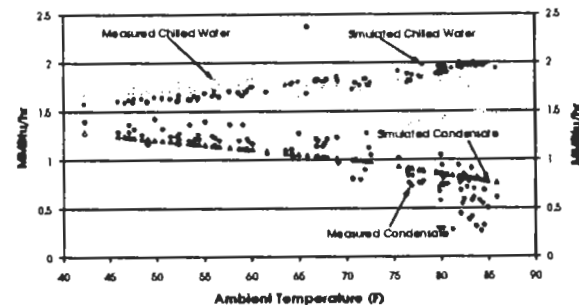


Figure 8: Comparison of Simulated & Measured Average Daily Energy Consumption (Moody Library Building, October 24, 1992 to June 29, 1993)

Figure 9 compares the predicted and measured energy consumption at the John Sealy South Building from February 1, 1993 to July 12, 1993. The simulated average chilled water consumption is 3% less than the measured value while the simulated condensate consumption is 0.3% higher than the measured value. The root mean square errors of the predictions are 1.12 MMBtu/hr and 0.3 MMBtu/hr for chilled water

and condensate respectively, while the coefficients of variation are 0.11 and 0.10 for chilled water and condensate, respectively.

The optimized operation schedule for each building is developed using the calibrated model by a trial and error method. The best operation schedule is chosen first. Then, the energy and mechanical performance are predicted using the simplified model and then compared with the previous best. Modification of the operation schedule is made and a new simulation performed. This process is repeated until the operation schedule is considered the optimal.

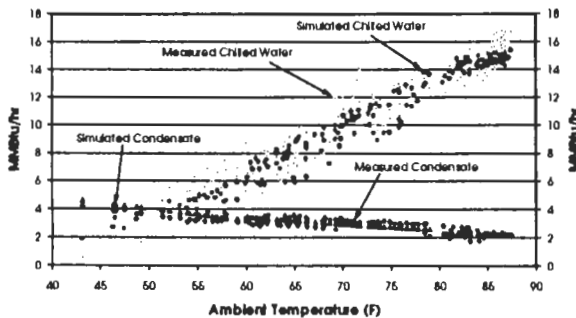


Figure 9: Comparison of Simulated & Measured Average Daily Energy Consumption (John Sealy South Building, February 1, 1993 to August 29, 1993)

It should be pointed out that the optimized operation schedule is developed subject to the following conditions: 1) room temperature should be in the same range; 2) room relative humidity should be of the same level; 3) the air flow rate to each room should be unchanged; and 4) the maximum CFM through cold and hot decks and ducts should be less than their maximum capacities.

Energy savings are taken as the difference between the base model's (calibrated model) annual energy consumption and the optimized model's (with energy conservation measures) annual energy consumption.

Optimized Operation Schedule

The aim of the Extended O&M Measures is to determine the optimized operation schedule. The

optimized and the current operation schedules for each building are summarized in Table 2.

Table 2 shows clearly that the optimized operation schedule increased the main cold deck temperature substantially and decreased the pre-treatment cold deck temperature when the ambient temperature was higher than 60 °F. The hot deck temperature is decreased in order to keep air flow through the cold deck within its maximum capacity. Clearly, the optimized operation schedule can reduce the chilled water and condensate energy substantially, provided suitable room relative humidity levels can be maintained.

The impacts of these optimized schedules on the room relative humidity levels and energy consumption are investigated using the simplified models. The model simulations were based on the bin data generated from LoanSTAR measured ambient dry bulb temperatures and dew points in Houston from July 1, 1991 to June 30, 1992 [10-14]. The room relative humidity levels and energy consumption were calculated using the simplified model for both the base and the optimized schedules.

Impact of Optimized Schedule on Room Relative Humidity Levels:

Figures 10, 11, 12, 13, 14 show the predicted room relative humidity levels under both the base and the optimized operation schedules. The horizontal axis is the ambient bin temperature. The vertical axis is the predicted room relative humidity levels. It should be pointed out that the model predicted room relative humidity levels under the base operation schedule are consistent with the EMCS measured room relative humidity levels.

Figure 10 shows that the optimized schedule can maintain the room relative humidity levels in the DDCVP system served zones at the John Sealy North building. The optimized operation schedule may increase room relative humidity levels by about 3% in the SDCV systems served zone. It should be noted that the model predicted room relative humidity levels in the single duct zone are not valid when the ambient temperature is lower than 60 °F because the model does not simulate humidifier operation.

Table 2: Comparison of the Base and the Optimized HVAC Operation Schedule

John Sealy North		
Item	Base	Optimized
DDCV		
O. A. treatment coil	If $T_0 > 60$ °F then 57 °F, else Off	if $T_0 > 60$ °F then Min(57, $57 - 0.125 * (T_0 - 60)$) else off
Main cold deck	53 °F	Min(63, $63 - 0.15 * (T_0 - 50)$)
Hot deck	Min(95, $85 + 0.2 * (90 - T_0)$)	If $T_0 < 80$ then Min(85, $85 - 0.125 * (T_0 - 40)$) Else off
SDCV		
Cold deck	53	Min(55, $55 - 0.05 * (T_0 - 60)$)
Clinical Science Building		
Main cold deck	54.5 °F	Min(62, $62 - 0.125 * (T_0 - 60)$)
Pretreat cold deck	57 °F	If $T_0 > 60$ then Min(57, $56 - 0.05 * (T_0 - 60)$) Else off
Main hot deck	If $T_0 < 80$ then Min(100, $80 + 0.5 * (80 - T_0)$) Else 85	If $T_0 < 80$ then Min(85, $85 - 0.25 * (T_0 - 60)$) Else off
Basic Science Building		
Cold deck	54 °F	Min(61, $61 - 0.09 * (T_0 - 58)$)
Hot deck	If $T_0 < 80$ then Min(90, $80 - 0.25 * (T_0 - 75)$) Else 80	If $T_0 < 80$ then Min(90, $80 - 0.25 * (T_0 - 75)$) Else 80
Moody Library Building		
Cold deck	56 °F	Min(62, $60 - 0.2 * (T_0 - 85)$)
Hot deck	If $T_0 < 80$ then Min(90, $80 - 0.25 * (T_0 - 75)$) Else 80	If $T_0 < 80$ then Min(90, $80 - 0.25 * (T_0 - 80)$) Else 70
John Sealy South		
O. A. treatment coil	If $T_0 > 60$ °F then 52.8 °F, else Off	if $T_0 > 60$ °F then Min(54, $54 - 0.05 * (T_0 - 60)$) else off
Main cold deck	51.5 °F	Min(59, $59 - 0.05 * (T_0 - 50)$)
Hot deck	If $T_0 < 80$ then Min(95, $90 - 0.25 * (T_0 - 75)$) Else 85	If $T_0 < 80$ then Min(85, $85 - 0.25 * (T_0 - 60)$) Else 75

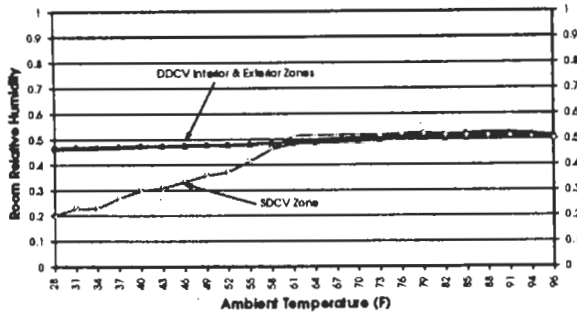


Figure 10: Comparison of the Predicted Room Relative Humidity under Base and Optimized Operation Schedules (John Sealy North Building)

Figure 11 compares the room relative humidity levels at the Clinical Science Building. It shows that the optimized operation schedule may increase the room relative humidity to 55%, which is about 3% higher than the current levels. However, this small change is hard to sense and could be acceptable to the occupants.

Figure 12 compares the predicted base and optimized room relative humidity levels at the Basic Science Building. It shows that the optimized operation schedule can increase the room relative humidity to as high as 61%. The optimized operation schedule was implemented in July 1993. The EMCS measured results show room relative humidity levels of 63%. It seems that the simplified model predicted the room relative humidity levels properly. It is interesting to note that this room relative humidity level has been very well accepted in this office and classroom building.

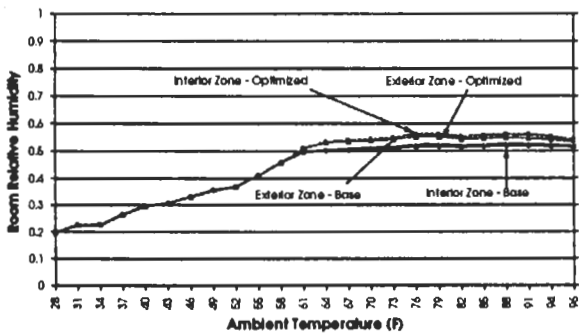


Figure 11: Comparison of the Predicted Room Relative Humidity under Base and Optimized Operation Schedules (Clinical Science Building)

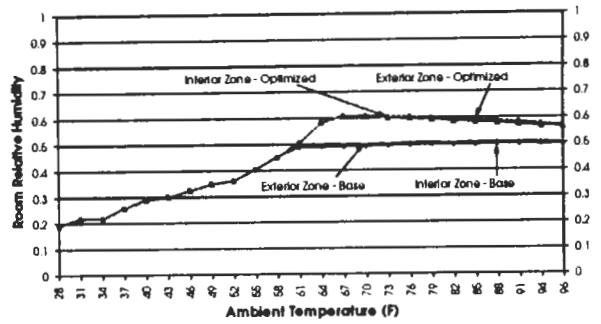


Figure 12: Comparison of the Predicted Room Relative Humidity under Base and Optimized Operation Schedules (Basic Science Building)

Figure 13 compares the room relative humidity levels at the Moody Library Building. The results show that the optimized schedule would increase the room relative humidity by about 2%. Since the Moody Library hosts rare and other book collections, the room relative humidity levels in the entire building must remain at the current levels. This requirement puts a severe limitation on any Extended O&M Measures.

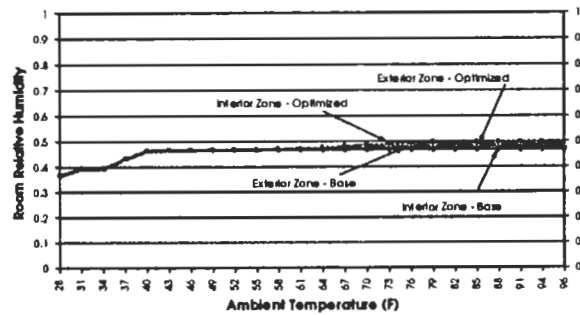


Figure 13: Comparison of the Predicted Room Relative Humidity under Base and Optimized Operation Schedules (Moody Library Building)

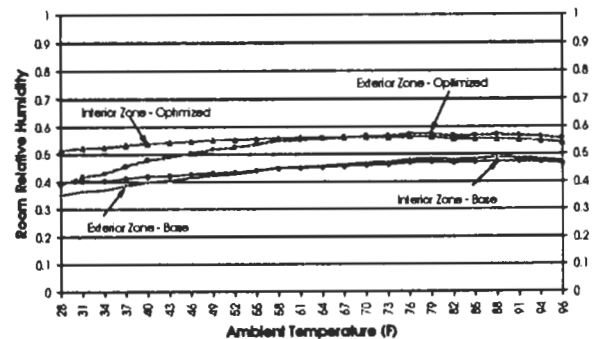


Figure 14: Comparison of the Predicted Room Relative Humidity under Base and Optimized Operation Schedules (John Sealy South Building)

Figure 14 compares the room relative humidity levels at the John Sealy South building. It shows that the optimized operation schedule can increase the room relative humidity to 55%, or 10% higher than the current levels. It is believed that this change is acceptable in this in-patient facility.

The simulation results show that the extended O&M measures would maintain the room relative humidity levels under 60% in all five buildings. Although the room relative humidity levels could increase as high as 10% in the Basic Science and the John Sealy South Building, these changes could be or already have been accepted by the occupants. It is important to point out that converting a constant air volume system to a variable air volume system may also increase room relative humidity levels by about 5% due to a decreased supply air flow rate.

Potential Energy Savings

Figures 15, 16, 17, 18, and 19 present the simulated chilled water and condensate energy consumption for each building. The horizontal axis is the ambient bin temperature. The vertical axis is the chilled water or condensate energy consumption (MMBtu/hr).

Figure 15 compares the base and the optimized energy consumption at the John Sealy North Building. It shows that the optimized schedule eliminates chilled water consumption when the ambient temperature is lower than 55 °F. The optimized operation schedule decreases chilled water consumption by about 1 MMBtu/hr and condensate energy consumption by about 0.5 MMBtu/hr. It also shows that the savings would decrease as the ambient temperature increases.

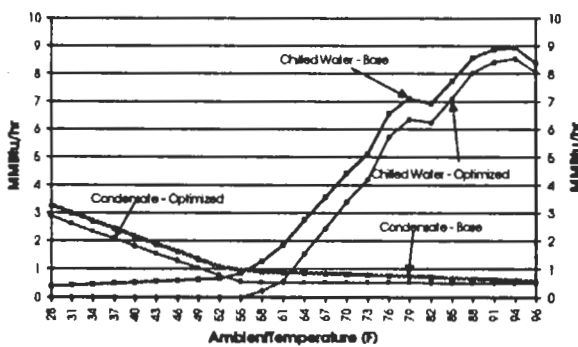


Figure 15: Comparison of Thermal Energy Consumption Under Base and Optimized Operation Schedules (John Sealy North Building)

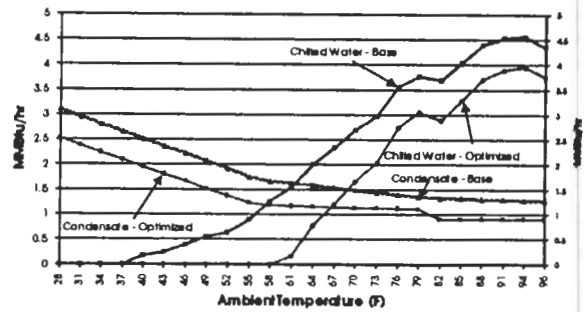


Figure 16: Comparison of the Thermal Energy Consumption Under Base and Optimized Operation Schedules (Clinical Science Building)

Figure 16 compares the base and the optimized energy consumption at the Clinical Science Building. It shows that the optimized schedule reduces chilled water consumption by approximately 0.8 MMBtu/hr and condensate consumption by 0.6 MMBtu/hr. The simultaneous reduction of chilled water and condensate consumption indicates that the major portions of the savings are due to elimination of simultaneous cooling & heating effects. The relatively larger chilled water savings indicate that the optimized schedule would remove less moisture, which may slightly increase the room relative humidity level.

Figure 17 compares the base and the optimized energy consumption at the Basic Science Building. It shows that the optimized schedule reduces chilled water consumption by approximately 1.9 MMBtu/hr and condensate consumption by 1.2 MMBtu/hr. The simultaneous reduction of chilled water and condensate consumption indicates that the major portions of the savings are due to elimination of simultaneous cooling & heating. The relatively larger chilled water savings indicate that the optimized schedule would remove less moisture, which may increase the room relative humidity levels.

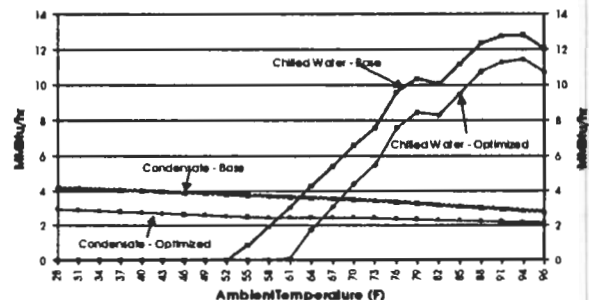


Figure 17: Comparison of the Thermal Energy Consumption Under Base and Optimized Operation Schedules (Basic Science Building)

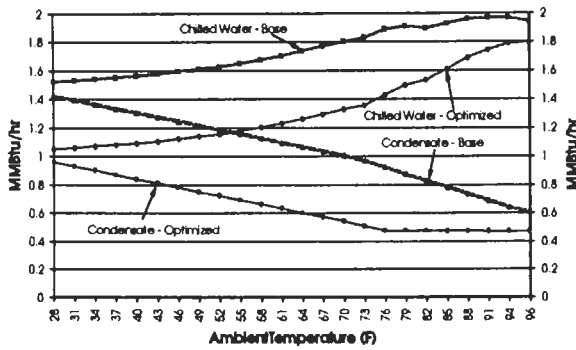


Figure 18: Comparison of the Thermal Energy Consumption Under Base and Optimized Operation Schedules (Moody Library Building)

Figure 18 compares the base and the optimized energy consumption at the Moody Library Building. It shows that the optimized schedule would reduce chilled water consumption by approximately 0.4 MMBtu/hr and by about the same amount in condensate consumption. This feature demonstrates that the savings are due to reduced reheat, and the room relative humidity levels would not be changed by the optimized operation schedule.

Figure 19 compares the base and the optimized energy consumption at the John Sealy South Building. It shows that the optimized schedule would reduce chilled water consumption by 1.95 MMBtu/hr and condensate consumption by 1.13 MMBtu/hr regardless of the ambient temperature. The simultaneous reductions of the chilled water and the condensate consumption indicate that the majority of savings, which are about 1.13 MMBtu for chilled water and 1.13 MMBtu for condensate, come from the reduction of reheat. The relatively larger chilled water savings (0.82 MMBtu/hr) indicates that the optimized

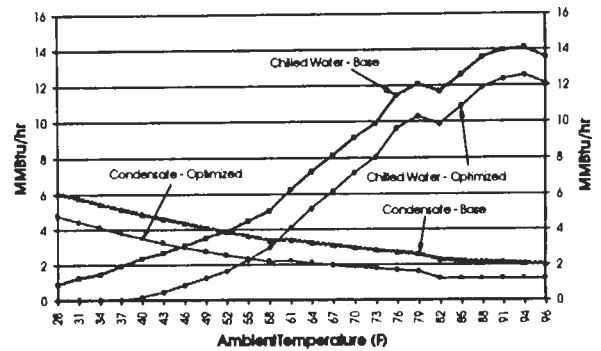


Figure 19: Comparison of the Thermal Energy Consumption Under Base and Optimized Operation Schedules (John Sealy South Building)

schedule would remove less moisture, which can increase the room relative humidity levels. It was also noted that there are sudden decreases in both the chilled water and the condensate consumption when the ambient temperature is 80 °F due to the schedule change of the hot deck.

The annual potential savings is calculated as the difference between predicted annual energy consumption under the base schedule and the predicted annual energy consumption under the optimized schedule. The annual energy consumption is calculated as the sum of the product of hourly energy consumption under each bin temperature and the number of hours for each bin. The potential cost savings were calculated using the following unit energy prices, \$7.30/MMBtu for chilled water and \$5.055/MMBtu for condensate. The annual potential savings are summarized in Table 3. The last row shows the percentage of savings to the total annual costs (chiller water, condensate, and electricity).

Table 3: Summary of Potential Costs Savings Due to Optimized Operation Schedules

Savings	JSN	CSB	BSB	MLB	JSS	Total
Chilled water (\$/yr)	\$54,300	\$55,700	\$108,700	\$27,700	\$124,500	\$370,900
Condensate (\$/yr)	\$12,700	\$18,000	\$47,300	\$18,800	\$50,100	\$146,900
Total (\$/yr)	\$67,000	\$73,700	\$156,000	\$46,500	\$174,600	\$517,800
\$/ft ² -yr	0.84	0.59	1.13	0.69	0.47	0.66
%	13%	21%	23%	24%	18%	19%

Table 4: Summary of LoanSTAR Measured Retrofit Savings on 14 Buildings

Building	Electricity Savings	Thermal Energy Savings	Total Savings	Floor Area ft ²	Recommended ECRMs	City
ZEC	7%	23%	31%	324,400	VAV*	College St.
GEA	18%	17%	35%	61,041	VAV, VSP**	Austin
WAG	8%	15%	23%	57,598	VAV	Austin
BUR	15%	26%	40%	103,440	VAV, VSP	Austin
NUR	12%	10%	22%	94,815	VAV, VSP	Austin
WIN	11%	40%	51%	109,000	VAV, VSP	Austin
WCH	4%	20%	24%	48,915	VAV, VSP	Austin
UNV	7%	9%	16%	123,450	VAV, VSP	Arlington
BUS	3%	16%	19%	149,900	VAV	Arlington
FNA	7%	14%	22%	223,000	VAV, VSP	Arlington
Average	9%	19%	28%			

* VAV: Variable Air Volume

** VSP: Variable Speed Pumping

he recommended extended O&M measures could reduce the total building energy cost of \$2.7 million dollars by 19%, or \$517,800/yr. This involves a saving of \$67,000/yr (13% of the annual building energy costs) in the John Sealy North Building, of \$73,700 (21% of the annual building energy costs) in the Clinical Science Building, of \$156,000 (23% of the annual building energy costs) in the Basic Science Building, of \$46,500 (24% of the annual building energy costs) in the Moody Library Building, and of \$174,600 (18% of the annual building energy costs) in the John Sealy South Building.

It is interesting to point out that the potential thermal energy savings due to Extended O&M Measures is comparable to the LoanSTAR measured thermal energy savings in 10 buildings on another campus where constant volume systems have been converted to variable volume systems by installing variable frequency motors and variable speed chilled water pumps. Table 4 summarizes the LoanSTAR measured savings and other necessary information in these 10 buildings. The first column is the building name code. The second column is the percentage of electricity savings. The third column is the percentage of thermal energy savings. The fourth column is the total percentage of savings. The fifth column is the floor area in ft². The sixth column is the ECRMs (energy conservation retrofit measures) implemented. VAV stands for the conversion of constant volume air handling units to variable air volume units. VSP stands for the conversion of constant speed chilled water pumps to variable speed pumps. The last column is the city where the building is located. The savings percentage is calculated as the ratio of the savings to

the whole building energy cost (electricity, chilled water, and condensate) [16].

Table 4 shows that the measured percentage of electricity savings varied from 3% to 18%, with an average of 9%. The percentage of thermal energy savings varies from 9% to 40%, with an average of 19%, which coincides with predicted savings due to extended O&M measures at five of UTMB's buildings. The total percentage of savings varies from 16% to 51%, with an average of 28%.

Measured Savings

In the Basic Science Building, the cold deck temperature for both air handling units was raised from 54 °F to 59 °F on July 2, 1993. Reduction in chilled water and condensate consumption was immediately noticed. Data from July 2, 1993 to February 28, 1994 were used to calculate the savings for 242 days by using a single linear regression model. Figure 20 shows the pre-and the post-chilled water consumption, and Figure 21 shows the pre-and the post-condensate consumption. The drop in energy consumption is very noticeable. As of February 28, 1994 the Basic Science Building has saved 6,950 MMBtu in chilled water energy and 5,950 MMBtu in condensate energy, which translates into \$50,900 and \$30,100, respectively. The total savings in 242 days comes out to be \$81,000. It seems that the measured savings are consistent with simplified model predictions.

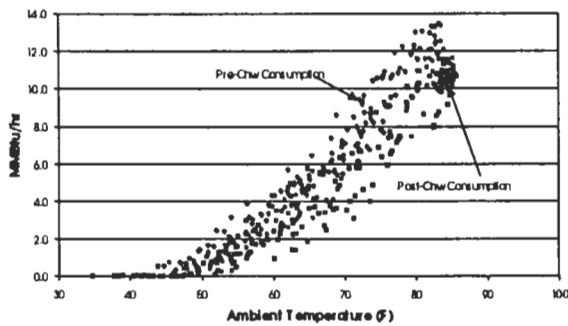


Figure 20: Pre-and Post-Chilled Water Consumption (January 1993 to February 1994) after raising Cold Deck Temperature to 59 °F on July 2, 1993.

CONCLUSIONS

Building energy consumption can be substantially reduced further than that suggested by traditional O&M measures by (i) optimal adjustment of cold deck and hot deck settings according to the ambient temperature and (ii) organizing cold deck settings where more than one deck is present. These Extended O&M Measures require an overall system optimization, but require no dollar investment.

In the five UTMB buildings studied, we found that Extended O&M Measures could reduce the total annual energy cost by \$517,800, or 19% without compromising indoor air quality or comfort. The annual potential savings translates into a savings of \$0.66/ft²-yr.

About \$81,000 savings have been measured within eight months in the Basic Science Building by increasing the cold deck temperature. The measured savings are consistent with the model predicted values.

It seems that the Extended O&M Measures are an excellent alternative to converting a constant volume system to a variable volume system, especially when retrofit funds are not available.

ACKNOWLEDGMENTS

This work was performed as part of the O&M project under the Texas LoanSTAR program. We would like to thank Susan Swanson for her editing assistance.

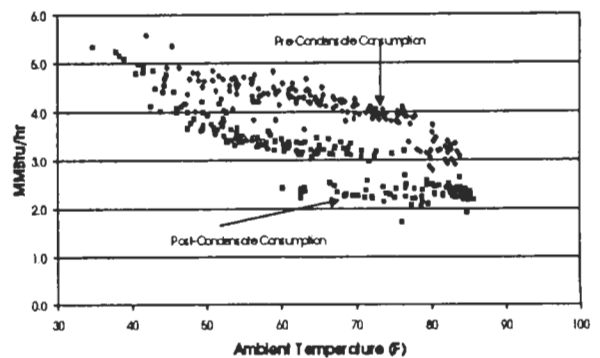


Figure 21: Pre-and Post-Condensate Consumption (January 1993 to February 1994) after raising Cold Deck Temperature to 59 °F on July 2, 1993.

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