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A COMPUTATIONAL PARAMETRIC STUDY OF ELEMENTARY SCHOOL ENERGY USE

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ABSTRACT

An energy analysis computer program was used to study elementary school energy use as a function of school size and geographic location. Three different sizes of elementary school were simulated in six different cities with varying climates. The cities included are Atlanta, Chicago, Detroit, Kansas City, Phoenix, and San Francisco. Four different types of heating and cooling systems were simulated: two heating-only systems and two combination heating-cooling systems. The heating-only systems included a steam radiator system and a unit ventilator system. The combination heating-cooling systems modeled were a constant-volume multizone system and a constant-volume reheat system.

INTRODUCTION

In the design of new buildings or the retrofitting of existing buildings, energy use should be included as a design parameter. The choice of an appropriate HVAC system will have a large impact upon the building's energy use as well as upon the initial capital cost. The optimum HVAC system for a particular building may depend upon the building's size and geographic location. The optimization of a building's HVAC system could be achieved via computer simulation. Several simulation studies of building energy use have been published in the literature.

Haines (1984) discussed the numerous computer programs available for estimating a building's energy consumption. He describes the usefulness of these programs as a design tool that facilitates comparison of various combinations of building construction, HVAC systems, and control strategies. In this way, energy costs can be determined so that the most economical system and control strategy can be selected.

Gujral (1984) studied eight different buildings in various climatic regions. Computer simulations of each building aided in the selection of an appropriate design for each climate, resulting in designs that were effective from both energy and economic standpoints.

Butera (1985) discussed the rehabilitation of 29 historic school buildings in Palermo, Italy. By using simulation models, several options were examined, ranging from active solar systems to properly designed heating systems. The study showed that, because of the characteristics of the buildings, their patterns of occupation, and the mild climate, the most cost-effective option was a properly controlled heating system.

Partridge (1988) discussed the selection of a new HVAC system for a large high school in Jackson, Michigan. He reports that, based upon an HVAC system analysis, a closed-loop water-source heat pump system was recommended to replace the existing rooftop multizone units.

Johnson (1989) simulated the energy use of a typical large office building. The building's envelope construction was studied, along with HVAC operating strategies and secondary and primary HVAC equipment. The effects of different climatic conditions were investigated by simulating the building's energy performance at four different geographic locations.

In this study, an energy analysis computer program was used to study elementary school energy use as a function of school size and geographic location. Three different sizes of elementary school were simulated in six different cities with varying climates. The cities included are Atlanta, Chicago, Detroit, Kansas City, Phoenix, and San Francisco. Four different types of heating and cooling systems were simulated: two heating-only systems and two combination heating-cooling systems. The heating-only systems include a steam radiator system and a unit ventilator system. The combination heating-cooling systems modeled were a constant-volume multizone system and a constant-volume reheat system.

DETERMINATION OF MODEL SCHOOL PARAMETERS

For this study, an "average" elementary school was determined by analyzing parameters of existing elementary school buildings. To obtain this "average" elementary school, data on 16 elementary schools in the Kansas City, Missouri, school district were obtained from an existing data base and averaged as discussed below. These average building parameters were then entered into an energy analysis computer program and energy use was determined for various HVAC systems and geographic locations.

Building Envelope Dimensions

The building envelope is composed of the floor area, wall area, glass area, and roof area. Analysis of the data base showed that the floor area of the 16 schools fell logically into three increments. Five schools were grouped around 60,000 ft^2, six schools were grouped around 45,000 ft^2, and five schools were grouped around 30,000 ft^2. Thus, it was determined to use three different models for a large, a medium, and a small elementary school. The average floor area for each model school is listed below:

Model Size	Floor Area (ft^2)
Large School	62,200
Medium School	46,700
Small School	31,293

The amount of glass area and the amount of gross wall area, which includes the glass area, door area, and basic

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wall area, were then determined for each size model. The values of these parameters are shown below:

Model Size	Gross Wall Area (ft^2)	Glass Area (ft^2)
Large School	31,845	7352
Medium School	25,880	6856
Small School	21,042	3177

These wall area parameters were then evenly divided into north, south, east, and west faces.

Finally, the average roof area for each size model was determined as follows:

Model Size	Roof Area (ft^2)
Large School	26,656
Medium School	22,616
Small School	20,430

Building Envelope Thermal Conductances

In addition to the dimensions of each component of the building envelope, it is also necessary to determine the thermal conductance in terms of a coefficient of thermal transmission, or U-value, for each of the following components: glass, roof, and walls. The 16 elementary schools analyzed contain single-pane windows, for which a U-value of 1.10 Btu/(h·ft^2·°F) was used in the current study (ASHRAE 1979). The U-value for the roof was computed using a roof type similar to that found on the 16 elementary schools analyzed. This typical roof is a built-up roof on a steel deck with 2 in. of rigid insulation. The U-value used for this type of roof is 0.14 Btu/(h·ft^2·°F) (ASHRAE 1979).

In the current study, the U-value used for the walls was determined as follows. First, the glass area was subtracted from the gross wall area to yield door plus basic wall area. Then, an overall wall conductance was found by proportioning the door and basic wall areas along with their corresponding U-values.

From existing school data, the number of doors for each of the three models was determined: 24 for the large school, 16 for the medium school, and 12 for the small school. These doors were found to be 3 ft by 7 ft hollow metal doors with a U-value of 1.15 Btu/(h·ft^2·°F) (ASHRAE 1979). From these data, the total door area can be found and subtracted, leaving the basic wall area.

The basic wall found in the 16 elementary schools analyzed consisted of an 8 in. masonry block interior wall and a 4 in. brick exterior wall with a 0.5 in. air gap between the two. The U-value for this type of basic wall is 0.22 Btu/(h·ft^2·°F) (ASHRAE 1979).

For example, the calculation of the overall wall U-value for the large school model is shown below:

Gross Wall Area:		31,845 ft^2
Glass Area:		−7,352
Wall and Door Area:		24,493 ft^2
Door Area (24 doors @ 3 ft by 7 ft):		−504
Wall Area:		23,989 ft^2
Wall Area x Wall U-value = 23,989 × 0.22 =		5,277.6 Btu/(h·°F)
Door Area × Door U-value = 504 × 1.15		+579.6
	Total:	5,857.2 Btu/(h.°F)
Overall Wall U-value (total/overall wall area)	= =	5,857.2 / 24,493 0.239 Btu/(h·ft^2·°F)

This same procedure was followed to determine U-values for the wall on the medium and small school models. The results of these calculations yield overall wall U-values of 0.236 Btu/(h·ft^2·°F) for the medium school and 0.233 Btu/(h·ft^2·°F) for the small school.

Additional Building Parameters

The shading coefficients for the buildings were calculated assuming all the windows were equipped with venetian blinds. The result of this calculation was a shading coefficient of 0.8 for the northern exposure, 0.6 for both the southern and eastern exposures, and 0.7 for the western exposure.

The interior temperatures, lighting schedule, and equipment schedule for the modeled school buildings were based on the operation of the 16 elementary schools analyzed. The interior temperature of all three model school buildings was determined to be:

Winter occupied temperature: 72°F
Summer occupied temperature: 76°F
Winter unoccupied setback temperature: 65°F

The lighting schedule for the three modeled schools was determined to be: lights turned on at 7:00 a.m. and turned off at 5:00 p.m., five days a week. The HVAC equipment for the three modeled schools was assumed to operate from 6:00 a.m. until 5:00 p.m., five days a week. Thus, all three model schools were assumed to be identical in terms of lighting and operating schedules and temperature control operation. The energy analysis program partitions each model into interior and exterior zones dependent upon floor area and perimeter wall length. Thus, the zoning of each size model was similar but proportional to the model's building size.

For each model school, all additional parameters required for the energy analysis computer program were determined by averaging the corresponding data values associated with the schools in that size category. These additional parameters include infiltration rates, ventilation, lighting and equipment loads, and occupancy. The values of these parameters for the three different model schools are given in the following table:

	Model Size		
Parameter	Large	Medium	Small
Infiltration Rate (cfm)	3,240	2,879	1,900
Ventilation Rate (cfm)	11,448	10,473	6,105
Daytime Lighting Load (kWh)	64	42	36
Evening Lighting Load (kWh)	6	4	4
Equipment Load: Sensible Heat (Millions Btu/h)	27	26	20
Equipment Load: Latent Heat (Millions Btu/h)	5	4	3
Occupancy (persons)	373	368	213

CITY SPECIFICS

The six cities used in the study were chosen because of their different geographic location and weather patterns. The energy analysis program utilizes a geographical data base of weather history, which contains daily weather parameters such as percent cloud coverage, relative humidity, high and low peak temperatures, and average temperatures for various geographic locations. The weather data are a major factor used by the energy analysis program to determine energy use for a given geographic location. As a means of comparison, the average winter and summer temperatures of the six cities are listed below:

City	Average Winter Temperature (°F)	Average Summer Temperature (°F)
Atlanta	42	78
Chicago	23	72
Detroit	26	73
Kansas City	27	78
Phoenix	51	91
San Francisco	51	59

HVAC SYSTEMS

In this study, four typical elementary school HVAC systems were analyzed in each of three model schools at each of six different locations. Thus, 72 different cases were modeled. The heating-only systems analyzed were perimeter radiators and unit ventilators. The combination heating-cooling systems analyzed were constant-volume multizone and constant-volume reheat.

Perimeter Radiators

In the perimeter radiator system, steam is generated in a boiler and then circulated throughout the building to individual room radiators. Energy is released through the radiator as the steam condenses. Typically, steam radiators are ineffective when a specific room temperature is desired. However, a throttling valve can be installed to make the system more effective.

Unit Ventilators

Unit ventilators are used in applications where the density of occupancy requires controlled ventilation, as in schools, meeting rooms, and offices. A typical unit ventilator is composed of a heating element, fan, dampers, filters, and diffusers, encased in a housing.

The typical unit allows heating and ventilating effects to vary while the fans are operating continuously. The discharge air temperature from the unit is varied to meet the temperature requirements of the area that the unit serves. Heating is achieved by blowing the air over a heating element. If the heat generated within the room by people, lights, solar gain, and miscellaneous equipment exceeds the heat losses, the temperature of the air delivered by the unit should be below room temperature. This is accomplished by switching off the heating element and bringing in outside air, provided that the outdoor temperature is below that of the room. The term used for this type of cooling is "ventilative cooling" or "economizer control."

Constant-Volume Multizone System

The constant-volume multizone system serves a number of different zones from a single, central air-handling unit. The multizone unit consists of a heating coil serving the hot deck, or hot air chamber, and a cooling coil serving the cold deck, or cold air chamber. Different zone requirements are met by mixing cold and warm air through zone dampers at the central air handler according to the thermostat setting for that zone. The mixed air is then distributed throughout the building by a system of single-zone ducts. The hot deck temperature must be sufficiently high to meet the heating demands of the coldest zone, and the cold deck temperature must be sufficiently low to meet the cooling demands of the hottest zone. All other zones are supplied with a mixture of hot and cold air. This wastes energy because, in effect, the supply air is initially heated or cooled beyond what may be necessary for a particular zone and then subsequently cooled or heated in the mixing process to arrive at the temperature required by that zone. This system does, however, allow for a single heating coil and a single cooling coil to serve a variety of different zones.

Constant-Volume Reheat System

The constant-volume reheat system was developed to give closer control of relative humidity and to overcome the zoning deficiencies of single-duct systems. A single-duct system consists of a single central duct with a number of branch ducts, each containing its own heating coil. Each branch duct then serves several zones, which may result in inaccurate temperature zoning.

Typically in the reheat system, outside air and return air are mixed together and subsequently heated or cooled to 55°F. This air is then sent by the central system through ducts to terminal units in each zone, where it is then reheated. Thus, reheat is controlled by individual thermostats located in each zone.

All supply air must be cooled to a temperature low enough to meet the most critical cooling load but must be reheated for zones of lesser cooling loads. Under light cooling loads, most of the reheat coils will be operating because the supply air will be too cold for direct use in most parts of the building. This results in unnecessary energy use in the cooling season, because only during peak cooling loads do the majority of the reheat coils become inactive. Thus, although this system supplies excellent zone control, it uses much more energy than other cooling systems.

RESULTS

Verification of Model Parameters

Verification of the model building parameters was achieved by comparing energy use of the 16 Kansas City elementary schools with that of the simulated buildings using Kansas City weather data. Of the 16 elementary schools analyzed, 3 contained a perimeter radiator system, 12 contained a unit ventilator system, and 1 contained a constant-volume multizone unit. All of the schools were gas heated.

Using the method of Sher (1985), building energy use was compared in terms of Btu/ft^2·yr. The computer program calculates simulated energy use in terms of kilowatt hours of electricity (kWh) and thousands of cubic feet of natural gas (MCF). These units were then converted to British thermal units (Btu):

1 kWh = 3,413 Btu
1 MCF = 1,000,000 Btu

The average energy use for the 16 Kansas City elementary schools is:

School Size	Actual Energy Use (Btu/ft^2·yr)
Large	81,982
Medium	101,383
Small	105,296

The calculated energy use for the model schools is:

	Simulated Energy Use in Kansas City (Btu/ft^2·yr)			
Model Size	Perimeter Radiators	Unit Ventilators	Constant-Volume Multizone	Constant-Volume Reheat
Large	83,832	83,326	89,168	149,757
Medium	95,738	95,383	103,846	178,118
Small	104,009	104,241	105,724	169,607

Comparison of these simulation results to actual energy use shows that except for the constant-volume reheat system, the energy use calculated by the computer program using Kansas City weather data compares very well with the actual energy use. As described earlier and verified in the results above, the constant-volume reheat system uses excessive amounts of energy. Therefore, since none of the 16 Kansas City schools contained reheat systems, it can be deduced that the modeled building parameters provide accurate representation of actual elementary schools.

Finally, it is interesting to note that energy use per square foot increases monotonically as the model size decreases for all HVAC systems except the constant-volume reheat system. This phenomenon is discussed at the end of the next section.

Analysis of the Results

The model parameters were then used as input to the energy analysis computer program along with the weather data from six different cities. The results of these simulations are given in both Tables 1 through 3 and Figures 1 through 3 for the

TABLE 1
Total Energy Use by a Large School (62,200 ft²)

	STEAM RADIATORS			UNIT VENTILATORS			CONSTANT-VOLUME MULTIZONE			CONSTANT-VOLUME REHEAT		
Location	kWh/ ft²	MCF/ ft²	Btu/ ft²	kWh/ ft²	MCF/ ft²	Btu/ ft²	kWh/ ft²	MCF/ ft²	Btu/ ft²	kWh/ ft²	MCF/ ft²	Btu/ ft²
Atlanta	3.72	0.043	56113	4.86	0.037	53806	11.36	0.028	66961	13.73	0.072	118941
Chicago	3.74	0.087	100086	5.60	0.079	97737	10.63	0.063	99339	13.18	0.109	154315
Detroit	3.74	0.081	93660	5.37	0.074	91979	10.64	0.057	93189	13.33	0.104	149376
Kansas City	3.73	0.071	83832	5.31	0.065	83326	11.89	0.049	89168	14.62	0.100	149757
Phoenix	3.70	0.024	36679	4.47	0.022	37080	14.35	0.018	66808	16.26	0.060	115150
San Francisco	3.78	0.049	61363	4.48	0.035	50148	10.14	0.024	58611	11.14	0.045	83295

TABLE 2
Total Energy Use by a Medium School (46,700 ft²)

	STEAM RADIATORS			UNIT VENTILATORS			CONSTANT-VOLUME MULTIZONE			CONSTANT-VOLUME REHEAT		
Location	kWh/ ft²	MCF/ ft²	Btu/ ft²	kWh/ ft²	MCF/ ft²	Btu/ ft²	kWh/ ft²	MCF/ ft²	Btu/ ft²	kWh/ ft²	MCF/ ft²	Btu/ ft²
Atlanta	3.41	0.052	63594	4.80	0.045	60935	12.93	0.033	77404	16.01	0.087	141742
Chicago	3.44	0.103	115144	5.59	0.093	111563	12.10	0.073	114387	15.43	0.131	183651
Detroit	3.44	0.095	106545	5.40	0.087	105587	12.25	0.067	108719	15.59	0.124	177340
Kansas City	3.43	0.084	95738	5.32	0.077	95383	13.60	0.057	103846	17.02	0.120	178118
Phoenix	3.38	0.029	40300	4.35	0.026	40693	16.42	0.021	76846	18.84	0.073	136950
San Francisco	3.48	0.059	70491	4.36	0.043	57984	11.51	0.028	67684	13.11	0.058	103038

TABLE 3
Total Energy Use by a Small School (31,293 ft²)

	STEAM RADIATORS			UNIT VENTILATORS			CONSTANT-VOLUME MULTIZONE			CONSTANT-VOLUME REHEAT		
Location	kWh/ ft²	MCF/ ft²	Btu/ ft²	kWh/ ft²	MCF/ ft²	Btu/ ft²	kWh/ ft²	MCF/ ft²	Btu/ ft²	kWh/ ft²	MCF/ ft²	Btu/ ft²
Atlanta	4.55	0.054	69920	5.95	0.048	67981	12.61	0.035	78477	15.16	0.083	134372
Chicago	4.59	0.108	123422	6.86	0.098	120928	11.65	0.078	117589	14.35	0.126	175093
Detroit	4.59	0.100	115165	6.65	0.092	114384	11.74	0.071	111314	14.45	0.120	168753
Kansas City	4.57	0.088	104009	6.57	0.082	104241	13.04	0.061	105724	16.07	0.115	169607
Phoenix	4.51	0.030	45744	5.44	0.028	46724	15.80	0.022	75824	17.95	0.068	128800
San Francisco	4.66	0.061	76941	5.62	0.042	61261	11.40	0.028	66809	12.17	0.046	87329

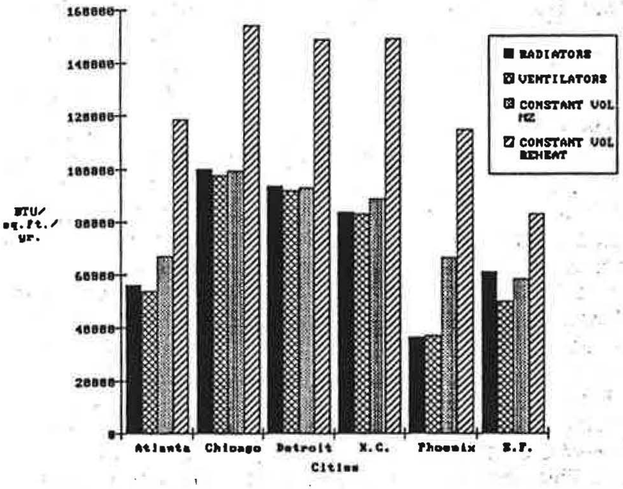

Figure 1 *Total energy use by a large school (62,200 ft²)*

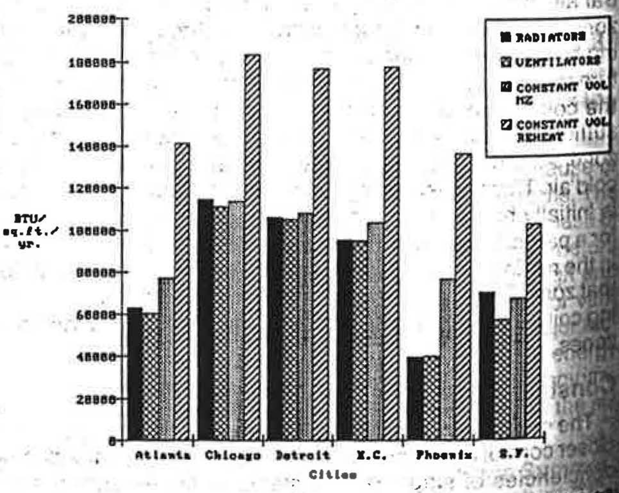

Figure 2 *Total energy use by a medium school (46,700 ft²)*

large, medium, and small model schools. These tables and figures give the total energy use, which includes energy used for lighting, miscellaneous equipment, circulating fans, heating, and cooling. Tables 4 through 6 present energy use for just the heating and cooling of the schools.

As shown by the total energy use given in Figures 1 through 3, for cities with cold winters (Chicago, Detroit, and Kansas City), nearly equal amounts of energy are used by the perimeter radiators, unit ventilators, and the constant-volume multizone system. However, when examining Tables 4

TABLE 4
Heating and Cooling Energy Use by a Large School (62,200 ft^2)

Location	STEAM RADIATORS		UNIT VENTILATORS		CONSTANT-VOLUME MULTIZONE		CONSTANT-VOLUME REHEAT	
	Cooling Btu/ft^2	Heating Btu/ft^2	Cooling Btu/ft^2	Heating Btu/ft^2	Cooling Btu/ft^2	Heating Btu/ft^2	Cooling Btu/ft^2	Heating Btu/ft^2
Atlanta	0	38197	0	32024	13690	22937	20944	67087
Chicago	0	82170	0	73484	10041	57905	17981	104338
Detroit	0	75744	0	68510	10014	51694	18217	98871
Kansas City	0	65916	0	60016	12670	43404	21224	94852
Phoenix	0	18763	0	16545	20703	12523	26722	54659
San Francisco	0	43446	0	29827	11062	18889	14107	40270

TABLE 5
Heating and Cooling Energy Use by a Medium School (46,700 ft^2)

Location	STEAM RADIATORS		UNIT VENTILATORS		CONSTANT-VOLUME MULTIZONE		CONSTANT-VOLUME REHEAT	
	Cooling Btu/ft^2	Heating Btu/ft^2	Cooling Btu/ft^2	Heating Btu/ft^2	Cooling Btu/ft^2	Heating Btu/ft^2	Cooling Btu/ft^2	Heating Btu/ft^2
Atlanta	0	45522	0	38135	16480	26802	25645	80938
Chicago	0	97065	0	86139	12095	66738	22232	124835
Detroit	0	88465	0	80842	12271	60544	22356	117983
Kansas City	0	77665	0	70835	15304	51022	25901	113871
Phoenix	0	22228	0	19338	24651	14237	32215	66484
San Francisco	0	52419	0	36885	12731	22140	17664	52158

TABLE 6
Heating and Cooling Energy Use by a Small School (31,293 ft^2)

Location	STEAM RADIATORS		UNIT VENTILATORS		CONSTANT-VOLUME MULTIZONE		CONSTANT-VOLUME REHEAT	
	Cooling Btu/ft^2	Heating Btu/ft^2	Cooling Btu/ft^2	Heating Btu/ft^2	Cooling Btu/ft^2	Heating Btu/ft^2	Cooling Btu/ft^2	Heating Btu/ft^2
Atlanta	0	47073	0	40293	14222	28047	21813	75729
Chicago	0	100575	0	90334	9925	70617	18040	119221
Detroit	0	92318	0	84471	10012	64014	18214	112543
Kansas City	0	81162	0	74526	12881	53942	21835	107845
Phoenix	0	22897	0	20372	21813	14379	28237	60614
San Francisco	0	54094	0	35121	12052	20857	14429	38884

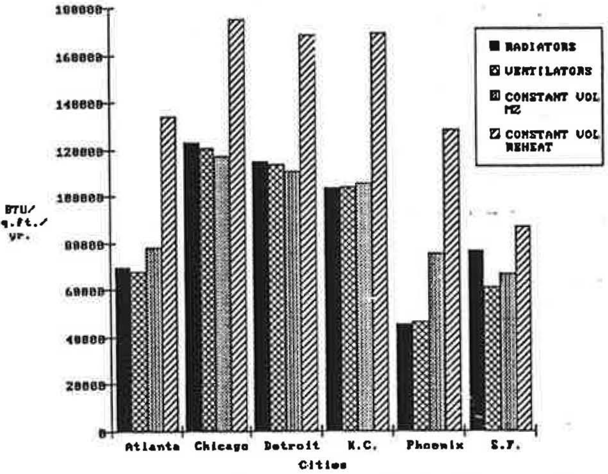

Figure 3 *Total energy use by a small school (31,293 ft^2)*

through 6, it appears that the unit ventilators and the constant-volume multizone system do not require as much energy to heat as does the perimeter radiator system. This discrepancy occurs because Tables 4 through 6 omit the energy required by the circulation fans, which are part of the unit ventilators and the constant-volume multizone system but are not required for perimeter radiators. In addition to circulating the air, these fans also provide some of the energy used to heat the building when unit ventilators or the constant-volume multizone system is used. Since the constant-volume multizone system provides heating and cooling along with better temperature control without using much more energy, this is the best system for these cities.

Figures 1 through 3 indicate that the energy required by the two heating-only systems, perimeter radiators and unit ventilators, is nearly the same in the two warm weather cities (Atlanta and Phoenix). For these cities, the constant-volume multizone system uses considerably more energy due to the large amount of cooling needed. Tables 4 through 6 show that the energy use for heating decreases in these cities, but, because of the great demand for cooling, the total energy use increases.

Figures 1 through 3 show that in San Francisco, energy use for the perimeter radiators, unit ventilators, and constant-volume multizone system displays the same trends as shown in the cold weather cities, except at lower levels of energy use, because the winters are not as cold.

As expected, for all the cities, the energy used by the constant-volume reheat system is much greater than that used by the other systems. As discussed earlier, this is due to the unnecessary energy use required to cool the supply air and then reheat it during the summer. However, by examining Figures 1 through 3, it can be seen that the energy use for this system does not increase as much in San Francisco as it does in the other cities. This can be explained because during the summer the average temperature in San Francisco is 59°F, which is only four degrees warmer than the temperature to which the outside air is typically cooled in the reheat system.

It can also be seen in Tables 4 through 6 that more energy is required to heat using the constant-volume reheat system as compared to other systems. This is because all return air is cooled to 55°F and then reheated. To avoid this, an air damper may be installed to draw in more outside air to mix with the return air to obtain a temperature of 55°F without cooling. In order to keep the amount of outside air leakage for the reheat system the same as that for the multizone system, no dampers were simulated in this study. By installing dampers, the reheat system's energy use during the winter would decrease.

By examining the trend of energy use as a function of building size, it can be seen that energy use per square foot increases monotonically as building size decreases for all HVAC systems except the constant-volume reheat system. For the other systems, this monotonic behavior can be explained by the fact that the ratio of exposed building (walls plus roof) divided by floor area increases as building size decreases because small buildings tend to be single story while large buildings usually have multiple stories. This larger ratio of exposed building to floor area results in a greater heat transfer area per square foot of floor space for a small building than for a large building.

However, in the case of the constant-volume reheat system, the trend of energy use per square foot is not monotonic but rather exhibits a maximum for the medium-size school and decreases as the school size is both increased and decreased. To explain this behavior, the internal heat load of the model must be taken into account. As noted earlier, both the equipment load and the occupancy of the medium-size school are nearly equal to that of the large school and considerably greater than that of the small school. Thus, on a per-square-foot basis, these two factors add a considerable internal heat load to the medium-size school. However, these two components are much less significant per square foot in both the small school and the large school. Due to the medium-size school's disproportionately large internal heat load, much more energy is expended to cool the return air to 55°F as required by the constant-volume reheat system. Thus, the constant-volume reheat system is particularly inefficient in the medium-size model school.

CONCLUSION

Analysis of the results shows that the reheat system is best suited to a climate such as San Francisco's, where the summer is mild. This system provides good zone control but is relatively expensive to operate in the cooling mode. Even in the San Francisco area, this system uses from 31% to 42% more energy than does the constant-volume multizone system.

In both colder and warmer climates, the constant-volume multizone system is better suited. In the warmer climates, it provides more efficient cooling than does the reheat system. In colder climates, it provides better zone control than radiators. It also provides cooling, which neither radiators nor unit ventilators provide, and is nearly as energy-efficient in the heating mode as the heating-only systems.

The results show that energy use per square foot increases as building size decreases, provided that the total internal heat load varies proportionately to building size.

Geographically, the results show the same trends regardless of building size. Energy use is significantly lower in the mild climate of San Francisco. It can be as much as 17% higher in Atlanta and 76% higher in Chicago. Total annual energy use in Atlanta is comparable to that of Phoenix. However, Atlanta uses 63% of its energy to heat and 37% to cool while Phoenix is nearly opposite, with 38% allocated to heating and 62% to cooling. Total annual energy use in Detroit is 5% higher than in Kansas City, while Chicago's use is 7% above that of Detroit. In Kansas City, 27% more energy is expended on cooling than in Chicago or Detroit. However, Detroit spends 19% more on heating than does Kansas City, while Chicago spends 12% more than Detroit.

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