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DESIGN GUIDELINES FOR USE OF AN ECONOMIZER WITH HEAT RECOVERY

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ABSTRACT

Energy conservation with building HVAC systems continues to be of concern to ASHRAE. This paper reports the results of ASHRAE RP-471, "Development of Design Guidelines for the Proper Use of an Economizer Cycle with Heat Recovery Systems." A method is presented that will enable the design engineer to properly select among an economizer system, a heat reclaim system, or a combination of both, based either on energy or cost consideration.

BACKGROUND

The concern for energy conservation has led to the development and use of heat recovery systems that recover the building internal heat before it is discarded in the exhaust air. On the other hand, economizer cycles have been widely used for many years in all-air and air-water types of HVAC systems. They are widely accepted as a means to reduce operating time for chilling equipment when cool outside air is available to be mixed with building return air in order to provide cooler air to the cooling/dehumidifying coil. This is done with a variable position outdoor air damper controlled by a temperature or enthalpy sensor ahead of the cooling coil. This damper is usually used in conjunction with a fixed minimum outdoor air damper so that the required ventilation air is always available for the building.

It has been suggested that heat reclaim chillers or heat pumps should not be used in conjunction with an air handling system that incorporates the variable position damper economizer control, because the economizer operation would result in higher annual operating costs than if only minimum outdoor ventilation air is used. Others suggest that outside air can be used economically in a heat recovery project if properly controlled to maintain an overall building heat balance.

In heat recovery systems, the term "balanced heat recovery" pertains to the functions of reclaiming internal heat, raising the temperature to a usable level if required, and redistributing this energy to the required locations in the proper amounts. It is implicit in this definition that heat is to be generated only if there is an insufficient amount of reclaimed heat to serve those areas needing heat. A truly or totally balanced system is one in which all components work together throughout the year to use all internal heat before adding more heat. When internal heat exceeds building requirements, the excess heat is stored and/or automatically rejected. If the economizer (free cooling) effect of the outdoor temperature is simply controlled from a local room or duct thermostat, outdoor air in excess of ventilating requirements may be automatically supplied and result in exhausting valuable internal heat. This, in turn, may cause external heat to be introduced elsewhere to satisfy another thermostat, violating the heat balance concept.

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The questions addressed in this study, ASHRAE RP-471, were: how does one determine whether to use the economizer cycle or a heat recovery chiller or both; how does one best control the total system; how complicated is the design process; what parameters are of major influence?

The study focused on HVAC heat recovery systems used in commercial, institutional, and industrial (CII) buildings and the applicability of the economizer cycle in such systems.

REVIEW OF PREVIOUS EFFORTS

A literature search was performed to locate appropriate available data on commercial heat recovery systems and economizers. The data bases searched contain over 4 million references. From this search, over 200 abstracts were printed out that pertained to combinations of heat reclaim, heat recovery, air economizers, thermal storage, and energy conservation. In addition, ASHRAE publications from the last 30 years were manually searched as was the Applied Science and Technology Index. From all of these searches, over 100 complete references were obtained.

However, only a few references directly address the questions at hand, namely Sun (1979), McFarlan (1955, 1965, 1967, 1969, 1972, 1983, 1985), and Henderson (1975).

The measured data found in the literature, such as Tishman (1983) and Hill (1981), are neither sufficiently complete nor reliable enough to be suitable for the establishment of guidelines. As determined from the references, neither clear-cut nor decisive guidelines for the use of an outside air economizer with internal heat recovery systems are available, although many good and valid recommendations are available on the factors that need be considered.

McFarlan (1969) provides an excellent summary of the problem with his statements:

> Frequently, a project will proceed without heat recovery because the engineer does not realize the penalties inflicted. For instance, large projects with interior spaces almost universally use the so-called economy or economizer cycle, which varies the quantity of outdoor air above the normal ventilation rate during the period of the year when the outdoor air temperature is below about 50 F. Many designers are not aware that this system can impose, to a greater or lesser extent, an artificial heat load which in turn may actually increase the refrigeration load beyond that which it would have been with the proper form of heat recovery. At the same time, the heating load may be substantially increased...
>
> It is here that a word of caution is most necessary. If anyone advocates that heat recovery, per se, in any form will solve the problems, then results will most emphatically prove this is not so. The end result may be worse than without heat recovery. It is only the proper form of heat recovery, used correctly, that can solve the problem...
>
> It can be seen that heat recovery can and must be analyzed for each project. With proper analysis, its relative value can be predicted and the cost of operation calculated.

Sun (1979) provides additional insights for "the complex evaluations required to determine whether one or the other, or a combination, will be most cost effective in a given situation." His statements include:

> Both refrigeration cycle heat recovery and the economizer cycle are designed to conserve energy. The concepts of these two energy conservation schemes are basically not compatible, however...
>
> In reality, however, refrigeration cycle heat recovery and the economizer cycle can be used harmoniously in a building air conditioning system to obtain maximum operating economy...

There are no simple rules for deciding what energy conserving scheme should be used in a given building...

As illustrated in this article, the evaluation process can be so complex that computer programs may be needed to help speed up what otherwise would be an almost impossible task.

Contact with consulting engineers, designers and manufacturers was carried out through letters, telephone calls, and visits. Responses have been received from about 50 of the letters/calls. Listed below are sample comments taken from a few of the responses.

We have been involved in numerous jobs where heat recovery centrifugal chillers and outdoor air economizers were employed. In many cases, the systems were not properly designed, however, all the systems designed by _____, work extremely well in that the air economizer cycle, heat recovery and condenser controls were coordinated in such a manner as to provide the heat requirements for the building with the greatest amount of outside air usage, which resulted in the lowest energy cost for the buildings.

Generally, most systems in this area (Atlanta) use a water side or cooling tower economizer rather than air side economizer. These economizers either use cooling tower directly in the chilled water system in those months when its temperature will provide building cooling or use the same water through a heat exchanger, which of course decreases the amount of hours of use because of the decrease in temperature availability. One objection I have to air side economizers is that they generally include very large outside air dampers and very large relief or exhaust dampers... One design recommendation should be the use of low leakage motor operated dampers and possibly dampers designed so that the sealing surfaces can be adjusted or replaced.

What we surmised was that it depends on the internal heat load. We have found that central chilled water systems have their own unique characteristics, and lend themselves to direct interchange between air handling units serving areas of respectively high and low internal heat gains. In every case we have considered, the complexity of the controls has been a factor.

Beginning designers of larger heat recovery systems for comfort air conditioning often perceive that the use of an outside air economizer cycle is counter-productive. After all, the idea in heat recovery is to use internal heat gains rather than lose them to ventilation loads. This is normally quite true at the heating design condition. But, systems often encounter load combinations where surplus internal heat gains more than offset the need for heat recovery.

Theoretically, the problem and solution look simple. In practice, the solutions are many, as the losses are minimized rather than eliminated. Likewise, as costs are considered, there are many technically possible solutions that become impractical.

METHODOLOGY

Fundamental to answering the questions posed, there is no doubt that an energy balance must be achieved. The first law of thermodynamics would not have it any other way -- but for what period of time?

-- Instantaneous Balance (hourly) - simplest to control - no storage
-- Daily Balance - most common storage system
-- Weekly, Monthly, Seasonal
-- Annual - theoretically, the best.

Another necessary requirement for the most efficient design with heat reclaim is to use the reclaimed heat at the lowest possible temperature level, allowing for high COPs (low HP/ton).

There is also no question, if there is excess heat, that an air economizer or its equivalent, such as the thermo cycle, the strainer cycle, or fluid coolers in place of cooling towers, must be included for an energy-efficient system.

The most reliable means of developing general guidelines for the use of air economizers with heat recovery is through the use of building load programs capable of taking into account the load reduction using outside air for cooling. The load program used in the following analysis was a modified version of the AXCESS Energy Analysis Computer Program, which performs an hour-by-hour analysis of buildings using actual hourly weather data. The analysis evaluates the detrimental effects of the economizer cycle as well as the positive effects. Within the limitations of the available data and the developed correlations of effectiveness and design parameters, recommended design guidelines for the proper use of an economizer cycle with heat recovery systems have been developed. These guidelines address the applicability of the economizer cycle and the probable design parameters governing the degree of effectiveness (energy use and costs) of the combined economizer cycle and heat reclaim systems. The following methodology was developed to evaluate the combination of an economizer cycle with a heat reclaim system.

An hourly "loads" program must first be used to determine hourly heating loads (QH), hourly cooling loads (QC) without an economizer, and hourly cooling loads (QW) with an air economizer. Once these hourly values are determined, daily, monthly and annual values for QH, QC, and QCW are found. These sets of loads for heating, cooling, and cooling with an economizer represent instantaneous (hourly) requirements, daily storage capability, monthly storage capability, and annual storage capability.

A separate algorithm or subroutine was developed to compare energy requirements for various priorities when an air economizer and/or heat recovery system are used. These four combinations are as follows:

1. Heating saved without an economizer and using a heat reclaim system with a selected heat rejection factor.
2. Heat reclaim lost when an air economizer (with economizer priority) is used.
3. Cooling saved when an economizer is used with economizer priority.
4. Cooling saved with an economizer in the system, except the heat reclaim had priority during operation.

Two programs were developed to calculate these four terms using hourly, daily, monthly, and yearly loads from the AXCESS Energy Analysis Program. The first program was done in BASIC in order to develop the logic and check results with manual calculations. A second subroutine was developed in FORTRAN and was added as an integral part of AXCESS to perform the same calculations within the framework of the AXCESS program. A sample output of the results is given as Table 1.

DATA ANALYSIS

A spreadsheet analysis was carried out for the data generated from the AXCESS program for the use of air economizers with heat reclaim systems. This analysis considered the use of the air economizer and heat reclaim with the various priorities for heating and cooling, the efficiency of the heating unit, heating value of the fuel, fuel cost, COP of the cooling unit, cost of electricity, additional cost for heat reclaim, and additional payback periods for reclaim only, economizer only, both, and economizer with reclaim priority were calculated and compared and a selection was made based on simple payback.

A sample of the output is shown as Table 2. Design/selection data are thus available to aid the engineer in evaluating the relative merits of the various combinations and their control (priority) systems. The following results are provided so that the potential savings in energy is available:

HEATING SAVED WITH RECLAIM (no economizer), kWh
HEATING SAVED WITH RECLAIM (economizer priority), kWh
HEAT RECLAIM LOST DUE TO ECONOMIZER, kWh
COOLING SAVED WITH ECONOMIZER (no reclaim), kWh
COOLING SAVED WITH ECONOMIZER (reclaim priority), kWh

Operating cost savings are also provided as:

HEATING COST SAVINGS WITH RECLAIM (no economizer), $
COOLING COST SAVINGS WITH ECONOMIZER (no heat reclaim), $
ENERGY COST SAVINGS WITH BOTH (reclaim priority), $
ENERGY COST SAVINGS WITH BOTH (economizer priority), $
HEATING COST SAVINGS (economizer priority), $
COOLING COST SAVINGS (heat reclaim priority), $
LOSS IN HEATING SAVINGS DUE TO ECONOMIZER PRIORITY, $

With sufficient input on equipment costs, results can be obtained for a decision based on life-cycle costing as follows:

DESIRED SIMPLE PAYBACK PERIOD, YRS
RECLAIM PAYBACK PERIOD, YR
ECONOMIZER PAYBACK PERIOD, YR
COMBINED PAYBACK PERIOD, YR
ECONOMIZER (after RECLAIM) PAYBACK PERIOD, YR
FINAL RECOMMENDATION
BOTH
RECLAIM
ECONO
NEITHER

SAMPLE RUNS

The spreadsheet program along with the "loads" program were used to develop tables of information comparing the different possible combinations of heat reclaim and air economizers. The heating efficiency was taken as 100% (electrical), the energy cost at \$0.08/kWh, heat reclaim installed cost at \$0.33/ft^2, and the economizer installed cost was \$0.15/ft^2. Various changes in chiller COP and building parameters were then incorporated into the calculations and payback periods were calculated. The maximum acceptable pay back period was arbitrarily set as three years. The selected chiller COP was 2.5. Calculations were done for nine cities in the U.S. for the four values of thermal storage with the results given in Table 3.

It must be emphasized that these results only demonstrate the design/selection procedure! They are examples only, with arbitrarily chosen energy costs and payback period. The design/selection procedure is the useful result.

Figure 1 shows the annual energy use for nine cities in the U.S. for both heating and cooling. The heating efficiency was taken as 100% (electric); the COP for the cooling unit was 2.5. This comparison shows that there is a wide variation in both the annual heating and cooling energy use for this building at various locations. Figure 2 compares the annual heating, cooling, and total costs for the same conditions as Figure 1 and for an electric cost of \$0.08 per kWh.

Figure 3 illustrates the potential energy cost savings for the combination of economizer with heat reclaim priority for various geographic locations where no thermal storage is used. The greatest cost savings has occurred in Seattle and San Francisco, and the remainder of the locations exhibited about equal savings. Savings of up to \$29,000 were possible with this type of system.

Figure 4 compares the instantaneous, daily, monthly, and yearly heat balances for the same conditions as in Figure 3. As expected, the greater the amount of storage (enough for a day, month, or year) the greater is the energy cost savings. There are significant differences in the annual cost savings, \$8,000 to \$50,000, for various quantities of storage and geographical locations for this building with heat reclaim (priority) and an air economizer.

Energy cost savings in percent for heat reclaim with economizer for various locations and various quantities of storage are illustrated in Figure 5. Likewise, cost savings in $/ft^2 for the same values and variations are shown in Figure 6. Wide variations in both of these parameters occur for different locations and quantities of thermal storage.

The same building located in St. Louis, MO, was equipped with different types of HVAC systems, and calculations were performed for the case of hourly heat balances. The results of these calculations are shown in Figure 7. The nomenclature for this graph is as follows:

DD - double-duct system with typical operating parameters.
RH - single-zone reheat system with typical operating parameters.
VV - variable - air - volume system with typical operating parameters.
FC - four - pipe fan coil system with typical operating parameters.
HO - closed-loop heat pump system using water-to-air heat pumps. No storage capacity in the water loop.
HT - closed-loop heat pump system with 10,000 gallons water storage in the water loop.
HH - closed-loop heat pump system with 100,000 gallons water water storage in the water loop.
HM - closed-loop heat pump system with 1 million gallons water storage in the water loop.
BA - Building requirements for HVAC if annual storage capabilities are available.
BM - Building requirements for HVAC if monthly storage capabilities are available.
BD - Building requirements for HVAC if daily storage capabilities available.
BI - Building requirements for HVAC without storage capabilities.

In Figure 7, the least amount of energy required for HVAC is when annual storage is available (BA). There is also some savings when either daily or monthly storage is provided. The other five systems illustrated in Figure 7 compare the HVAC energy requirements. The four-pipe fan coil and closed-loop heat pump system with storage approach the minimum requirements of the building as indicated by BI, BD, BM, and BA. This comparison illustrates the potential range of differences in HVAC energy requirements, as various types of HVAC systems are applied to the same building. However, no attempt has been made to optimize the operation of each type of system.

Once again it must be emphasized that these numerical values are only examples of how the design procedure can work.

RECOMMENDED GUIDELINES

As a result of this analytical investigation and discussions with knowledgeable HVAC systems engineers, the following conclusions and guidelines have been developed toward the correct selection of one of the three schemes: heat reclaim, air economizer or equivalent, or heat reclaim and economizer combination (with reclaim priority). As previously pointed out, many important and interrelated factors must be evaluated in the decision-making process. These factors are:

-- Heating and cooling load profiles
-- Geographic location
-- Quantity of glass
-- Ventilation air requirements
-- Economizer set point and control sequence
-- Quantity of thermal storage
-- Amount of internal heat loads
-- Quantity of solar gain
-- Zoning pattern in building
-- Initial component and system costs
-- Energy rates
-- Building owner's desires

The suggested guidelines are as follows:

Guideline 1: Accurately evaluated, time related heating and cooling loads are an integral part of the design/selection process. The use of a computerized hour-by-hour simulation is almost mandatory for this information.

Guideline 2: If an economizer is used with a heat reclaim system, its control is critical. As control is critical, the control and operation must provide for reclaim priority when an economizer is used, otherwise over cooling could occur, resulting in heating energy cost penalties. Control must not be based on needs of individual building zones.

Guideline 3: The use of an economizer will result in energy savings only when there is excess heat available. That is, only discard by economizer operation the heat in excess of what can be used instantaneously for heating plus that later needed for heating and being placed in storage.

Guideline 4: The amount of cooling from an economizer should not exceed the difference between the total cooling requirement and the cooling requirement that results from a heat balance based on the instantaneous building requirements and the requirements of the thermal storage system if available.

Guideline 5: When the cost of boiler heat is lower than the cost of reclaimed heat in terms of dollars per million Btu, the use of an economizer may be justified in lieu of a heat reclaim system.

Guideline 6: If a heat reclaim system is to be used, cost considerations will favor the additional use of a properly controlled and operated economizer for high electrical energy rates.

Guideline 7: The use of properly controlled and operated thermal storage will, in general, make the use of an economizer less cost-effective, i.e., increase its payback period.

Guideline 8: Buildings with large internal loads or solar loads will be more likely to benefit from an economizer when used in conjunction with heat recovery.

Guideline 9: If a heat reclaim system has been ruled out for some extraordinary reason, energy considerations will usually dictate the use of an economizer.

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Table 1. Sample Output for 'THE BUILDING'

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        THE VALUES OF QH,QC,AND QCW ON AN HOURLY BASIS HAVE BEEN ANALYZED FOR A COMPLETE YEAR
        THE RESULTS ARE GIVEN BELOW

HEATING SAVED WITH RECLAIM=                50174.
HEAT RECLAIM LOST WITH ECONOMIZER(ECONOMIZER PRIORITY)=          37080.
COOLING SAVED WITH ECONOMIZER=             37834.
COOLING SAVED WITH ECONOMIZER(RECLAIM PRIORITY)=          8166.

        THE VALUES OF QH,QC,AND QCW ON A  DAILY  BASIS HAVE BEEN ANALYZED FOR A COMPLETE YEAR
        THE RESULTS ARE GIVEN BELOW

HEATING SAVED WITH RECLAIM=                91425.
HEAT RECLAIM LOST WITH ECONOMIZER(ECONOMIZER PRIORITY)=          41241.
COOLING SAVED WITH ECONOMIZER=             37834.
COOLING SAVED WITH ECONOMIZER(RECLAIM PRIORITY)=          4841.

        THE VALUES OF QH,QC,AND QCW ON A MONTHLY BASIS HAVE BEEN ANALYZED FOR A COMPLETE YEAR
        THE RESULTS ARE GIVEN BELOW

HEATING SAVED WITH RECLAIM=               153245.
HEAT RECLAIM LOST WITH ECONOMIZER(ECONOMIZER PRIORITY)=          38564.
COOLING SAVED WITH ECONOMIZER=             37834.
COOLING SAVED WITH ECONOMIZER(RECLAIM PRIORITY)=          6983.

        THE VALUES OF QH,QC,AND QCW ON A YEARLY  BASIS HAVE BEEN ANALYZED FOR A COMPLETE YEAR
        THE RESULTS ARE GIVEN BELOW

HEATING SAVED WITH RECLAIM=               463864.
HEAT RECLAIM LOST WITH ECONOMIZER(ECONOMIZER PRIORITY)=              0.
COOLING SAVED WITH ECONOMIZER=             37834.
COOLING SAVED WITH ECONOMIZER(RECLAIM PRIORITY)=          37834.
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Table 2. Spreadsheet Analysis of Results

1	ASHRAE RP-471: Heat Reclaim Economizer Study	
2		
3	GENERAL CONDITIONS:	
4		EFFICIENCY (heating) %/100
5		1
6		COP (cooling)
7		2.5
8		ENERGY COST, $/kWh
9		0.08
10	LOCATION	
11	STORAGE	
12	ECONOMIZER CONTROL TEMPERATURE,F	
13	GLASS, %	
14	VENTILATION AIR, %	
15	INTERNAL LOAD LEVEL, W/SQ FT	
16	NUMBER OF ZONES	
17	----------	
18	ANNUAL HEATING ENERGY, kWh	
19	ANNUAL COOLING ENERGY, kWh	
20		
21	HEATING SAVED WITH RECLAIM (no economizer),kWh	
22	HEATING SAVED WITH RECLAIM (economizer priority), kWh	
23	HEAT RECLAIM LOST DUE TO ECONOMIZER, kWh	
24	COOLING SAVED WITH ECONOMIZER (no reclaim), kWh	
25	COOLING SAVED WITH ECONOMIZER (reclaim priority), kWh	
26		
27	HEATING SAVED WITH RECLAIM (no economizer), % OF TOTAL HEATING	
28	HEATING SAVED WITH RECLAIM (econo priority), % OF TOTAL HEATING	
29	COOLING SAVED WITH ECONOMIZER (no reclaim), % OF TOTAL COOLING	
30	COOLING SAVED WITH ECONOMIZER (recl priority), % OF TOTAL COOLING	
31		
32	HEATING COST SAVINGS WITH RECLAIM (no economizer), $	
33	COOLING COST SAVINGS WITH ECONOMIZER (no heat reclaim), $	
34	ENERGY COST SAVINGS WITH BOTH (reclaim priority), $	
35	ENERGY COST SAVINGS WITH BOTH (economizer priority), $	
36		
37	HEATING COST SAVINGS (economizer priority), $	
38	COOLING COST SAVINGS (heat reclaim priority), $	
39	LOSS IN HEATING SAVINGS DUE TO ECONOMIZER PRIORITY, $	
40		
41	HEATING COST, $	
42	COOLING COST, $	
43	TOTAL ANNUAL ENERGY COST (base), $	
44	COST SAVINGS, % OF TOTAL	
45		
46	COST SAVINGS (RECLAIM ONLY), $/SQ FT	
47	COST SAVINGS (ECONOMIZER ONLY), $/SQ FT	
48	COST SAVINGS (ECONOMIZER AFTER RECLAIM), $/SQ FT	
49	COST SAVINGS (BOTH), $/SQ FT	
50	HEAT RECLAIM INSTALLED COST, $/SQ FT	
51	ECONOMIZER INSTALLED COST, $/SQ FT	
52	DESIRED SIMPLE PAYBACK PERIOD, YRS	
53		
54	RECLAIM PAYBACK PERIOD, YR	
55	ECONOMIZER PAYBACK PERIOD, YR	
56	COMBINED PAYBACK PERIOD, YR	
57	ECONOMIZER (after RECLAIM) PAYBACK PERIOD, YR	
58	FINAL RECOMMENDATION	
59	BOTH	
60	RECLAIM	
61	ECONO	
62	NEITHER	

Table 3. Sample Results of Economizer/Heat Recovery System Evaluation

GENERAL CONDITIONS:

EFFICIENCY (heating) %/100
1
COP (cooling)
2.5
ENERGY COST, $/kWh
0.08

LOCATION	ST.LOUIS	ST.LOUIS	ST.LOUIS	ST.LOUIS	ATLANTA	ATLANTA	ATLANTA	ATLANTA	CHICAGO	CHICAGO	CHICAGO	CHICAGO
STORAGE	I	D	M	A	I	D	M	A	I	D	M	A
ECONOMIZER CONTROL TEMPERATURE,F	75	75	75	75	75	75	75	75	75	75	75	75
GLASS, %	44	44	44	44	44	44	44	44	44	44	44	44
VENTILATION AIR, %	10/0	10/0	10/0	10/0	10/0	10/0	10/0	10/0	10/0	10/0	10/0	10/0
INTERNAL LOAD LEVEL, W/SQ FT	2.9	2.9	2.9	2.9	2.9	2.9	2.9	2.9	2.9	2.9	2.9	2.9
NUMBER OF ZONES	16	16	16	16	16	16	16	16	16	16	16	16
ANNUAL HEATING ENERGY, kWh	461114	461114	461114	461114	213338	213338	213338	213338	574243	574243	574243	574243
ANNUAL COOLING ENERGY, kWh	632797	632797	632797	632797	758139	758139	758139	758139	483999	483999	483999	483999
HEATING SAVED WITH RECLAIM (no economizer),kWh	55596	108031	166438	461114	55372	117125	195221	213338	66974	128753	195041	574243
HEATING SAVED WITH RECLAIM (economizer priority), kWh	4075	28817	69263	461114	10578	40204	88188	213338	1021	32373	72950	341251
HEAT RECLAIM LOST DUE TO ECONOMIZER, kWh	51521	79214	97175	0	44794	76921	107033	0	65953	96380	122091	232992
COOLING SAVED WITH ECONOMIZER (no reclaim), kWh	175463	175463	175463	175463	241306	241306	241306	241306	210998	210998	210998	210998
COOLING SAVED WITH ECONOMIZER (reclaim priority), kWh	134197	112089	97223	175463	205383	179763	155680	241306	158178	133325	113325	24604
HEATING SAVED WITH RECLAIM (no economizer),% OF TOTAL HEATING	12.1	23.4	36.1	100.0	26.0	54.9	91.5	100.0	11.7	22.4	34.0	100.0
HEATING SAVED WITH RECLAIM (econo priority),% OF TOTAL HEATING	0.9	6.2	15.0	100.0	5.0	18.8	41.3	100.0	0.2	5.6	12.7	59.4
COOLING SAVED WITH ECONOMIZER (no reclaim),% OF TOTAL COOLING	27.7	27.7	27.7	27.7	31.8	31.8	31.8	31.8	43.6	43.6	43.6	43.6
COOLING SAVED WITH ECONOMIZER (recl priority),% OF TOTAL COOLING	21.2	17.7	15.4	27.7	27.1	23.7	20.5	31.8	32.7	27.5	23.4	5.1
HEATING COST SAVINGS WITH RECLAIM (no economizer), $	4447.68	8642.48	13315.04	36889.12	4429.76	9370.00	15617.68	17067.04	5357.92	10300.24	15603.28	45939.44
COOLING COST SAVINGS WITH ECONOMIZER (no heat reclaim), $	5614.82	5614.82	5614.82	5614.82	7721.79	7721.79	7721.79	7721.79	6751.94	6751.94	6751.94	6751.94
ENERGY COST SAVINGS WITH BOTH (reclaim priority), $	8741.98	12229.33	16442.18	42503.94	11002.02	15122.42	20599.44	24788.83	10419.62	14566.64	19229.68	46726.77
ENERGY COST SAVINGS WITH BOTH (economizer priority), $	3940.82	7920.18	11155.86	42503.94	8568.03	10938.11	14776.83	24788.83	6833.62	9341.78	12587.94	34052.02
HEATING COST SAVINGS (economizer priority), $	326.00	2305.36	5541.04	36889.12	846.24	3216.32	7055.04	17067.04	81.68	2589.84	5836	27300.08
COOLING COST SAVINGS (heat reclaim priority), $	4294.30	3586.85	3127.14	5614.82	6572.26	5752.42	4981.76	7721.79	5061.70	4266.40	3626.40	787.33
LOSS IN HEATING SAVINGS DUE TO ECONOMIZER PRIORITY, $	4121.68	6337.12	7774.00	0.00	3583.52	6153.68	8562.64	0.00	5276.24	7710.40	9767.28	18639.36
HEATING COST, $	36889.12	36889.12	36889.12	36889.12	17067.04	17067.04	17067.04	17067.04	45939.44	45939.44	45939.44	45939.44
COOLING COST, $	20249.50	20249.50	20249.50	20249.50	24260.45	24260.45	24260.45	24260.45	15487.97	15487.97	15487.97	15487.97
TOTAL ANNUAL ENERGY COST (base), $	57138.62	57138.62	57138.62	57138.62	41327.49	41327.49	41327.49	41327.49	61427.41	61427.41	61427.41	61427.41
COST SAVINGS, % OF TOTAL	15.30	21.40	28.78	74.39	26.62	36.59	49.84	59.98	16.96	23.71	31.30	76.07
COST SAVINGS (RECLAIM ONLY), $/SQ FT	0.10	0.19	0.29	0.81	0.10	0.21	0.34	0.37	0.12	0.23	0.34	1.01
COST SAVINGS (ECONOMIZER ONLY), $/SQ FT	0.12	0.12	0.12	0.12	0.17	0.17	0.17	0.17	0.15	0.15	0.15	0.15
COST SAVINGS (ECONOMIZER AFTER RECLAIM), $/SQ FT	0.09	0.08	0.07	0.12	0.14	0.13	0.11	0.17	0.11	0.09	0.08	0.02
COST SAVINGS (BOTH), $/SQ FT	0.19	0.27	0.36	0.93	0.24	0.33	0.45	0.54	0.23	0.32	0.42	1.02
HEAT RECLAIM INSTALLED COST, $/SQ FT	0.33	0.33	0.33	0.33	0.33	0.33	0.33	0.33	0.33	0.33	0.33	0.33
ECONOMIZER INSTALLED COST, $/SQ FT	0.15	0.15	0.15	0.15	0.15	0.15	0.15	0.15	0.15	0.15	0.15	0.15
DESIRED SIMPLE PAYBACK PERIOD, YRS	3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0
RECLAIM PAYBACK PERIOD, YR	3.4	1.7	1.1	0.4	3.4	1.6	1.0	0.9	2.8	1.5	1.0	0.3
ECONOMIZER PAYBACK PERIOD, YR	1.2	1.2	1.2	1.2	0.9	0.9	0.9	0.9	1.0	1.0	1.0	1.0
COMBINED PAYBACK PERIOD, YR	2.5	1.8	1.3	0.5	2.0	1.4	1.1	0.9	2.1	1.5	1.1	0.5
ECONOMIZER (after RECLAIM) PAYBACK PERIOD, YR	1.6	1.9	2.2	1.2	1.0	1.2	1.4	0.8	1.4	1.6	1.9	8.7
FINAL RECOMMENDATION	ECONO	BOTH	BOTH	BOTH	ECONO	BOTH	BOTH	BOTH	BOTH	BOTH	BOTH	RECLAIM

Table 3. (continued)

GENERAL CONDITIONS:

EFFICIENCY (heating) %/100: 1
COP (cooling): 2.5
ENERGY COST, $/kWh: 0.08

LOCATION	HOUSTON	HOUSTON	HOUSTON	HOUSTON	MINN.	MINN.	MINN.	MINN.	NEW YORK	NEW YORK	NEW YORK	NEW YORK
STORAGE	I	D	M	A	I	D	M	A	I	D	M	A
ECONOMIZER CONTROL TEMPERATURE,F	75	75	75	75	75	75	75	75	75	75	75	75
GLASS, %	44	44	44	44	44	44	44	44	44	44	44	44
VENTILATION AIR, %	10/0	10/0	10/0	10/0	10/0	10/0	10/0	10/0	10/0	10/0	10/0	10/0
INTERNAL LOAD LEVEL, W/SQ FT	2.9	2.9	2.9	2.9	2.9	2.9	2.9	2.9	2.9	2.9	2.9	2.9
NUMBER OF ZONES	16	16	16	16	16	16	16	16	16	16	16	16
ANNUAL HEATING ENERGY, kWh	84794	84794	84794	84794	865885	865885	865885	865885	375716	375716	375716	375716
ANNUAL COOLING ENERGY, kWh	1029474	1029474	1029474	1029474	498550	498550	498550	498550	549079	549079	549079	549079
HEATING SAVED WITH RECLAIM (no economizer),kWh	32540	59323	84794	84794	57542	111521	164694	623187	68352	124811	164085	375716
HEATING SAVED WITH RECLAIM (economizer priority), kWh	2650	20164	49371	84794	2451	32033	90867	423820	1290	27118	52423	375716
HEAT RECLAIM LOST DUE TO ECONOMIZER, kWh	29890	39159	35423	0	55091	79488	73827	199367	67062	97693	111662	0
COOLING SAVED WITH ECONOMIZER (no reclaim), kWh	210280	210280	210280	210280	159494	159494	159494	159494	232023	232023	232023	232023
COOLING SAVED WITH ECONOMIZER (reclaim priority), kWh	186300	178948	181942	210280	115386	95902	100432	0	178300	153863	242693	232023
HEATING SAVED WITH RECLAIM (no economizer),% OF TOTAL HEATING	38.4	70.0	100.0	100.0	6.6	12.9	19.0	72.0	18.2	33.2	43.7	100.0
HEATING SAVED WITH RECLAIM (econo priority),% OF TOTAL HEATING	3.1	23.8	58.2	100.0	0.3	3.7	10.5	48.9	0.3	7.2	14.0	100.0
COOLING SAVED WITH ECONOMIZER (no reclaim),% OF TOTAL COOLING	20.4	20.4	20.4	20.4	32.0	32.0	32.0	32.0	42.3	42.3	42.3	42.3
COOLING SAVED WITH ECONOMIZER (recl priority),% OF TOTAL COOLING	18.1	17.4	17.7	20.4	23.1	19.2	20.1	0.0	32.5	28.0	44.2	42.3
HEATING COST SAVINGS WITH RECLAIM (no economizer), $	2603.20	4745.84	6783.52	6783.52	4603.36	8921.68	13175.52	49854.96	5468.16	9984.88	13126.80	30057.28
COOLING COST SAVINGS WITH ECONOMIZER (no heat reclaim), $	6728.96	6728.96	6728.96	6728.96	5103.81	5103.81	5103.81	5103.81	7424.74	7424.74	7424.74	7424.74
ENERGY COST SAVINGS WITH BOTH (reclaim priority), $	8564.80	10472.18	12605.66	13512.48	8295.71	11990.54	16389.34	49854.96	11173.76	14908.50	20892.98	37482.02
ENERGY COST SAVINGS WITH BOTH (economizer priority), $	6940.96	8342.08	10678.64	13512.48	5299.89	7666.45	12373.17	39009.41	7527.94	9594.18	11618.58	37482.02
HEATING COST SAVINGS (economizer priority), $	212	1613.12	3949.68	6783.52	196.08	2562.64	7269.36	33905.6	103.2	2169.44	4193.84	30057.28
COOLING COST SAVINGS (heat reclaim priority), $	5961.60	5726.34	5823.14	6728.96	3692.35	3068.86	3213.82	0.00	5705.60	4923.62	7766.18	7424.74
LOSS IN HEATING SAVINGS DUE TO ECONOMIZER PRIORITY, $	2391.20	3132.72	2833.84	0.00	4407.28	6359.04	5906.16	15949.36	5364.96	7815.44	8932.96	0.00
HEATING COST, $	6783.52	6783.52	6783.52	6783.52	69270.80	69270.80	69270.80	69270.80	30057.28	30057.28	30057.28	30057.28
COOLING COST, $	32943.17	32943.17	32943.17	32943.17	15953.60	15953.60	15953.60	15953.60	17570.53	17570.53	17570.53	17570.53
TOTAL ANNUAL ENERGY COST (base), $	39726.69	39726.69	39726.69	39726.69	85224.40	85224.40	85224.40	85224.40	47627.81	47627.81	47627.81	47627.81
COST SAVINGS, % OF TOTAL	21.56	26.36	31.73	34.01	9.73	14.07	19.23	58.50	23.46	31.30	43.87	78.70
COST SAVINGS (RECLAIM ONLY), $/SQ FT	0.06	0.10	0.15	0.15	0.10	0.20	0.29	1.09	0.12	0.22	0.29	0.66
COST SAVINGS (ECONOMIZER ONLY), $/SQ FT	0.15	0.15	0.15	0.15	0.11	0.11	0.11	0.11	0.16	0.16	0.16	0.16
COST SAVINGS (ECONOMIZER AFTER RECLAIM), $/SQ FT	0.13	0.13	0.13	0.15	0.08	0.07	0.07	0.00	0.13	0.11	0.17	0.16
COST SAVINGS (BOTH), $/SQ FT	0.19	0.23	0.28	0.30	0.18	0.26	0.36	1.09	0.24	0.33	0.46	0.82
HEAT RECLAIM INSTALLED COST, $/SQ FT	0.33	0.33	0.33	0.33	0.33	0.33	0.33	0.33	0.33	0.33	0.33	0.33
ECONOMIZER INSTALLED COST, $/SQ FT	0.15	0.15	0.15	0.15	0.15	0.15	0.15	0.15	0.15	0.15	0.15	0.15
DESIRED SIMPLE PAYBACK PERIOD, YRS	3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0
RECLAIM PAYBACK PERIOD, YR	5.8	3.2	2.2	2.2	3.3	1.7	1.1	0.3	2.8	1.5	1.1	0.5
ECONOMIZER PAYBACK PERIOD, YR	1.0	1.0	1.0	1.0	1.3	1.3	1.3	1.3	0.9	0.9	0.9	0.9
COMBINED PAYBACK PERIOD, YR	2.6	2.1	1.7	1.6	2.6	1.8	1.3	0.4	2.0	1.5	1.0	0.6
ECONOMIZER (after RECLAIM) PAYBACK PERIOD, YR	1.1	1.2	1.2	1.0	1.9	2.2	2.1	ERR	1.2	1.4	0.9	0.9
FINAL RECOMMENDATION	ECONO	ECONO	BOTH	BOTH	ECONO	BOTH	BOTH	ERR ERR	BOTH	BOTH	BOTH	BOTH

Table 3. (concluded)

GENERAL CONDITIONS:

EFFICIENCY (heating) %/100: 1

COP (cooling): 2.5

ENERGY COST, $/kWh: 0.08

LOCATION	PHOENIX	PHOENIX	PHOENIX	PHOENIX	FRISCO	FRISCO	FRISCO	FRISCO	SEATTLE	SEATTLE	SEATTLE	SEATTLE
STORAGE	I	D	M	A	I	D	M	A	I	D	M	A
ECONOMIZER CONTROL TEMPERATURE,F	75	75	75	75	75	75	75	75	75	75	75	75
GLASS, %	44	44	44	44	44	44	44	44	44	44	44	44
VENTILATION AIR, %	10/0	10/0	10/0	10/0	10/0	10/0	10/0	10/0	10/0	10/0	10/0	10/0
INTERNAL LOAD LEVEL, W/SQ FT	2.9	2.9	2.9	2.9	2.9	2.9	2.9	2.9	2.9	2.9	2.9	2.9
NUMBER OF ZONES	16	16	16	16	16	16	16	16	16	16	16	16
ANNUAL HEATING ENERGY, kWh	88714	88714	88714	88714	257102	257102	257102	257102	375184	375184	375184	375184
ANNUAL COOLING ENERGY, kWh	1158604	1158604	1158604	1158604	485109	485109	485109	485109	995149	995149	995149	995149
HEATING SAVED WITH RECLAIM (no economizer),kWh	32381	77819	88714	88714	87457	201728	257102	257102	123431	323209	348513	375184
HEATING SAVED WITH RECLAIM (economizer priority), kWh	2068	44888	71656	88714	2081	69120	105883	133890	10377	76259	94406	355972
HEAT RECLAIM LOST DUE TO ECONOMIZER, kWh	30313	32931	17058	0	85376	132608	151219	123212	113054	246950	254107	19212
COOLING SAVED WITH ECONOMIZER (no reclaim), kWh	200189	200189	200189	200189	377997	377997	377997	377997	710371	710371	710371	710371
COOLING SAVED WITH ECONOMIZER (reclaim priority), kWh	175878	174840	186544	200189	309585	271900	257021	279427	619757	512802	507085	695002
HEATING SAVED WITH RECLAIM (no economizer),% OF TOTAL HEATING	36.5	87.7	100.0	100.0	34.0	78.5	100.0	100.0	32.9	86.1	92.9	100.0
HEATING SAVED WITH RECLAIM (econo priority),% OF TOTAL HEATING	2.3	50.6	80.8	100.0	0.8	26.9	41.2	52.1	2.8	20.3	25.2	94.9
COOLING SAVED WITH ECONOMIZER (no reclaim),% OF TOTAL COOLING	17.3	17.3	17.3	17.3	77.9	77.9	77.9	77.9	71.4	71.4	71.4	71.4
COOLING SAVED WITH ECONOMIZER (recl priority),% OF TOTAL COOLING	15.2	15.1	16.1	17.3	63.8	56.0	53.0	57.6	62.3	51.5	51.0	69.8
HEATING COST SAVINGS WITH RECLAIM (no economizer), $	2590.48	6225.52	7097.12	7097.12	6996.56	16138.24	20568.16	20568.16	9874.48	25856.72	27881.04	30014.72
COOLING COST SAVINGS WITH ECONOMIZER (no heat reclaim), $	6406.05	6406.05	6406.05	6406.05	12095.90	12095.90	12095.90	12095.90	22731.87	22731.87	22731.87	22731.87
ENERGY COST SAVINGS WITH BOTH (reclaim priority), $	8218.58	11820.40	13066.53	13503.17	16903.28	24839.04	28792.83	29509.82	29706.70	42266.38	44107.76	52254.78
ENERGY COST SAVINGS WITH BOTH (economizer priority), $	6571.49	9997.09	12138.53	13503.17	12262.38	17625.50	20566.54	22807.10	23562.03	28832.59	30284.35	51209.63
HEATING COST SAVINGS (economizer priority), $	165.44	3591.04	5732.48	7097.12	166.48	5529.6	8470.64	10711.2	830.16	6100.72	7552.48	28477.76
COOLING COST SAVINGS (heat reclaim priority), $	5628.10	5594.88	5969.41	6406.05	9906.72	8700.80	8224.67	8941.66	19832.22	16409.66	16226.72	22240.06
LOSS IN HEATING SAVINGS DUE TO ECONOMIZER PRIORITY, $	2425.04	2634.48	1364.64	0.00	6830.08	10608.64	12097.52	9856.96	9044.32	19756.00	20328.56	1536.96
HEATING COST, $	7097.12	7097.12	7097.12	7097.12	20568.16	20568.16	20568.16	20568.16	30014.72	30014.72	30014.72	30014.72
COOLING COST, $	37075.33	37075.33	37075.33	37075.33	15523.49	15523.49	15523.49	15523.49	31844.77	31844.77	31844.77	31844.77
TOTAL ANNUAL ENERGY COST (base), $	44172.45	44172.45	44172.45	44172.45	36091.65	36091.65	36091.65	36091.65	61859.49	61859.49	61859.49	61859.49
COST SAVINGS, % OF TOTAL	18.61	26.76	29.58	30.57	46.83	68.82	79.78	81.76	48.02	68.33	71.30	84.47
COST SAVINGS (RECLAIM ONLY), $/SQ FT	0.06	0.14	0.16	0.16	0.15	0.35	0.45	0.45	0.22	0.57	0.61	0.66
COST SAVINGS (ECONOMIZER ONLY), $/SQ FT	0.14	0.14	0.14	0.14	0.27	0.27	0.27	0.27	0.50	0.50	0.50	0.50
COST SAVINGS (ECONOMIZER AFTER RECLAIM), $/SQ FT	0.12	0.12	0.13	0.14	0.22	0.19	0.18	0.20	0.43	0.36	0.36	0.49
COST SAVINGS (BOTH), $/SQ FT	0.18	0.26	0.29	0.30	0.37	0.54	0.63	0.65	0.65	0.93	0.97	1.15
HEAT RECLAIM INSTALLED COST, $/SQ FT	0.33	0.33	0.33	0.33	0.33	0.33	0.33	0.33	0.33	0.33	0.33	0.33
ECONOMIZER INSTALLED COST, $/SQ FT	0.15	0.15	0.15	0.15	0.15	0.15	0.15	0.15	0.15	0.15	0.15	0.15
DESIRED SIMPLE PAYBACK PERIOD, YRS	3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0
RECLAIM PAYBACK PERIOD, YR	5.8	2.4	2.1	2.1	2.2	0.9	0.7	0.7	1.5	0.6	0.5	0.5
ECONOMIZER PAYBACK PERIOD, YR	1.1	1.1	1.1	1.1	0.6	0.6	0.6	0.6	0.3	0.3	0.3	0.3
COMBINED PAYBACK PERIOD, YR	2.7	1.9	1.7	1.6	1.3	0.9	0.8	0.7	0.7	0.5	0.5	0.4
ECONOMIZER (after RECLAIM) PAYBACK PERIOD, YR	1.2	1.2	1.1	1.1	0.7	0.8	0.8	0.8	0.3	0.4	0.4	0.3
FINAL RECOMMENDATION	ECONO	BOTH	BOTH	BOTH	BOTH	BOTH	BOTH	BOTH	BOTH	BOTH	BOTH	BOTH

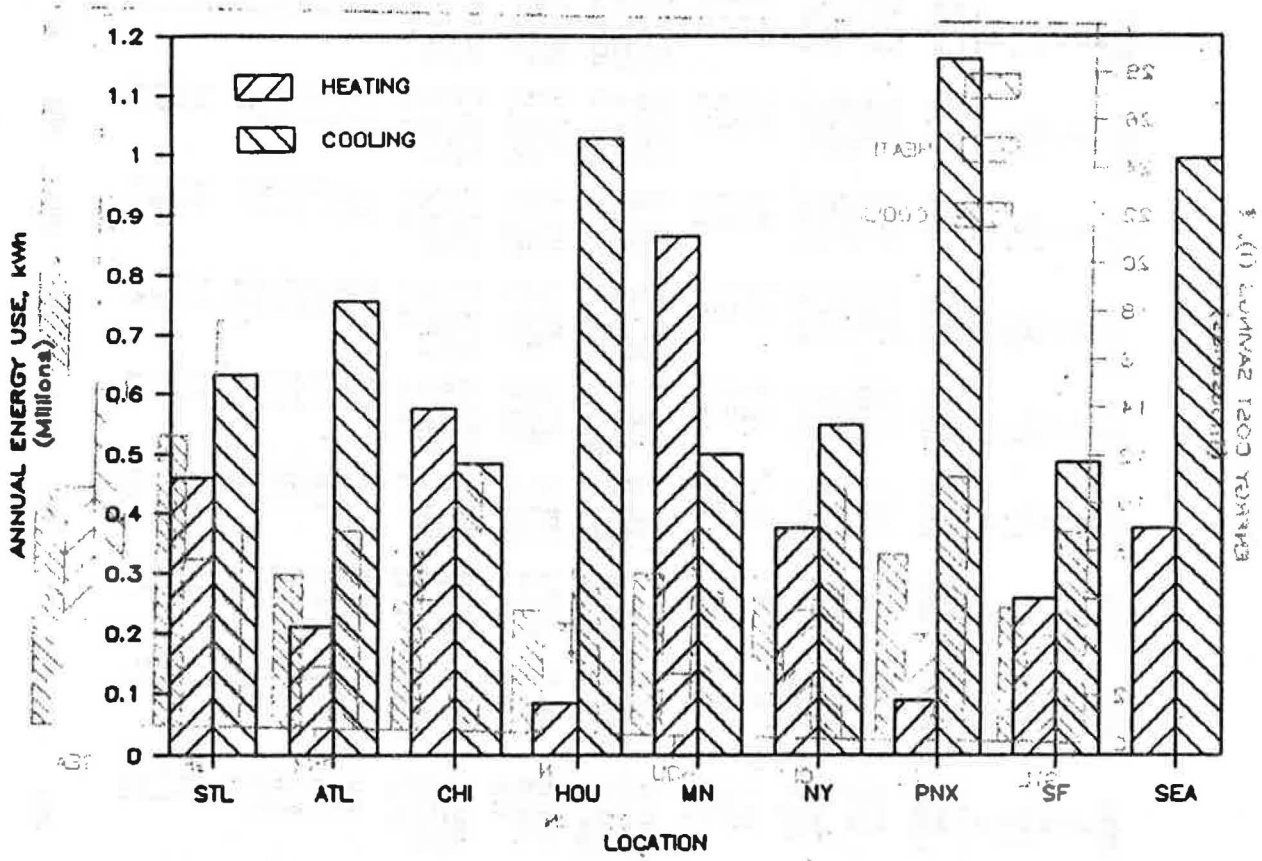

Figure 1 Relative annual energy use by geographical location

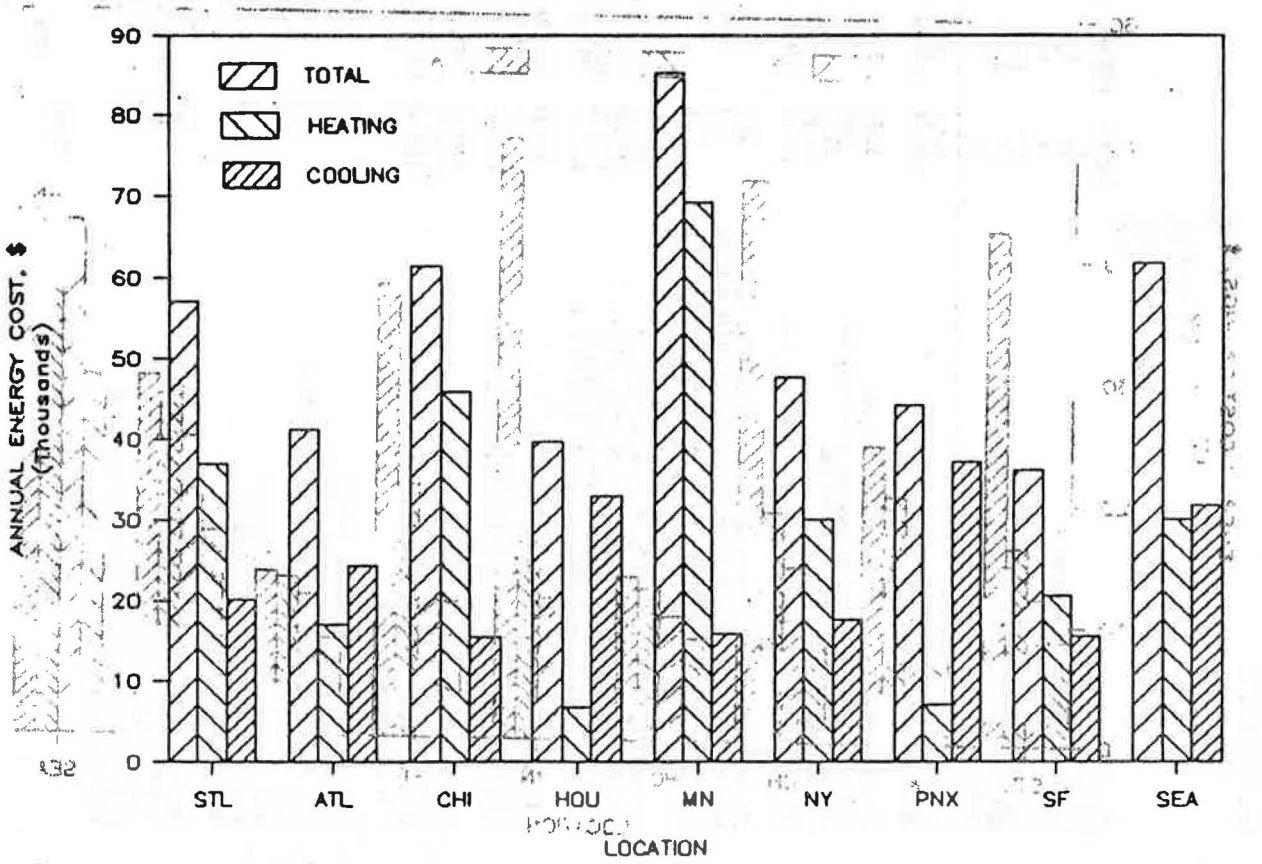

Figure 2 Relative annual energy cost by geographical location

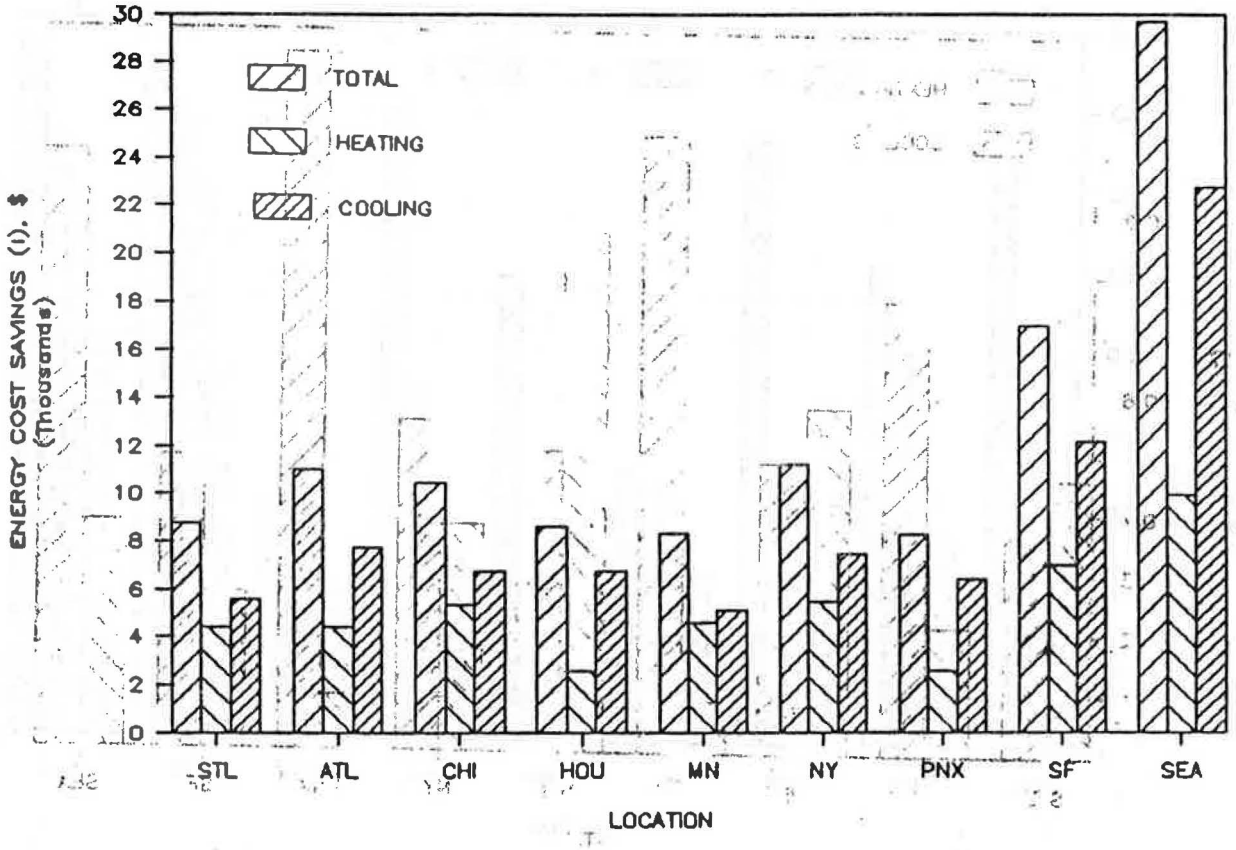

Figure 3. Relative energy cost savings by geographical location

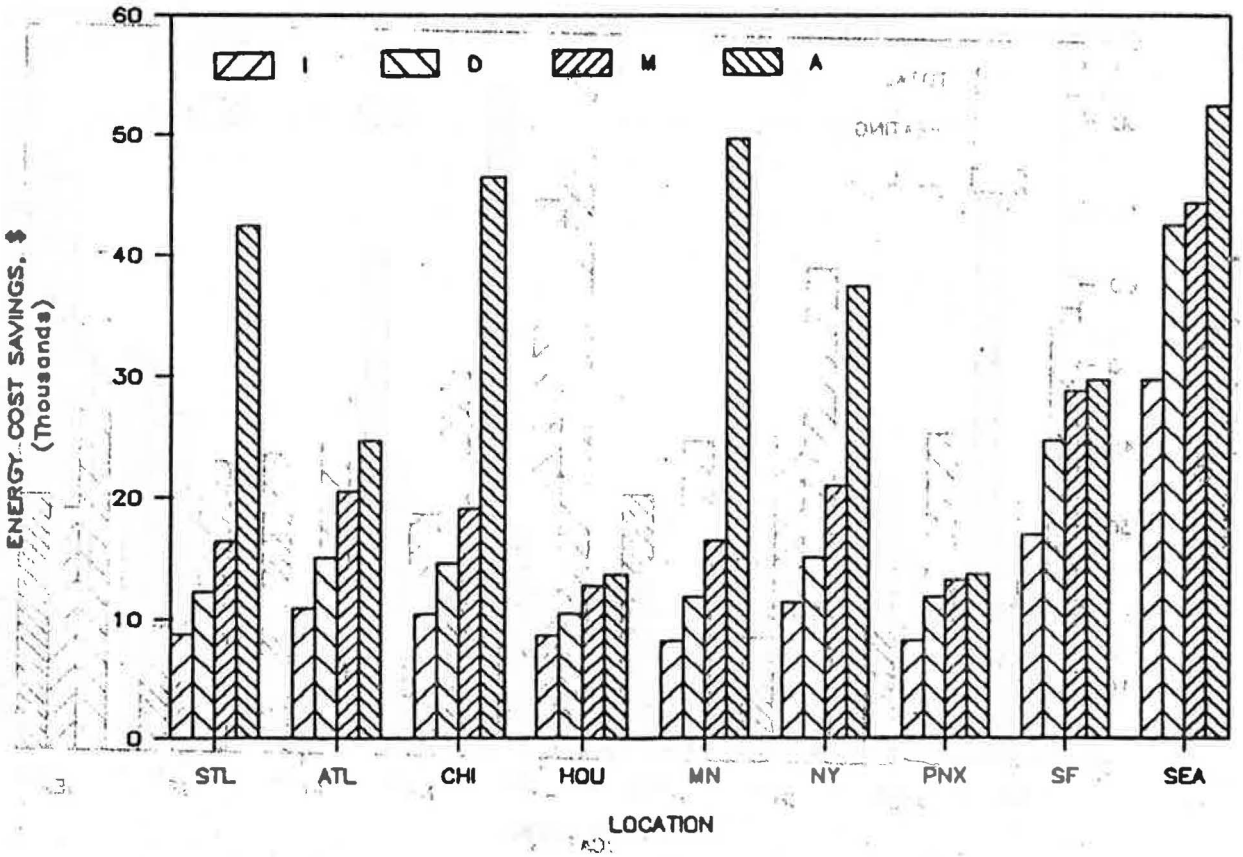

Figure 4 Effect of storage on energy cost savings, by location

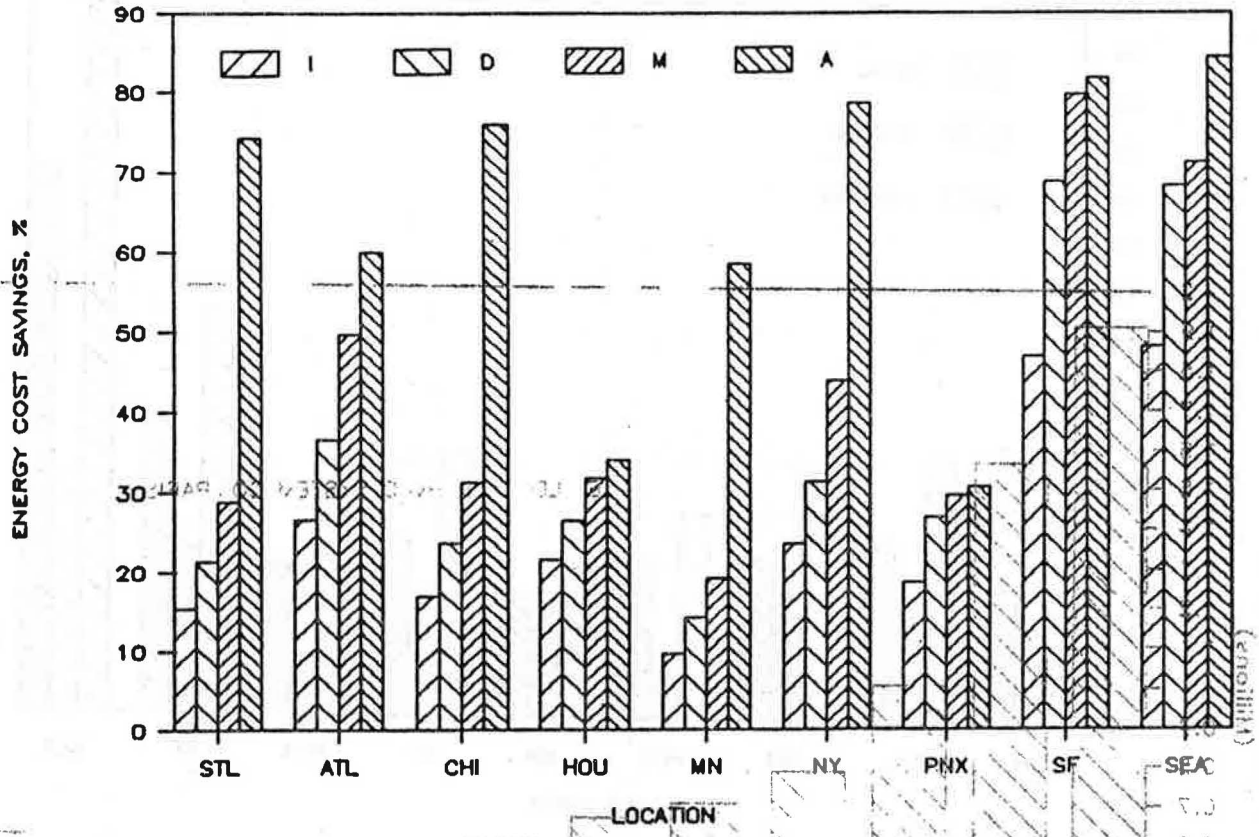

Figure 5 Effect of storage on energy cost savings, as %

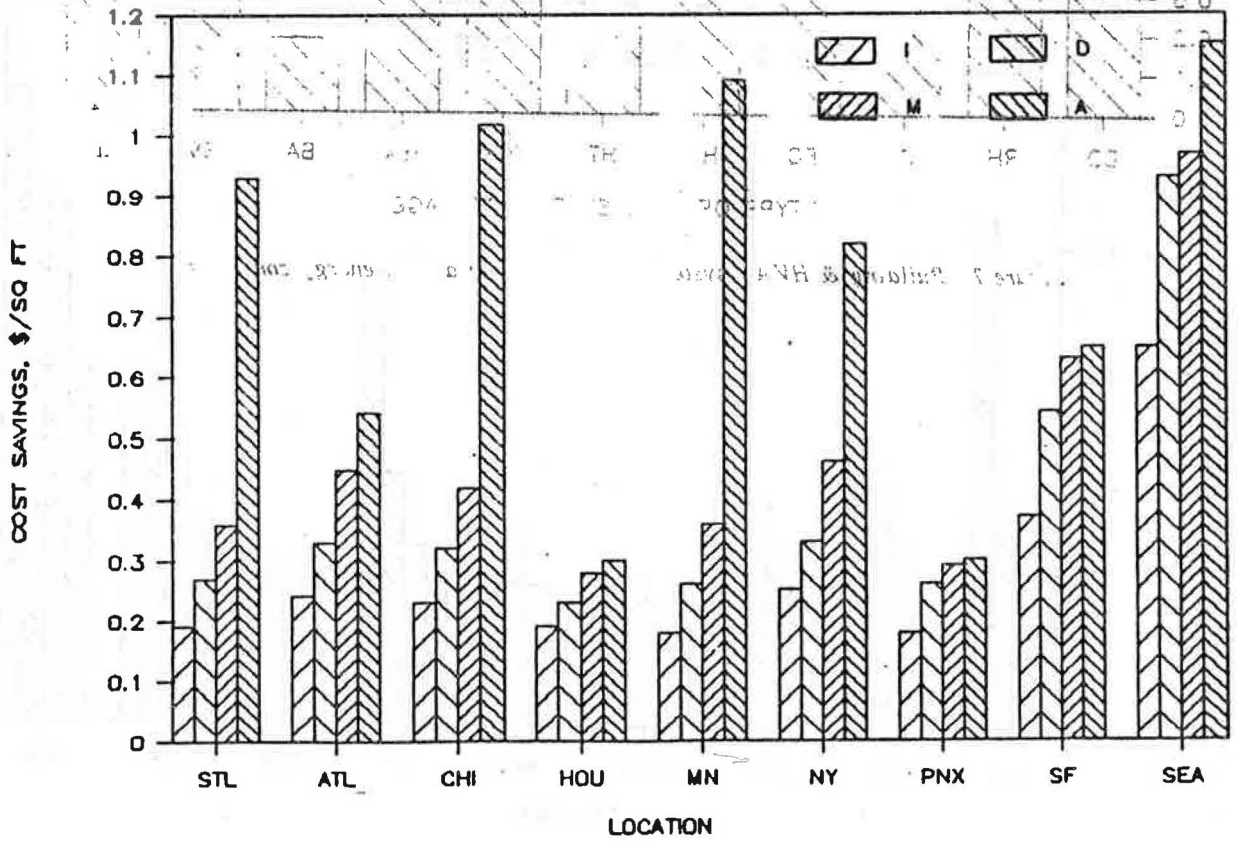

Figure 6 Effect of storage on energy cost savings, per square foot

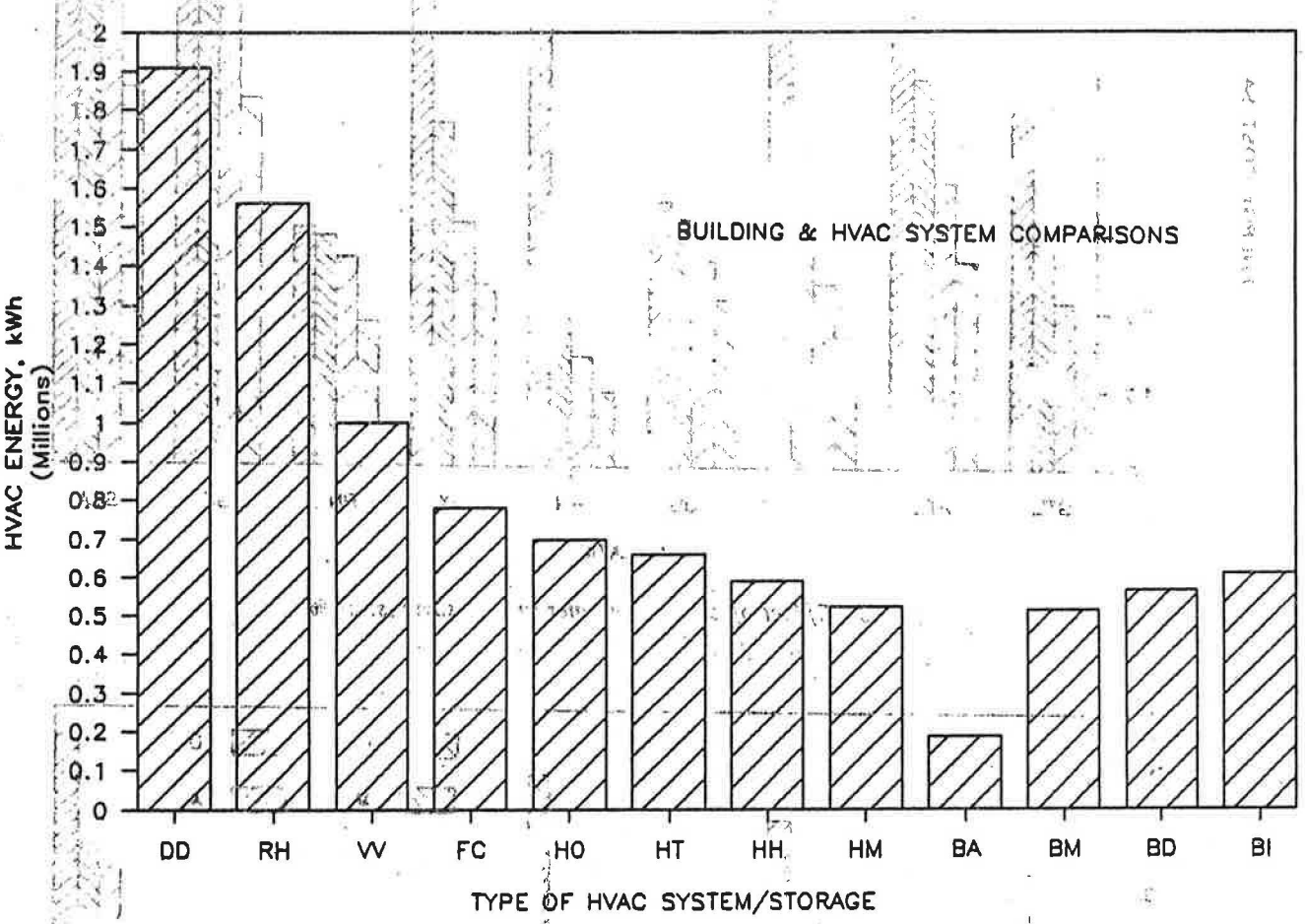

Figure 7 Building & HVAC system comparisons on annual energy consumption