A COMPUTER ANALYSIS OF ENERGY USE AND ENERGY CONSERVATION OPTIONS FOR A TWELVE STORY OFFICE BUILDING IN AUSTIN, TEXAS

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ABSTRACT

The energy use of the Travis Building at Austin, Texas was analyzed using the DOE 2.1B building energy simulation program. An analysis was made for the building as specified in the building plans and as operated by the personnel currently occupying the building. The energy consumption of the building was compared with the energy consumption of the building modified to comply with the proposed ASHRAE 90.1p standards. The base design and the ASHRAE design of the Travis building were evaluated in Brownsville, Houston, Lubbock, and El Paso to study the influence of the weather on its energy consumption. In addition, a glass with high reflectivity and low overall heat transfer coefficient was used to study the reduction of glass conduction and glass solar loads. Finally, the energy consumption of the modified building was compared with the energy consumption of the modified building which conformed to the California energy standards.

INTRODUCTION

The cost of comfort heating and cooling is typically the largest single component of annual energy costs in commercial buildings. Even though oil and gas prices have moderated, electricity prices are continuing to increase in Texas. In Texas, 63% of the total energy use in the commercial sector is used for heating, ventilation and air-conditioning (HVAC), which is about 8.5% of the total energy consumption of Texas [1].

The Energy Management Group at Texas A&M is working with Texas Public Utility Commission (PUC), State Purchasing and General Services Commission (SPGSC) to develop a minimum efficiency standard for all new state buildings. To develop a standard, detailed energy analyses of some buildings in Texas are being performed to evaluate how energy is being used and the potential for reducing energy use. The Travis building at Austin, Texas was one of the buildings chosen for preliminary studies.

There is a wide variation of weather conditions in the state of Texas. It is hot and humid in the South and relatively mild in the North. Because of such wide variation of weather conditions, formulation of standards becomes difficult and requires the knowledge of the effect of weather on the energy use of building. This study looks at the effect of climate on the energy use of the Travis building by evaluating it in five Texas cities.

The United State Department of Energy (DOE), with ASHRAE, has been developing energy standards for new buildings. The DOE's involvement in development of energy efficiency standards for the buildings is primarily a result of public laws which have mandated the development of performance standards [1]. The most recently proposed ASHRAE standards in 1985 contain both prescriptive and performance components [2]. The prescriptive standards typically spell out the thermal, electrical or physical parameters which should lead to energy efficient operation of the design. The performance component has energy budgets for the whole building.

The state of California has both prescriptive and performance standards for 16 different weather zones in Califronia [3]. The energy standards of California are similar to the proposed ASHRAE standards in many respects, except that the California standards are generally more stringent.

The purpose of developing standards in Texas is to encourage innovative design of new buildings so that they use less energy without constraining the necessary building functions.

DESCRIPTION OF BUILDING

To make estimates of the energy use of the Travis building using the DOE 2.1B computer program, the various operational schedules of the building are required. This section provides a description of the Travis building schedules, external shading and various zones.

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SCHEDULES

The Travis building is an office building, so the operating schedules are assumed to be the same Monday through Friday. Two schedules were assumed for the building: a schedule for Monday through Friday and another for holidays and weekends. Five schedules are discussed below: (1) occupancy, (2) lighting, (3) office equipment, (4) internal shading and (5) infiltration.

Occupancy

The number of people occupying each zone were estimated from the total figures obtained from the personnel of the State Purchasing and General Services Commission (SPGSC). The occupancy schedules are shown in Table 1. The maximum number of people in the building, as estimated, is 2100.

Table 1. Assumed Occupancy Schedule for Travis Building.+

Time	Monday-Friday	Weekends & Holidays
12am-8am	0.1	0.1
8am-11am	0.9	0.2
11am-2pm	0.5	0.2
2pm-6pm	0.8	0.2

+1.0 = 175 people/floor

Lighting

The peak lighting levels were estimated to be 2.2 w/sf from the number of fixtures in each zone using the floor plans. This value is slightly larger than the 1.8 w/sf recommended by proposed ASHRAE standards [2]. The lighting schedules are shown in Table 2.

Table 2. Assumed Lighting Schedule for Travis Building.+

Time	Monday-Friday	Holidays & Weekends
12am-8am	0.2	0.2
8am-5pm	0.9	0.2
5pm-12am	0.3	0.2

+ where 1.0 = 2.2 w/sf

Office Equipment

The peak equipment wattage for an office was estimated to be 3 w/sf. The main computers in the Travis building were assumed to use 1 w/sf. The office equipment wattage was based on a walk through audit, and the estimate of the computers was from the total cooling capacity of the comuter rooms given by the personnel from the SPGSC. The office equipment included: computer terminals, Xerox machines, typewriters, table lamps, coffee pots, microcomputers etc. The office equipment schedules are shown in Table 3. During weekends and holidays, 20% of the equipment is assumed to be on line, because the main computers are never shut down.

Table 3. Assumed Equipment Schedule for Travis Building.+

Time	Monday-Friday	Holidays & Weekends
12am-8am	0.2	0.2
8am-12pm	0.5	0.2
12pm-2pm	0.4	0.2
2pm-6pm	0.5	0.2
6pm-12am	0.2	0.2

+ where 1.0 = 4.0 w/sf

Internal Shading for Windows

All the exterior glass in the Travis building is double pane with a slight tint. Since the Travis building had blinds on all the windows, it was assumed that the blinds were closed on 80% of the windows receiving direct sunlight. Closing the blinds would cutoff direct solar radiation into the space thus reducing the peak load and also the total energy use. Since the glass solar loads have significant impact on the peak and also the total energy use in hot climate zones, the change in the percent shading could have a significant impact on estimation of the energy use. Seventy-seven percent of the exterior walls are glass. The shading schedules for the East and South windows are shown in Table 4 and for the West and North windows in Table 5.

Table 4. Assumed Shading Schedule for East and South Windows of Travis Building.+

Time	Monday-Friday	Holidays & Weekends
12am-8am	0.2	0.2
8am-12pm	0.8	0.2
12pm-12am	0.2	0.2

+where 1.0 is blinds fully open

Infiltration

Infiltration was assumed to be 0.25 air-changes/hr. This corresponds to about 7 to 8 cfm/person for the building being fully occupied. The infiltration schedules are shown in Table 5. During week nights, weekends and holidays, the infiltration is reduced to 20% because of the lower occupancy and reduced movement of people through doors.

Table 5. Assumed Infiltration Schedule for Travis Building.+

Time	Monday-Friday	Holidays & Weekeneds
12am-8am	0.2	0.2
8am-6pm	1.0	0.2
6pm-12am	0.2	0.2

+ where 1.0 = 0.25 Air-Changes/hr

BUILDING SHADING

The shading from two adjacent high rise buildings (Johnson & Austin) are included when estimating the loads on Travis building. Also, external shading due to the window offsets are taken into account. The Travis building has 30 inch offsets for the windows on all sides of the building except the North and Northeast side. These offsets provide shading to a substantial amount of glass during the day.

ZONES

The ground floor and the 12th floor are treated as single zones because these floors have heat transfer through the ground and the roof respectively. The first floor was divided into five different zones. The second through eleventh were treated as ten separate but identical zones. The schematic of the zones is shown in Figure 1. The typical zone has a conditioned area of 33,154 square feet. The gross area of the Travis building is 460,855 square feet.

SYSTEM DESCRIPTION

A variable air volume (VAV) system is used in the Travis building. VAV systems vary the quantity of a constant temperature air to match system load requirements. Thus, the energy consumption closely parallels the load on the air conditioning systems. The VAV system has a variable speed fan. A temperature based economizer cycle is also used with the VAV system.

The temperature for cooling was set at 75 F during the day and allowed to float to 90 F during the week nights, weekends and holidays. The temperature for heating was set at 74 F during day and 65 F during week nights, weekends and holidays. The maximum humidity was set at 70% and the minimum at 40%. Each zone, described earlier, has a separate fan. The fresh air requirements per person was assumed to be 7 cfm/hr. This corresponds to the minimum recommended level of ventilation [4].

RESULTS AND ANALYSIS

The energy consumption of the Travis building at Austin was estimated using the DOE 2.1B building energy simulation program [5]. Because the building was completed in late 1985, measured data on the annual performance of the building is not yet available. The program simulates hourly load's profile and hourly system simulation of the building. It also has a provision to output various data, such as peak loads for each zone, peak loads for the entire building, and total energy use for each zone, total energy use for the entire building, etc.

The energy consumption of the Travis building was estimated for five Texas cities, including Austin, to study the influence of weather. The cities were: Brownsville, Houston, El Paso, and Lubbock. The energy consumption of a modified building which conformed to the proposed ASHRAE standards was also studied [2]. In addition, a glass with high reflectivity and low overall heat transfer coefficient was used to study the reduction of glass conduction and glass solar loads. Finally, the energy consumption of the Travis building was compared with the energy consumption of the modified building which conformed to the California energy standards [3].

BASE BUILDING PEAK LOADS AND ENERGY USE

Figure 2 shows the estimated distribution of the peak cooling loads for the base building. The internal loads from equipment and the lights constitute about 50% of the total peak load. Since the Travis building is an office building, much of the internal loads are office equipment.

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The loads from lights are unavoidable, but keeping the lighting levels to those recommended by ASHRAE or California would reduce the contribution of lights to the heat gains. Because 77% of its exterior walls are glass, the glass solar and glass conduction loads are also quite significant (37%). Figure 3 shows the distribution of the peak heating loads for the building. The infiltration and glass conduction loads make up almost the entire heating load. The infiltration loads, in case of heating, are much more significant than cooling, because the indoor-outdoor temperature difference is much greater in winter than summer. As mentioned earlier, the building has more glass than walls, hence the glass conduction loss constitutes 64% of the peak heating load of the building.

Figure 4 shows the breakup of the total cooling energy and Figure 5 shows the total heating energy for the Travis building. The internal loads constitute the major portion of the total cooling energy use (67%) followed by the glass solar which is about 27% of the total cooling load. The glass conduction was quite high in case of the peak cooling loads, but is not a significant contributor to the total energy use. Keeping the lighting level in the building to the recommended level would substantially reduce the total energy use because the lighting level in the Travis building is higher than the recommended level. As seen earlier, from the distribution of the peak heating loads, the total heating energy also consists of infiltration and glass conduction losses. The glass conduction loss constitutes about 73% of the total heating energy, and infiltration is about 19%.

EFFECT OF WEATHER ON PEAK LOADS AND ENERGY USE

The peak loads and the energy use of the Travis building were estimated for different cities in Texas to study the influence of the weather on these variables. Table 6 shows the breakup of various loads and also the EUI for each location. It can be seen from Table 6 that cooling loads decreased, and the heating loads increased as the building was moved from South to North. The higher cooling energy for Brownsville is due to extended summer days and also to the higher humidity. The heating energy for El Paso is far greater than that at any other location, and this may be due to a faulty weather data diskette. The HVAC equipment load, as seen, is roughly proportional to the heating and cooling energy use. Also, it is clear from Table 6 that there is a wide variation of EUI for the same building at different locations. Brownsville is extremely hot and humid; therefore, the cooling energy for this location is more than any other location. Because El Paso and Lubbock are in colder climates, the heating energy in these locations is higher.

ASHRAE STANDARDS

ASHRAE has recently proposed a major update to the previously published studies on the non-residential buildings [2]. The update affects several major areas such as; (1) lighting levels and its controls, (2) control of equipment loads, and (3) HVAC systems.

Lighting and its Controls

The major difference between the base building and that required with the proposed ASHRAE standards was in lighting levels. The base building had 2.2 w/sf compared to 1.8 w/sf recommended by the standards. It was assumed that the most efficient lamp/ballasting systems and luminaries were installed in the base building. For example, the fluorescent fixture with 2 lamps are required to have an efficacy of 68 lumens/watt (including ballast losses). The standards also call for automatic controls including occupancy sensors, light level sensors etc. These reduce the lighting level during unoccupied hours to those levels needed for safety and security, and also adjust the lighting levels when adequate daylight is present. The Travis building had no such controls. These controls would be useful in perimeter zones of the Travis building where there is abundant indirect solar isolation.

Control of Equipment Loads

The proposed standards specify that major heat generating equipment should, where practical, be located where it can balance other heat losses. For example, computer centers of kitchen areas could be located in the north or northwest perimeter areas of buildings depending on the climate and prevailing wind directions.

HVAC Systems

The standards call for VAV systems in any office building which are more than four stories high. Systems serving areas with large internal loads (lighting, equipment and people), especially interior zones with little or no exposure to weather, should be designed to take advantage of mild or cool weather conditions to reduce cooling energy. Economizer controls should be integrated with the mechanical cooling controls so that mechanical cooling is only operated when necessary, and the supply air is not

Table 6 - Comparison of Energy Use For Travis Building at Different Locations in Texas

Location	Chilling+ MBTU	Heating MBTU	Lighting & Equipment MBTU (MWH)	Fans MBTU (MWH)	Total MBTU	EUI KBTU/SF
Brownsville	10375	1084	18795(5507)	15219(4459)	45473	98.7
Houston	6987	2762	18795(5507)	14494(4247)	43038	93.4
Austin	6972	5873	18795(5507)	14968(4386)	46608	101.0
Lubbock	4779	14113	18795(5507)	16115(4723)	53802	116.7
El Paso	5803	22367	18795(5507)	14638(4289)	61603	133.7

+ Assume COP = 3

overcooled to a temperature below the desired supply temperature. The system and controls should be designed so that economizer operation does not increase heating energy use. The supply air quantity should vary with the sensible load (i.e., VAV system). The recommended temperature controls during occupancy are 70 F for heating and 75 F for cooling. A VAV system is used in the Travis building with an economizer cycle. Also, the standards call for temperature setbacks during week nights and weekends. Current operation of the Travis building is consistent with this requirement. Chilled water is provided to the Travis building from a central chilling plant. A coefficient of performance (COP) of 3.0 is assumed for the chillers.

RESULTS

Table 7 shows the distribution of loads with the ASHRAE standards. The change in peak loads for the Travis building and the building with ASHRAE standards is shown in Table 8. There is an average change of 4 percent in peak cooling load. The reduction as compared to the base is from the heat gain from lighting since the lighting levels were reduced by 0.4 w/sf. The peak heating load increased for the building with ASHRAE standards. The increase in heating load is due to lower lighting levels recommended by the proposed ASHRAE standards. The change in total EUI is given in Table 9. There was an average reduction of 7 percent in the total energy with the use of ASHRAE standards. Both heating and cooling energy use were reduced with the ASHRAE design. The reduction in cooling loads is from the reduced lighting levels and the increase in design cooling temperature. The reduction in heating energy is primarily from the decrease in the design heating temperature.

IMPROVED GLASS

Glass is a major contributor to the peak load and energy use in the Travis building. As seen from Figure 3 and 4, DOE 2.1B estimates 36% of the peak cooling load and 27% of the total cooling energy use either from glass solar or glass conduction. The glass in the Travis building is tinted. There are other glasses which reflect much of the direct solar energy and have a lower thermal conductivity. Table 10 shows one such glass which was documented in the DOE 2.1B library. Table 11 shows the percent reduction of the peak glass solar and glass conduction for cooling with the improved glass. Table 12 shows the change of glass conduction load for heating with the improved glass.

Table 13 compares the loads of base Travis building with that of ASHRAE and with the improved glass type. There is a reduction of 22 percent in energy consumption with the building with ASHRAE standards and improved glass. There was a reduction of 6.4% in total energy use for ASHRAE design building as compared with the base. Hence, the reduction in total energy use due to the improved glass on the base building is about 15.6%.

CALIFORNIA STANDARDS

California has had strict energy requirements for the past few years [3]. A copy of the California standards was obtained to evaluate what impact these standards might have on the EUI for buildings in this part of the country. Table 14 shows the major differences between the base building and the California Standards. The California Standard's run assumes use of standards applicable to climate zones 14 and 15 in California.

Table 7 - Comparison of Energy Use For Travis Building with

Proposed ASHRAE Standards at Different Locations in Texas

Location	Chilling+ MBTU	Heating MBTU	Lighting & Equipment MBTU (MWH)	Fans MBTU (MWH)	Total MBTU	EUI KBTU/SF
Brownsville	9768	1062	16885(4947)	14593(4276)	42308	91.8
Houston	6591	2489	16885(4947)	13845(4057)	39810	86.4
Austin	6562	5745	16885(4947)	14452(4234)	43644	94.7
Lubbock	4430	12622	16885(4947)	14614(4282)	48551	105.3
El Paso	5470	20499	16885(4947)	5047(4409)	57901	125.6

+ Assumes COP = 3

Table 8 - Comparison of Peak Loads For Travis Building

Proposed ASHRAE Standards at Different Locations In Texas

(MBtu/hr)

Location	Base Cooling Load	ASHRAE Cooling Load	Percent Reduction	Base Heating Load	ASHRAE Heating Load	Percent Reduction
Brownsville	11.09	10.68	3.6	2.11	2.43	-1.5
Houston	9.89	9.48	4.2	3.13	3.23	-3.0
Austin	9.17	8.76	4.5	2.78	3.10	-1.0
Lubbock	9.24	8.84	4.4	5.26	5.61	-6.1
El Paso	9.21	8.79	4.5	3.53	3.62	-2.7

Table 9 - Comparison of Base and ASHRAE EUI For Travis Building

at Different Locations in Texas (KBtu/Sf).

Location	Base EUI	ASHRAE EUI	Percent Reduction
Brownsville	96.7	91.8	7.0
Houston	93.4	86.4	7.5
Austin	101.0	94.7	6.4
Lubbock	116.7	105.3	9.8
El Paso	133.7	125.6	6.0

Table 10 - Comparison of Existing Glass Properties to Modified Glass Type

Type of Glass	Reflectivity (Percent)	Transmissivity (Percent)	"U' Value (Btu/hr-sf-F)
Existing	14	75	0.79
Improved	45	19	0.27

Table 11 - Comparison of Glass Solar, Glass Conduction (peak cooling) For Base Glass and Glass-1 for Travis Building at Austin

Type	Glass Solar (MBtu/hr)	Glass Conduction (MBtu/hr)
Base	1.51	1.90
Glass-1	0.43	0.71
% Reduction	72	63

Table 12 - Comparison of Glass Conduction (Peak Heating) for Base Glass and Glass-1 for Travis Building at Austin

Glass Conduction Base	(MBtu/hr) Glass-1	Percent Reduction
3.33	1.07	68

Table 13 - Comparison of Total Energy Use For Travis Building with Base Glass and Glass-1

Option	Chilling (Mbtu)	Heating (Mbtu)	Electricity (Mbtu)	Total (Mbtu)	EUI(kbtu/sf)
Base	6972	5873	33763	46608	101.0
ASHRAE	6562	5745	31337	43644	94.7
ASHRAE & GLASS-1	5143	5171	25996	36310	78.8

Table 14. Comparison of Base Building and California Standard Requirements

Item	Base	Standards
Lighting	2.2 w/sf	1.5 w/sf
Design Heating	74 F	70 F
Design Cooling	75 F	78 F
Maximum Glazing	77%	50%
Heating	Electrical	Non-Electrical or Heat Pump

Table 15 shows the comparisons of peak heating and cooling loads for the base building and the modified building which conformed to the California standards. The reduction in peak cooling load with California was 19%. The reduction of the peak cooling load was because the total glazed surface was reduced to half of the total exterior wall area and also the lighting levels were lowered by 0.7 w/sf. The reduction in peak heating load with the California standard was about 12%. The peak heating load decreased because the conduction through the glass dropped since the window surface area was reduced to half of the exterior wall area. Table 16 shows the comparison of total heating, cooling and electric energy for base building, building with California standards and building with California standards and improved glass. Because the California standards restrict the total glazing to 50% of the exterior wall area, restrict lighting levels to 1.5 w/sf and require a heat pump for heating, the total energy consumption has dropped by 36%. The major reduction in cooling energy use was the solar through the glass, light-to-space and also because of the increase in design cooling temperature. The reduction of total heating energy is basically from glass conduction and also from the decrease in design heating temperature. There was a drop of 41% in total energy use for California standards with improved glass as compared with the base building. This reduction was due to higher reflectivity and lower 'U' value of the improved glass and also due to the California Standard.

Although implementing the California Standard shows a substantial reduction in both peak loads and total energy use, the economics still have to be worked out. The requirement for heat pumps for heating may drive up the initial cost of the building significantly. More expensive direct expansion coils would have to be used as compared to relatively inexpensive electric resistance heaters. However, it would also be possible to use water source heat pumps to move heat from one section of the building to another. Thus, the heat extracted from an area needing cooling could be rejected in an area needing heating. This operation would also reduce the chiller power in the winter months.

Table 15 - Comparison of Peak Loads For Base Travis Building with the Building with California Standards

Option	Cooling Load (Mbtu/h)	Heating Load (Mbtu/h)
Base	9.17	2.78
Cal. Stand.	7.42	2.45

Table 16 - Comparison of Energy Use For Base Travis Building with Modified Building with California Standards

Option	Chilling+ Mbtu	Heating Mbtu	Lighting & Equipment Mbtu (MWH)	Fans Mbtu (MWH)	Total Mbtu	EUI Kbtu/SF
Base	6972	5873	18795 (5507)	14968 (4386)	46608	101.0
Cal. Stand	4873	2083*	15454 (4528)	311 (2142)	29722	64.5
Cal. Stand + Glass-1	4099	2321*	15454 (4528)	5497 (1611)	27371	59.4

* Heat pump COP=2.0
+ Chiller COP = 3.0

CONCLUSIONS

The current construction of the Travis building reflects improvements in energy use over buildings built several years ago (EUI of 101 Kbtu/sf/yr compared to as much as 250 kbtu/sf/yr [6]). Weather plays a significant role even with an office building with big internal loads. Some of the options for reducing the building energy use, are using glass with high reflectivity and low 'U' value, reducing the lighting levels, and reducing glass area. These options will not only reduce the peak loads but also reduce the total energy use. Both the proposed ASHRAE standards and the California standards appear to reduce energy use. California standards are more stringent and may be a better choice for state owned buildings which have a life of 40 to 50 years.

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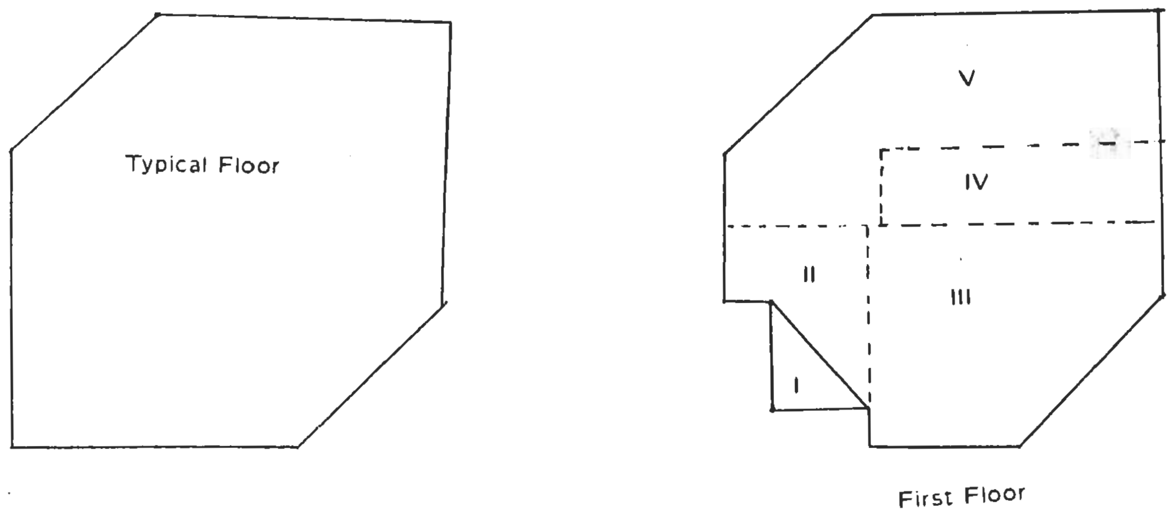

Figure 1 - Schematic of Zones in Travis Building

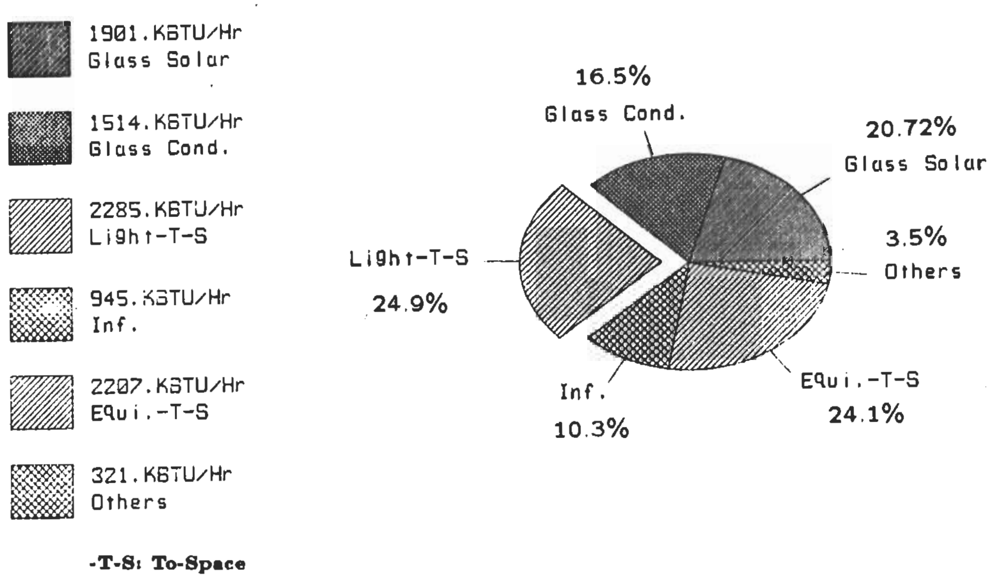

Figure 2 - Peak Cooling Load-Base Travis Building

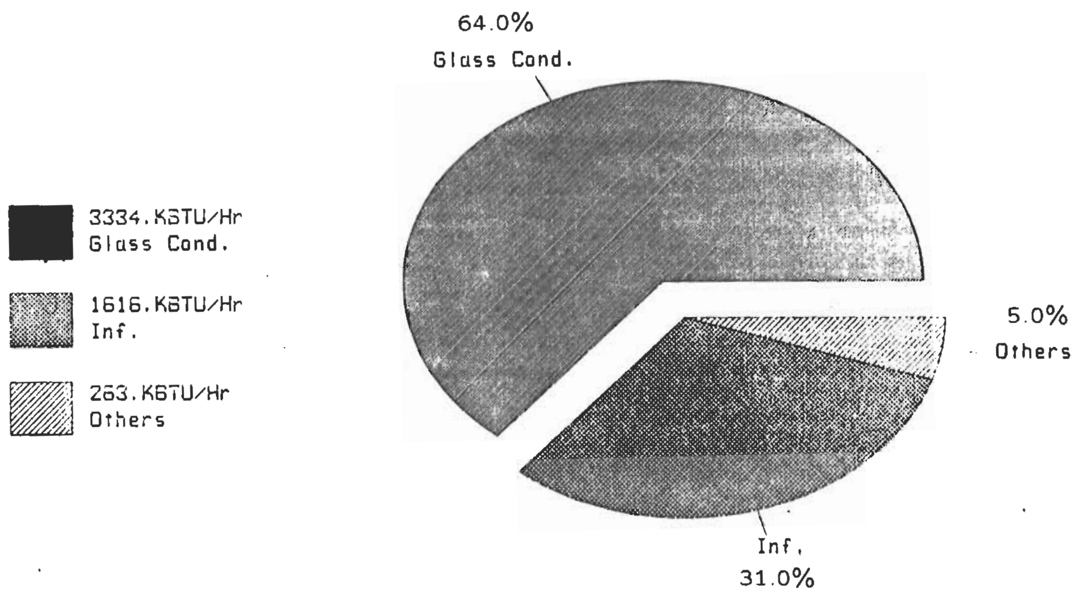

Figure 3 - Peak Heating Load-Base Travis Building

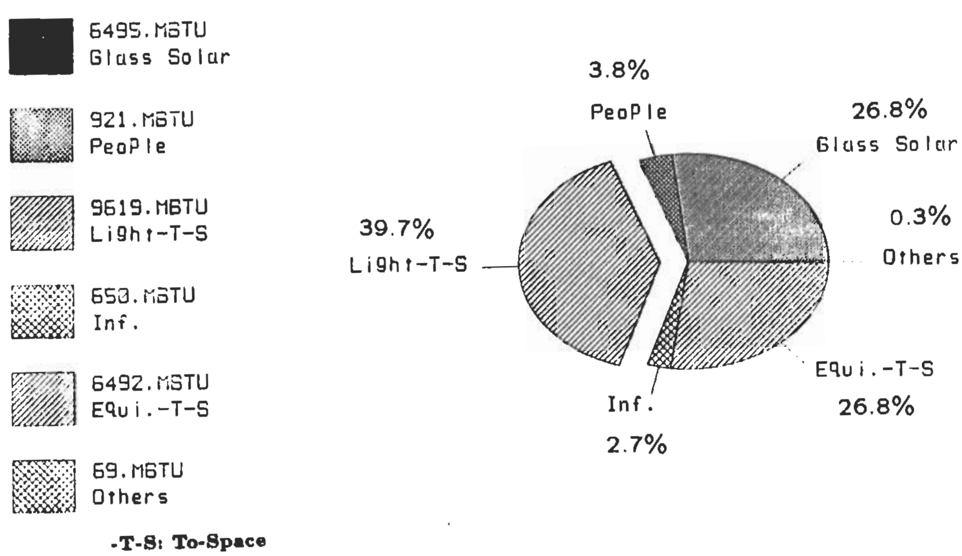

Figure 4 - Total Cooling - Base Travis Building

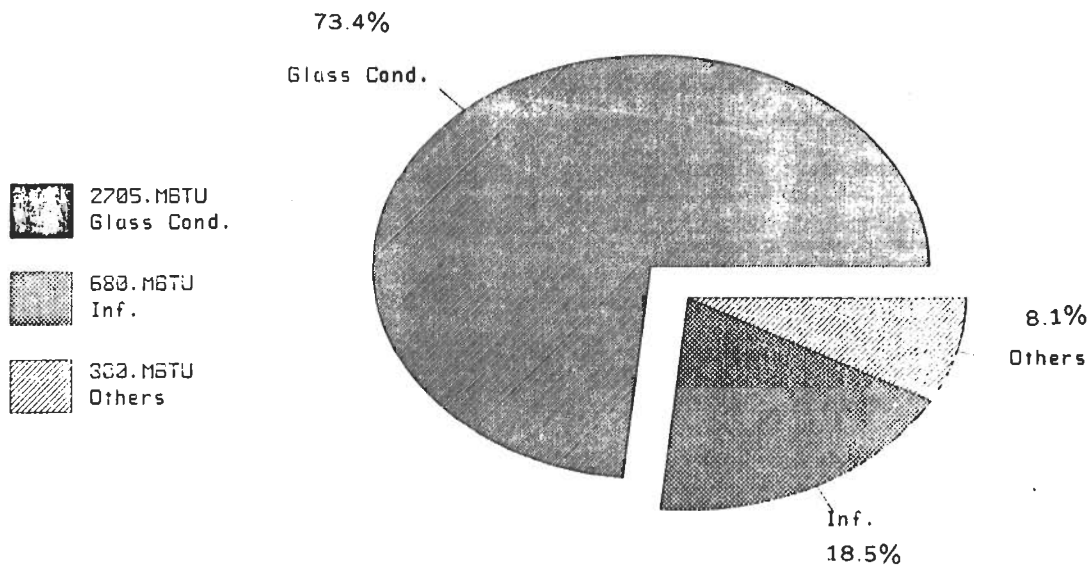

Figure 5 - Ttoal Heating-Base Travis Building