Energy Conservation Study for Puerto Rico Aqueduct and Sewer Authority Building

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ABSTRACT

This paper is about the study and investigation of various energy conservation opportunities in connection with the building envelope and mechanical and electrical systems of the Puerto Rico Aqueduct and Sewer Authority building. The ten-story building, located in San Juan, has a gross floor area of 165,000 square feet and is used mainly for offices.

The Cal/ERDA computer program (presently DOE-2) for energy utilization analysis of buildings was the principal basis for the calculations with manual and other computer calculations for wall and window heat transmission and solar heat gains used to complement the Cal/ERDA calculations.

The results of the study of each Energy Conservation Opportunity is reported including yearly savings in electrical energy and the resulting pay back periods. Table shows comparable individual savings of all the various Energy Conserving Opportunities for 1 year, 5 years, and 10 years including long term monetary savings and savings in barrels of oil over a 20 year period.

The results of the computer program evaluation indicates close agreement between the actual building energy consumption and that predicted by the computer calculations.

The annual energy savings when all the energy conserving measures are combined amounts to 28% of the annual energy consumption with a pay back period of 18 months.

INTRODUCTION

This study was made to determine the energy savings potential for the various selected energy conserving options which could be applied to this building and its air conditioning,ventilating and electrical systems.

Fundamental to an accurate prediction of the energy savings possible for each of the opportunities to be investigated was the computer program. The selection of the program; therefore, became the first priority of the study.

COMPUTER PROGRAM SELECTION

The primary criteria for selection of the program was to select that program with the necessary refined calculation procedure for the most accurate determination of hour-by-hour cooling load and the most precise simulation of the building's air conditioning and mechanical ventilating systems.

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Based on a review of the ASHRAE Bibliography of Available Computer Programs[1], those energy analysis programs which appeared most capable of meeting the criteria were selected for further investigation. During the investigation, it was learned that the Cal/ERDA program[2] was available. Its proponents indicated its advantages were as follows:

* The program met the primary criteria for refinement and accuracy and was based on the widely accepted ASHRAE algorithims and procedures.

* It was a public domain program.

* The program utilized a free-format "Building Design Language" which greatly facilitates the user's task in defining the building and its air conditioning and mechanical ventilating systems for its LOADS, SYSTEMS, PLANTS and ECONOMICS simulation programs.

* The computer "runs" were considerably less expensive.

Based on the indicated advantages, this was the program which was chosen and used.

The author of this paper, who was in charge of this study, had no previous computer experience and was fortunate in being able to retain the services of one of the principal authors of the program and also the services of a computer program applications engineer familiar with the program and its language.

The author also, in providing all the input data of the building envelope and its systems, worked directly with the applications engineer who translated this data into the "Building Design Language" (BDL) to form the input for the program. This exposure to the program's language was used to advantage during the review, verification and manual calculations process when it was necessary to refer to the program input and output printout.

THE BUILDING

The building selected for this study is the principal headquarters office building of the Puerto Rico Aqueduct and Sewer Authority. A photograph of the building as viewed from the East and South is shown in Fig. 1. The principal building information is as follows:

Location: San Juan, Puerto Rico (18.5°North)
Orientation: Long sides facing directly North and South
Typical floor size: 170 ft. x 86 ft. (51.8 m x 26.2 m)
Second floor size: 183 ft. x 98 ft. (55.8 m x 29.9 m)
Total gross floor area: 165,000 ft^2 (15,329 m^2)
Walls R-Value: 1.8 $hr \cdot ft^2 \cdot F/Btu$ (0.32 $m^2 \cdot K/W$)
Net wall area (typical floor): 4,612 ft^2 (428 m^2)
Net glass area (typical floor): 918 ft^2 (85.3 m^2)
Glass-wall area ratio: 20%
Glass shading coefficient: 0.88
Outdoor typical design condition: 87 Fdb and 80 Fwb (30.6°Cdb and 26.7°Cwb)
Indoor occupied condition: 74°Fdb (23.3°C)
Exterior wall color: medium

SYSTEMS

A brief description of the various systems follows:

Main Air System

This is a variable volume system with a single large cooling coil bank and fan located on the roof. This coil bank utilizes chilled water from the central plant in basement. This system serves most of the building from the first floor through the tenth floor except for the small systems described below. Multiple individual zones on each floor are controlled by variable volume terminals located above the ceiling and supplying air through lamp fixtures which also serve as return and lamp heat extraction means.

The supply fan is a centrifugal airfoil with inlet vanes. Fan and system capacity is 130,000 cfm (61.4 m^3/s) at 6 in. of water (1493 Pa) with a 250 hp (186.4 kw) fan motor with a V-belt drive.

The normal daily operating schedule is from 5 AM to 5 PM.

Basement System

This is a constant volume air system utilizing a 20 ton (70 kw) self-contained water-cooled unit. Condenser water used for unit condenser and reheat is from central spray-pond-cooled condenser water system. The normal operating schedule is from 6 AM to 4:30 PM.

First Floor Telephone Equipment Room

This is a small 3 ton (10.6 kw) water-cooled packaged unit. Condenser water fed from secondary system pump from the central spray-pond-cooled condenser water system. Normal operating hours for this system is 24 hours.

Second Floor Computer Rooms

Three water-cooled package units serve this area and consist of two 15 ton (53 kw) water-cooled units with 6 kw electric reheat coils and one 7 ton (24.6kw) unit with 6 kw electric reheat coil. Also, one 10 ton (35.2 kw) air-cooled package unit with two compressors serves this same area. Condenser water for the water-cooled units is fed by the secondary pump from the spray-pond-cooled central condenser water system. Normal operation is 24 hoursand seven days a week.

Third Floor

The assembly-meeting room unit is a separate single zone 17 ton (60 kw) air handling unit utilizing chilled water from the central chilled water plant. The reheat coil for this unit is an 8 kw electric unit. Operating hours is same as for main system.

The cafeteria unit is a similar system with a 20 ton (70.3 kw) unit with a 4 kw electric reheat coil. Operation is the same as for the main system.

Tenth Floor Administrative Offices

This 7.5 ton (26.4 kw) unit is a split-system direct expansion type. Normal operating hours is from 7:30 AM until 6 PM.

Chilled Water Plant

This system consists of two centrifugal water-cooled chillers having a catalog rated capacity of 398 tons (1400 kw) each. Condenser water is supplied from the main central spray-pond-cooled condenser water system. Condenser water flow is in parallel through the condensers utilizing two 25 hp (18.6 kw) pumps (one for each chiller condenser). Chilled water flow is in parallel through the chiller evaporators utilizing a single 50 hp (37.3 kw) pump which supplies chilled water to the main system for first through tenth floors and the cafeteria and assembly-meeting room units located on the third floor. Operation of this system is the same as for the main air system.

WEATHER

The average temperature in San Juan is between 79 F (26.1 °C) and 80 F (26.7°C) dry bulb and between 74 F (23.3°C) and 75 F (23.9°C) wet bulb. The average daily range is approximately 10 F (5.5°C). San Juan has no heating degree days. The highest and lowest temperatures ever recorded are 96 F (35.6°C) and 62 F

(16.7°C) respectively.

The warm and humid climate prevailing in Puerto Rico together with the relatively high solar radiation makes it a year-round "all cooling" climate. All the weather data including cloud cover constitutes an important input for the computer program. The 1961 weather tape data consisting of 8,760 hours of data was selected and used for the weather input.

COMPUTER INPUT

Initially and prior to input of the building envelope and systems data, different possibilities were considered for handling the input data for the miscellaneous small air conditioning systems and air conditioning for the computer rooms. It was important that the computer program output reflect accurately the building envelope load, the energy conservation options to be investigated and their effects on the building systems. It was also important that the program output reflect accurately the energy used by the central chilled water plant while at the same time minimize computer time.

To meet these objectives, the miscellaneous loads such as building exhaust fans, computer equipment loads, and the supply fans and pumps for the smaller air conditioning systems were input as part of the basement system. Also, the input was done so that the main air system would reflect the building envelope loads and the effect of the envelope options to be studied. This would maintain reasonable accuracy for the various options to be studied, for the central plant and building energy use, and achieve simplification of the computer input.

COMPUTER OUTPUT

Review of the final computer output reports indicated the computer program did not have the capability of re-selection of fan speed and the retrofit of fan drive and motor to take advantage of the smaller motor required and the energy savings made possible by each of the energy conservation options. Therefore, the output from the building loads and energy reports was utilized as a basis for manual calculations to determine the new reduced air flow requirements, reduced fan speed, reduced fan motor size, and the energy reductions due to the reduced loads and energy use resulting from the implementation of each of the options. This is further explained under Manual Calculations which follow.

MANUAL CALCULATIONS

Manual calculations were made for the purpose of verifying, where possible, the results from the computer program output. The verification for the reflective film for window option and the wall insulation option were made possible by special computer studies which had been made previously and independent of the Cal/ERDA computer study.

As previously indicated, the computer program had no provision for fan motor and drive retrofit to match the reduced peak loads resulting from each energy conservation opportunity (ECO); therefore, manual re-selection of fan motor and drive, and manual calculation of yearly energy use was done for each ECO. Output data from the building load and energy use reports of the computer program were used as a basis for these manual calculations. Fan motor and drive retrofitting proved to be a substantial part of the total energy savings potential.

For most ECO's, a substantial reduction in peak air flow rate was realized due to the reduction in peak cooling load. In each case, the new fan peak air flow and fan pressure were calculated. The fan catalog for the fan was then used to re-select the new fan speed and motor power required. In most cases, a retrofit to a smaller motor was possible. Using fan curve in combination with the system curve; the power requirements, energy use and costs for the year were calculated.

Using the same computer program output report data in combination with the chiller load-capacity curve, the power requirements, energy use and energy costs for chiller operation were calculated.

Combining the yearly chiller and fan energy costs gave the total energy cost for fan and chiller for each ECO. Finally, the energy cost saving due to the implementation of each ECO was determined by calculating the difference between the total energy cost of the "base building" fan and chiller versus the fan and chiller total energy cost but with the ECO implemented.

RESULTS AND DISCUSSION

The results of the study are summarized in Table 1 and 2. Each energy conservation option was given an Energy Conservation Opportunity (ECO) number for reference purposes. The cost savings due to savings in electrical energy use are based on a first year, 1980, expected energy cost of 7.4 cents/kwh with escalation in energy costs estimated at 4% per year.

Table 1 electrical energy savings for ECO's 1 through 12, are the energy savings predicted for the implementation of the single ECO alone; i.e., not in combination with any other ECO. Savings for ECO's 13, 16 and 18 are the predicted saving when the various ECO's are implemented in combination. The savings for ECO-14 are predicted for this ECO implemented either alone or in combination with others. ECO-15 savings are dependent upon implementation of ECO's 2,7 and 14 and should be implemented only after load reductions made possible by these other ECO's. ECO-17 savings are those predicted for heat recovery installation only after reduction of outside air through ECO-14.

Table 2 savings and pay back periods are indicated for two conditions; i.e., the single ECO implemented alone or implemented together with other ECO's. Pay back periods are estimated based on estimates of cost to implement each ECO.

Computer Energy Use Predictions

The computer program calculated the total energy use for the building and was reported in the summary output report. This predicted energy use was for the "base building" based on the actual building envelope and systems survey input data. The actual energy use for the year 1977 and 1978 were available.

For 1977, the actual use of electric energy was 3,989,500 kwh. For 1978, the actual use of electrical energy was 4,332,750 kwh. The computer predicted use was 3,893,385 kwh. The computer predicted use was lower than the 1977 actual use by 2.4% and lower than the 1978 actual use by 10.1%.

The 1978 electrical energy use for the building mechanical and electrical systems was approximately 89,600 Btu/ft^2·yr (32.3 W/m^2). Based on a predicted savings of 28% through implementation of all energy conservation opportunities, the energy use expected would be reduced to approximately 64,500 Btu/ft^2·yr (23.2 W/m^2). The pay back period predicted for implementing all the options is 18 months.

Relative to ECO-15, retrofit of the chilled water plant, it is significant that the load reductions made possible by the reduction in lighting, application of reflective film to windows and reduction of outside air ventilation from 29,000 cfm (13.69 m^3/s) to 11,000 cfm (5.19 m^3/s) were enough to reduce the total load on the cooling coil bank and chiller plant to within the capacity of a single chiller. This then will make possible the retrofitting of the chilled water and condenser water pumping and piping systems for operation with a single chiller in lieu of the present two chillers. The reduction in pumping costs resulting from decrease in water flow rates through the retrofit is substantial.

Graphic Comparisons

Figure 2 shows the comparison of the relative savings of the various Energy Conserving Opportunities in percent of the total savings and on the basis of Btu/yr·ft^2 based on the gross floor area.

Figure 3 shows the comparison ot the building envelope options. Savings are indicated as percent of total savings for all envelope options and also on the basis of Btu/yr·ft^2 based on the building gross floor area.

Figure 4 shows the same savings comparison of the building envelope options except that the values have been adjusted as if the building were square in plan; i.e., with equal wall and glass areas on each facade. This shows then the comparison on an equal area basis; indicating that reflective film is most effective on the South glass with the film about equally effective on the East and West exposures.

CONCLUSIONS

** Large and significant savings in electrical energy along with the related costs are possible through implementation of the principles of energy conservation related to efficient building envelope and systems. Most energy conservation options pay back in a short time the cost to implement them.

** Savings due to implementation of energy conserving options in existing buildings are comparable to savings to be expected in applying the same options in new building construction.

** The Cal/ERDA program has been found to be an accurate and effective tool for use in prediction of energy utilization for the building and building systems considered in this study. Its use in analysis of energy conserving options in existing buildings is apparently as effective as with new buildings. Its new "engineer oriented" BDL language permits verification of input and output data and provides the user, even with limited experience, the access to the program which is needed to use and develop confidence in the program. The detailed output reports built into the program provide information which can be used in the manual verification and manual re-selection of system components important in the retrofit of existing buildings.

** The DOE-2 computer program[3] which is the present and updated version of the original Cal/ERDA program should provide a better tool in the improved utilization of energy in buildings. Its improvements in the Loads, Systems, Plants and Economics programs should make it an even more accurate and effective tool for energy conservation, utilization and analysis.

REFERENCES

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SAVINGS FOR IMPLEMENTING ENERGY CONSERVATION OPPORTUNITIES (ECO)

ECO, ENERGY CONSERVATION OPPORTUNITY	ELECTRICAL ENERGY SAVINGS Kwh/Yr.	COST SAVINGS - ELECTRICAL ENERGY				BARRELS FUEL OIL SAVED IN 20 Years
		$ per 1 Year	$ per 5 Years	$ per 10 Years	$ per 20 Years	
ECO-1, One hour late start	90,459	6,694	36,184	80,509	199,010	3,119
ECO-2, Reduce lights 25%	513,811	38,022	205,524	457,292	1,130,384	17,718
ECO-3, Film glass, North	18,216	1,348	7,286	16,212	40,075	628
ECO-4, Film glass, South	65,176	4,823	26,070	58,007	143,387	2,247
ECO-5, Film glass, East	34,311	2,539	13,724	30,537	75,484	1,183
ECO-6, Film glass, West	38,257	2,831	15,303	34,049	84,165	1,319
ECO-7, Film glass, All sides	143,041	10,585	57,216	127,306	314,690	4,932
ECO-8, Insul. walls, North	38,095	2,819	15,238	33,905	83,809	1,314
ECO-9, Insul. walls, South	51,324	3,798	20,530	45,678	112,913	1,770
ECO-10, Insul. walls, East	31,351	2,320	12,540	27,902	68,972	1,081
ECO-11, Insul. walls, West	27,297	2,020	10,919	24,294	60,053	941
ECO-12, Insul. walls, All	115,135	8,520	46,054	102,470	253,297	3,970
ECO-13, Multiple: * One hour late start * Reduce lights 25% * Film, All Glass * Insul., All Walls	802,122	59,357	320,849	713,889	1,764,668	27,659
ECO-14, Reduce outside air	140,932	10,429	56,373	125,429	310,050	4,860
ECO-15, Retrofit chiller plant	107,257	7,937	42,903	95,459	235,965	3,699
ECO-16, Multiple: * One hour late start * Reduce lights 25% * Film, All Glass * Insul., All Walls * Reduce outside air * Retrofit chiller plant	1,050,311	77,723	420,124	934,777	2,310,684	36,218
ECO-17, Heat Recovery, o.a.	31,230	2,311	12,492	27,795	68,706	1,077
ECO-18, Multiple: * One hour late start * Reduce lights 25% * Film, All Glass * Insul., All Walls * Reduce outside air * Retrofit chiller plant * Heat recovery, o.a.	1,081,541	80,034	432,616	962,571	2,379,390	37,295

Notes: 1. Except for multiple ECO's indicated, savings are for single ECO implemented alone.
2. See Table 2 for savings for each ECO when implemented together with other ECO's. Pay back periods for each ECO also included in Table 2.
3. Cost of electrical energy based on expected cost of 0.074 $/Kwh by 1980 with escalation in cost estimated at 4 % per year.
4. Barrels of fuel oil saved is based on 580 Kwh/barrel at building for oil burned at generating plant.

SAVINGS FOR IMPLEMENTING ENERGY CONSERVATION OPPORTUNITIES (ECO)

TABLE 1.

SAVINGS AND SIMPLE PAY BACK PERIODS FOR ENERGY CONSERVATION OPPORTUNITIES (ECO)

ECO ENERGY CONSERVATION OPPORTUNITY	SINGLE ECO IMPLEMENTED ALONE		SEE NOTE	CONTRIBUTION OF SINGLE ECO WHEN IMPLEMENTED TOGETHER WITH OTHER ECO OR AS MULTIPLE ECO		SEE NOTE
	SAVINGS $/year	PAY BACK years		SAVINGS $/year	PAY BACK years	
ECO-1, One hour late start	6,694	immediate		5,682	immediate	1,2
ECO-2, Reduce lights 25%	38,022	small	2	36,820	small	1,2
ECO-3, Film glass, North	1,348	2.3	2	1,215	2.5	1,2
ECO-4, Film glass, South	4,823	0.6	2	4,468	0.7	1,2
ECO-5, Film glass, East	2,539	0.6	2	1,767	0.9	1,2
ECO-6, Film glass, West	2,831	0.6	2	1,940	0.8	1,2
ECO-7, Film glass, all sides	10,585	0.9	2	9,390	1	1,2
ECO-8, Insul. walls, North	2,819	8.2	2	1,917	12.1	1,2
ECO-9, Insul. walls, South	3,798	6.1	2	3,066	7.6	1,2
ECO-10, Insul. walls, East	2,320	5.1	2	1,415	8.4	1,2
ECO-11, Insul. walls, West	2,020	5.9	2	1,068	11.1	1,2
ECO-12, Insul. walls, all	8,520	8.2	2	7,466	9.4	1,2
ECO-13, Multiple:				59,357	1.5	
*One hour late start						2
*Reduce lights 25%						2
*Film, All glass						2
*Insul., All walls						2
ECO-14, Reduce outside air	10,429	less than 1		10,429	less than 1	
ECO-15, Retro. chiller plant				7,937	less than 1.5	
ECO-16, Multiple:				77,723	less than 1.25	
*One hour late start						2
*Reduce lights 25%						2
*Film, All glass						2
*Insul., All walls						2
*Reduce outside air						
*Retrofit chillerplant						
ECO-17, Heat Recov., o.a.				2,311	more than 10	
ECO-18, Multiple:				80,034	approx. 1.5	
*One hour late start						2
*Reduce lights 25%						2
*Film, all glass						2
*Insul., all walls						2
*Reduce outside air						
*Retrofit chiller plant						
*Heat recovery, o.a.						

Note 1. This saving and pay back period represents the proportionate contribution of this single ECO towards the total combined saving for the multiple ECO's of ECO-13.

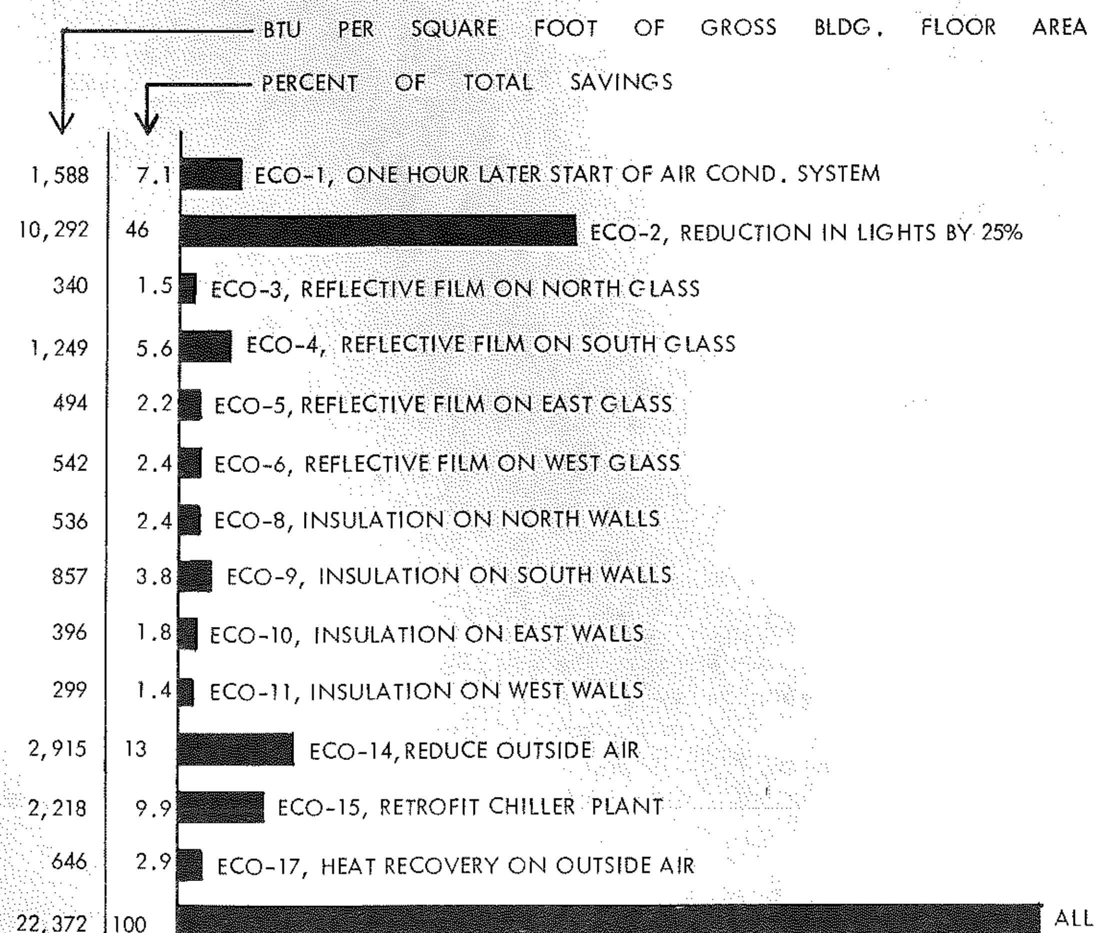
2. Operating economies provided by the load reduction of this ECO can be realized only through reduction of fan speed by fan motor and/or drive retrofit to match the new reduced load and by satisfactory operation of the fan inlet vanes and their automatic control system. It is essential that the lowest fan speed and the smallest fan motor required by the new load be utilized.

SAVINGS AND SIMPLE PAY BACK PERIODS
FOR ENERGY CONSERVATION OPPORTUNITIES (ECO)

TABLE 2.

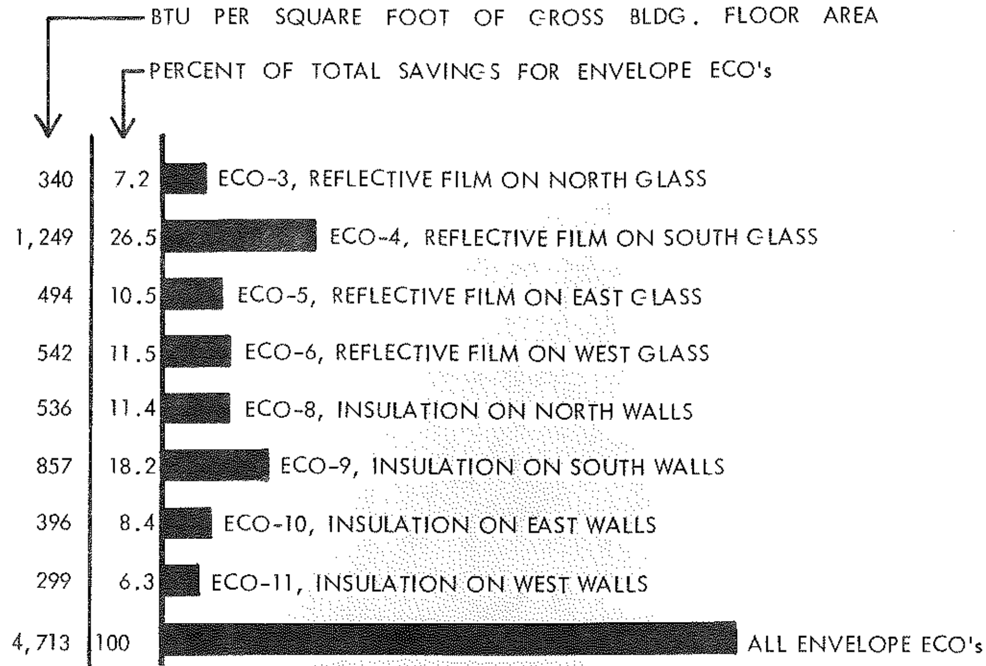
THE BUILDING

Fig. 1



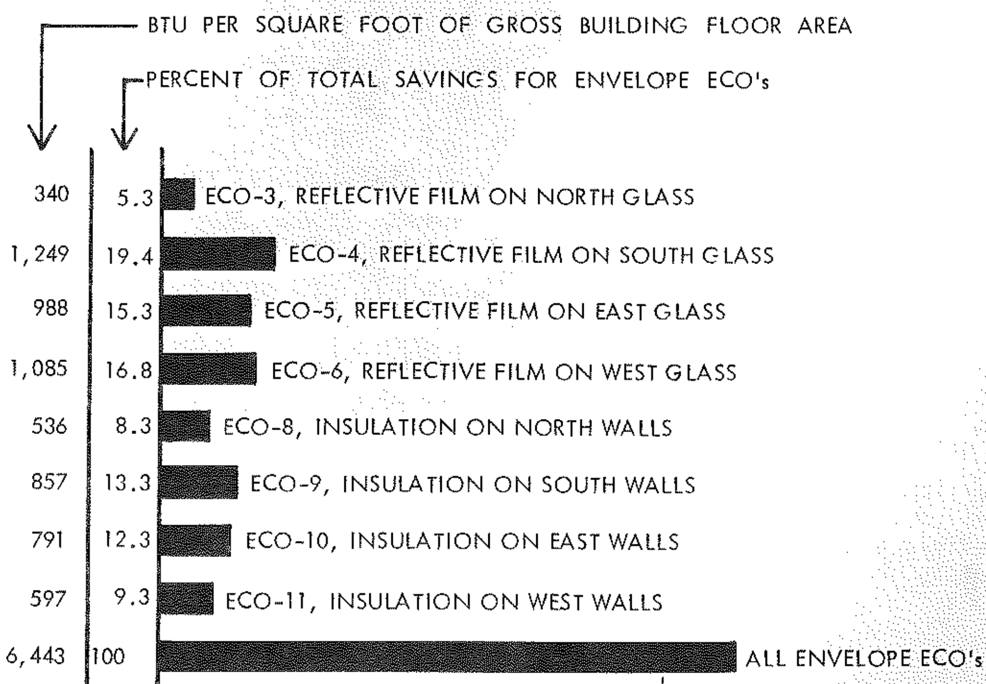
YEARLY ENERGY SAVINGS

Fig. 2



YEARLY ENERGY SAVINGS - ENVELOPE ONLY
FOR ENVELOPE ENERGY CONSERVATION OPPORTUNITIES (ECO)

Fig. 3



YEARLY ENERGY SAVINGS - ENVELOPE ONLY
FOR ENVELOPE ENERGY CONSERVATION OPPORTUNITIES, ADJUSTED FLOOR PLAN

(Adjusted for equal facade areas on North, South, East and West with square floor plan)

Fig. 4