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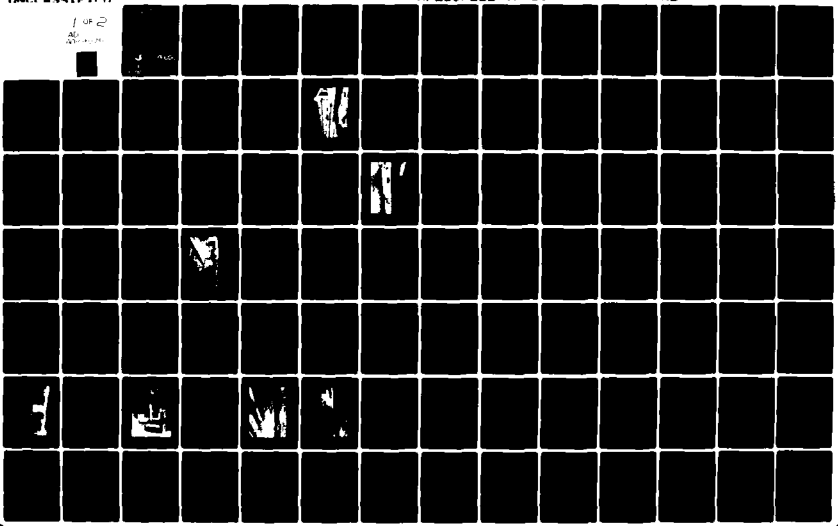

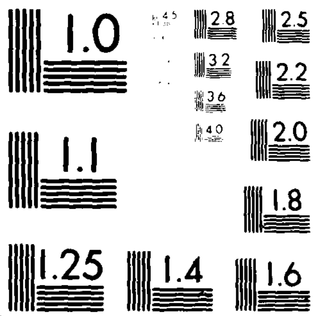

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ENERGY CONSERVATION AND MANAGEMENT STUDY OF AIRCRAFT HANGARS AT SELECTED AIR FORCE BASES

NEIL P. LESLIE
GARD, INCORPORATED
7449 NORTH NATCHEZ AVENUE
NILES, ILLINOIS 60648

JANUARY 1980

FINAL REPORT
JULY 1979 – DECEMBER 1979

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20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

Most existing Air Force aircraft hangars were not originally designed to conserve energy according to present criteria. This study determines the sources of energy waste in hangars at three representative bases, quantifies the losses, and analyzes the economic feasibility of various retrofit ideas to reduce losses.

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SUMMARY

The objective of this report was to perform an energy conservation and management survey for fifteen aircraft hangars at three selected Air Force Bases. To achieve this objective, it was necessary to perform field surveys for each hangar, develop a descriptive listing of potential energy conservation opportunities (ECO's) for review by the sponsor, and perform an energy and economic analysis of thirty ECO's selected by the sponsor.

Section II discusses the approach used in the surveys and economic analyses. Section III summarizes the results of on-site surveys and lists ECO's currently being implemented as a part of the Energy Conservation Investment Program (ECIP). Section IV provides a detailed discussion of each ECO selected and summarizes the results of the economic analysis of ECO's for each hangar. Section V discusses the recommendations made based on the results of the survey and economic analysis.

The detailed on-site surveys at Langley AFB, Minot AFB, and Tinker AFB generated some interesting results. Infiltration is one of the most important factors in energy consumption in hangars. Ceilings are up to 40 feet higher than required for aircraft service clearance, but fire protection systems reduce the feasibility of lowering ceilings. Stratification causes temperatures to exceed 100 degrees F in the truss space in winter while floor temperatures are as low as 50 degrees F. Windows are not always needed, and blocking them offers substantial energy savings. Heating systems are often undersized for comfort heating. Fighter aircraft are deiced using building heat because deicing fluid corrodes electronic wiring.

Based on the field surveys, almost one hundred potential ECO's were developed in the architectural, electrical, mechanical, operational, and structural disciplines. From this list, the following fourteen distinct ECO's were selected for economic analysis: remove windows; paint floors with reflective paint; add portable door seals; interlock heaters with hangar doors; lower light fixtures; supply air at 25-degree F ΔT; add destratification fans; use infrared radiant heaters; use vehicle doors for aerospace ground equipment (AGE); minimize deicing of aircraft; lower ceiling; add power factor correction; add air curtains; and add vehicle doors.

The results of an energy savings analysis showed that all modifications except electric infrared heaters, lowering light fixtures, painting floors with reflective paint, and supplying air at 25 degrees F ΔT would save resource energy.

The results of the economic analysis performed for each ECO are summarized below. The ECO's are ranked in descending order of economic attractiveness using the energy/cost ratio as the ranking criterion.

Modification	LCC*	Project Cost	B/C* Ratio	E/C* Ratio
Use Vehicle Doors	258,800	0	∞	∞
Minimize Deicing	6,000	0	∞	∞
Add Air Curtains	343,000	23,000	16	376
Interlock Heaters	290,100	38,760	8.5	234
Portable Door Seals	283,500	34,140	9.3	216
Add Vehicle Doors	47,200	34,200	2.4	68
Destratification Fans	537,000	450,000	2.2	50
Remove Windows	5,700	5,100	2.1	43
Radiant Heaters	102,800	315,000	1.3	36
Power Factor Correction	358,300	48,900	8.3	None

*Notes:
LCC - Life Cycle Cost B/C Ratio - Benefit to Cost Ratio
E/C Ratio - Energy to Cost Ratio

The low indoor design temperature (55 degrees F) and the current low cost of energy at these bases reduces the economic attractiveness of infrared heaters and removing windows. With increasing fuel costs, currently unattractive ECO's will become increasingly attractive.

RECOMMENDATIONS SUMMARY

The following recommendations are based on results of field surveys, energy analyses, and economic analyses for selected ECO's.

Low intensity gas-fired infrared radiant heaters should be installed at Minot AFB to evaluate their true effectiveness. Bids should be received on removing windows at all three bases to reassess the economic attractiveness of this ECO. Portable door seals should be designed and purchased to reduce infiltration through hangar doors. Heaters should be interlocked to shut off when hangar doors are opened. Air curtains should be tested on vehicle doors at each base to determine their actual value. Destratification fans should be installed in high bay hangars at Tinker AFB and Langley AFB. Where vehicle doors are already installed, they should be used for transporting AGE. Where no vehicle doors exist, they should be added. Power factor should be corrected on all bases whose utility charges for poor power factor. Aircraft should be deiced when possible by means other than building heat. Ceilings cannot be lowered due to existing fire protection systems. Lights should be lowered only when replacing old fixtures. Floors should be painted with reflective paint only as a part of scheduled maintenance.

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PREFACE

This report was prepared by GARD, Inc., Niles, Illinois 60648 under Contract No. F08635-79-C-0266 with the Air Force Engineering and Services Center, Tyndall Air Force Base, Florida 32403. The initial Project Officer responsible for development of this work unit was First Lieutenant Michael R. Mantz of the Engineering and Services Laboratory (AFESC/RD). This work was accomplished from July 1979 to December 1979.

This report has been reviewed by the Public Affairs Office (PA) and is releasable to the National Technical Information Service (NTIS). At NTIS it will be available to the general public, including foreign nations.

This technical report has been reviewed and is approved for publication.

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SECTION I

INTRODUCTION

The Air Force has been tasked to reduce energy consumption on its bases by 20 percent in 1985 compared to 1975 usage. As a part of this task, aircraft hangars have been selected for study because they are typically the largest volume spaces and large users of energy on a base.

The purpose of this study is to survey fifteen hangars at three selected Air Force Bases, develop creative energy conservation schemes for each hangar, and perform energy and economic analyses of thirty schemes selected by the Air Force. This work is intended to generate schemes which go beyond opportunities such as those considered in current Energy Conservation Investment Programs (ECIP) at each base.

Section II of this report discusses the approach to the study. This discussion includes a summary of the methodology used to survey and analyze Energy Conservation Opportunities (ECO's) for each hangar. Section III describes the results of the on-site survey at each base. The description includes hangar location, physical characteristics, and operating procedures as well as the list of potential ECO's which were developed as a result of the surveys. Section IV examines the evaluation of the 30 ECO's selected by the Air Force. This evaluation consists of an analysis of energy and cost savings compared to project costs. Section V presents conclusions and recommendations generated as a result of the energy and economic analysis.

SECTION II

APPROACH TO THIS STUDY

INTRODUCTION

The energy conservation and management survey for hangars required that field surveys be performed for a total of fifteen hangars at three selected Air Force Bases (AFB). The bases chosen by the Air Force represent a cross-section of missions and climatic conditions throughout the country. The three bases selected were Langley AFB (Tactical Air Command) in Langley, Virginia; Minot AFB (Strategic Air Command) in Minot, North Dakota; and Tinker AFB (Air Force Logistics Command) in Oklahoma City, Oklahoma.

Based on results of the field surveys, potential Energy Conservation Opportunities (ECO's) were developed using a multi-disciplinary approach to the problem. Since this program was to go beyond the scope of the current Energy Conservation Investment Program (ECIP), creative and unusual ECO's were encouraged.

After the list of potential ECO's was developed, a review meeting was held at Tyndall AFB to select those ECO's considered attractive by the Air Force.

The thirty schemes selected by the Air Force were then analyzed to determine the energy and cost savings associated with each modification. The results of these energy and economic analyses were presented in a technical briefing outlining recommendations detailed in this report.

APPROACH

The proper performance of the tasks on this project required a methodical and organized approach to ensure a successful completion within the allotted budget. GARD's past experience in the energy audit field has resulted in the development of a standard energy audit procedure to provide a framework for the engineer to follow for a complete and comprehensive energy audit. The applicable portions of GARD's standard energy audit procedure used on this job are given in Figure 1.

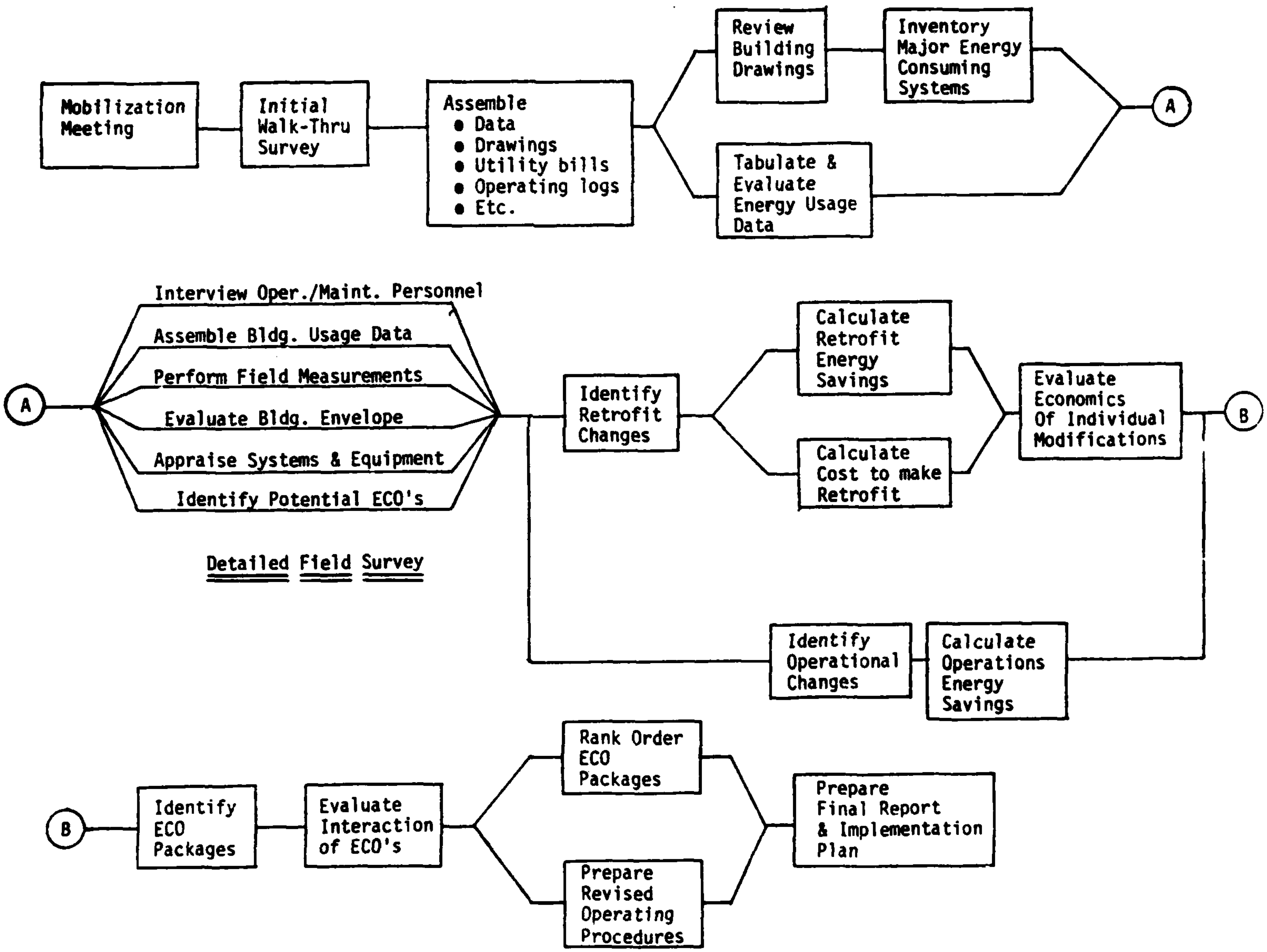


Figure 1. Applicable Portions of GARD's Energy Audit Procedure

SECTION III

RESULTS OF ON-SITE HANGAR SURVEYS

In order to gather data and become familiar with the operation of each hangar, a detailed field survey was conducted at each base.

The survey at each base encompassed five hangars chosen as representative of base missions. Table 1 lists the hangar mission summary of each base as well as gross hangar area in square feet. Figure 2 shows a typical hangar at Langley AFB.

Operating characteristics for each hangar were determined by in-depth interviews with base personnel responsible for hangar operations. In addition to the interviews, meetings were held with the base civil engineering staffs to discuss the current ECIP at each base. Of the fifteen hangars studied, only two were less than 20,000 square feet and thus too small to be audited by base personnel as a part of the Building Energy Audit Program (BEAP).

DATA GATHERED DURING SURVEYS

Several types of data were gathered at each base. Some of the more pertinent data is discussed in the following paragraphs.

The most important set of data for each hangar was the building construction, including dimensions and thermal transmission characteristics. Where necessary, building drawings were used to determine dimensions. All thermal characteristics had been detailed for each hangar as a part of the BEAP at each base.

Operating schedules were gathered through discussions with the chief of operations at each hangar. Frequency and length of opening of hangar and vehicle doors, occupancy schedules, hangar function, light schedules, and inside air temperature in winter were reviewed at each hangar. In addition, a preliminary list of suggested ECO's was discussed to see if these ECO's

TABLE 1. HANGAR MISSION SUMMARY

Langley AFB (TAC)

HANGAR	MISSION	SIZE (sq ft)
338	48th Intercept Maintenance and Shelter Hangar For F-106	37,430
351	Maintenance and Shelter Hangar	67,330
752	Maintenance and Engine Repair Hangar For F-15	72,725
753	Maintenance and Shelter Hangar	62,615
756	Maintenance and Parts Storage Hangar	41,135

Minot AFB (SAC)

HANGAR	MISSION	SIZE (sq ft)
718	F-106 Alert Hangar	19,330
763	Fifth Fighter Maintenance and Shelter Hangar For F-106 and T-38	39,960
836	Fuel Cell Repair Hangar	17,150
837	Corrosion Control and Wash Dock Hangar	33,250
867	Maintenance and Cannibalization Hangar for KC-135 and B-52	26,690

Tinker AFB (AFLC)

HANGAR	MISSION	SIZE (sq ft)
230	AWACS and KC-135 Maintenance Hangar	540,821
240	KC-135 Repair and Modification Hangar	181,894
1030	F-106 Wash and Maintenance Hangar	96,698
2122	KC-135 Modification and Wash Rack Hangar	323,509
3102	Fuel Cell Repair and Aircraft Flight Preparation Hangar	168,479

Figure 2. Building 752, Langley AFB

could be applied or if certain conditions would prohibit their implementation. Operating personnel also contributed numerous worthwhile ideas which were incorporated into the final list of suggested ECO's developed after the survey.

Since none of the buildings studied were submetered, current energy consumption could only be roughly estimated. However, for most of the ECO's selected for economic analysis, this information was not required. The analysis usually compared a specific calculable factor such as transmission loss through walls before and after a modification as the basis for savings (i.e., per square foot). Thus, the amount of savings credited to an individual ECO was essentially independent of the initial overall hangar energy consumption.

Data on building services equipment such as heating equipment, lights, and motors was available from the BEAP and design drawings at Minot AFB and Tinker AFB. At Langley AFB, the information was gathered from the TRACE® [1] input data for each hangar and was considered adequately accurate for the purposes of this study. Since none of the hangar space was air conditioned (although connecting office space usually was), no data was gathered on cooling equipment.

Energy costs were gathered just prior to performance of the economics analysis to represent the most current prices since costs are escalating rapidly.

[1] Trane's Building Simulation Computer Program

RESULTS OF CURRENT ECIP

Based on a directive from the Department of the Air Force to perform a computerized simulation of each building over 20,000 square feet in area, civil engineers at each base used the TRACE® computer program to compare current estimated energy usage with usage after implementing certain energy conservation schemes selected by the base civil engineers. Based on these results, many ECO's are currently being implemented at each base and for this reason were not included for consideration in this report. Table 2 summarizes these modifications for each of the thirteen hangars simulated. Buildings 718 and 836 at Minot AFB are under 20,000 square feet in area and were not simulated. In analyzing this table, it should be noted that Langley AFB avoids the use of water-cooled refrigeration systems because of water treatment problems resulting in high maintenance and poor performance. Also, the results from Building 753 should be reviewed. Since Building 753 is virtually identical to Building 752, similar results should have been achieved for each building.

LIST OF SUGGESTED ECO's

Based on the results of the field surveys at each base, a comprehensive list of potential ECO's was developed. In formulating this list, a brainstorming approach was used. Any ECO which could conceivably apply to hangars was initially included in the list. ECO's were then classified according to the following disciplines: Architectural, Electrical, Mechanical, Operations, and Structural. As the list was compiled, ECO's currently being implemented were eliminated. In addition, ECO's relating to alternative energy approaches such as solar heating and cogeneration were eliminated because these approaches were being analyzed by others. The final list of potential ECO's contained close to one hundred different ECO's in the various disciplines. A summary of these ECO's is given in Appendix A.

LIST OF SELECTED ECO's

In order to aid the sponsor with the selection of final ECO's from among the potential ECO's listed, a review meeting was held at Tyndall AFB on

19 October 1979. Each ECO was discussed in detail to determine which schemes would best suit the intent of the job. Based on this review, ten ECO's were selected by the Air Force for each base. Many ECO's which were selected for one base were also selected for the other bases to analyze the impact of the different climates on the feasibility of the ECO. A total of fourteen unique ECO's were selected for the three bases. Table 3 summarizes these modifications for each base. The type of modification is listed as Architectural (A), Electrical (E), Mechanical (M), or Operations (O). A complete description of each ECO follows in Section IV.

TABLE 2. RESULTS OF CURRENT ENERGY CONSERVATION INVESTMENT PROGRAM AT EACH BASE

Langley AFB

Building 338

1. Add insulation to ceiling and walls
2. Replace existing air conditioning systems and add economizer
3. Add night setback control
4. Add thermostatic control on steam radiators
5. Repair seals on hangar doors
6. Replace four small floor-mounted unit heaters with larger capacity heaters
7. Lower light fixture

Building 351

1. Insulate offices
2. Install new heaters designed to operate on demand only
3. Install timers on lights

Building 752

1. Change office air conditioning system to split system
2. Insulate office walls and add insulated ceiling
3. Add thermostatic radiator valves
4. Add insulation to hangar ceiling
5. Repair hangar door seals

Building 753

None recommended, but the following were investigated.

1. Add insulation to hangar ceiling
2. Replace heaters
3. Add fan cut-off switches and controls
4. Add economizer to office air conditioning system

Building 756

1. Insulate walls and reduce glass area
2. Add night setback controls
3. Change to HPS lights

TABLE 2. RESULTS OF CURRENT ENERGY CONSERVATION INVESTMENT PROGRAM AT EACH BASE (CONTINUED)

Tinker AFB

Building 230

1. Add night setback control
2. Cut holes in hangar doors for AGE hookup

Building 240

1. Remove glass (rejected)
2. Insulate walls and roof
3. Add night setback controls
4. Cut holes in hangar doors for AGE hookup

Building 1030

1. Add night setback controls
2. Remove windows

Building 2122

1. Insulate walls, roof and doors of hangar area
2. Add night setback controls

Building 3102

1. Add night setback controls
2. Connect to Energy Management Control System (EMCS)
3. Cut holes in hangar doors for AGE hookup
4. Insulate doors (rejected)

Minot AFB

Buildings 718 and 836 were not analyzed

Building 763

1. Insulate walls, roof and doors
2. Reduce glass area in shop and replace remaining windows

TABLE 2. RESULTS OF CURRENT ENERGY CONSERVATION INVESTMENT PROGRAM AT EACH BASE (CONCLUDED)

Building 837

1. Insulate walls and roof
2. Provide return air ducts to floor mounted heaters to circulate ceiling air
3. Replace weatherstripping at doors

Building 867

1. Insulate walls and roof
2. Reduce glass area and replace remaining windows
3. Replace heaters (rejected)

TABLE 3. SELECTED ENERGY CONSERVATION OPTIONS

Langley AFB		Minot AFB		Tinker AFB	
TYPE	MODIFICATION	TYPE	MODIFICATION	TYPE	MODIFICATION
A	Remove Windows	A	Lower Ceilings	A	Lower Ceilings
A	Reflective Paint	A	Remove Windows	A	Remove Windows
A	Portable Door Seals	A	Portable Door Seals	A	Reflective Paint
E	Interlock Heaters	E	Interlock Heaters	A	Add Vehicle Doors
E	Lower Lights	E	Power Factor Correction	E	Interlock Heaters
M	Supply Air ΔT of $25^{O}F$	M	Supply Air ΔT of $25^{O}F$	E	Lower Lights
M	Destratification Fans	M	Destratification Fans	E	Power Factor Correction
M	Radiant Heaters	M	Radiant Heaters	M	Supply Air ΔT of $25^{O}F$
O	Use Vehicle Doors For AGE	M	Air Curtains	M	Destratification Fans
O	Minimize Deicing of Aircraft	O	Use Vehicle Doors For A.G.E.	M	Radiant Heaters

SECTION IV

ECONOMIC ANALYSIS OF SELECTED ENERGY CONSERVATION SCHEMES

INTRODUCTION

The determination of cost savings generated by implementing the selected energy conservation schemes represents a complex problem. Energy saved in one form which results in an increase in energy consumed in another form, i.e., gas versus electricity, may save considerable energy at the building line while actually increasing raw source energy consumption and total energy-related costs, since the energy and economic cost per BTU is different for each form. In addition, the complex and fluctuating variables involved in a cost analysis greatly influence the economic attractiveness of any scheme being reviewed.

Recognizing these facts, the Air Force has developed a standard procedure to analyze ECO's which accounts for the type of fuel and relative escalation rates of different factors (see Appendix B). Since there were over one hundred separate cost analyses required, a computer program was written to perform the actual calculations (see Appendix C).

Table 4 summarizes the factors used to calculate escalation rates, economic life, and other necessary variables which were obtained from the Air Force Facilities Energy Plan, AFESC, 1 July 1979.

The current working estimate (CWE), which includes construction costs and supervision, inspection and overhead (SIOH) at five percent, is escalated at six percent per year for three years to determine the escalated CWE in 1983. Project cost is assumed to be 23 percent higher than the escalated CWE after design costs (9 percent), profit (9 percent), and contingency (4 percent) are included.

TABLE 4. EQUATIONS USED FOR ECONOMIC ANALYSIS

Escalated CWE = CWE x $(1.06)^3$

Project Cost = Escalated CWE x $(1.09)^2$ x (1.04)

Cost of Oil = 56 ¢/Gal (Langley)

Cost of Gas = 21 ¢/Therm (Minot)
19.9 ¢/Therm (Tinker)

		Quantity	Demand	
Cost of Electricity	=	3.5 ¢/KWH	$ 0/KW	(Langley)
	=	1.0 ¢/KWH	$1.20/KW	(Minot)
	=	2.6 ¢/KWH	$2.64/KW	(Tinker)

Discount Rate = 10%

Differential Escalation Rate = 8% (Oil)
= 8% (Gas)
= 7% (Electricity)

Economic Life = 25 Years

B/C Ratio = Net Discounted Benefits/Project Cost

E/C Ratio = Net KBTU Saved/Escalated CWE

Life Cycle Cost = Project Cost - (B/C Ratio) x Project Cost

Dollars Saved Per Dollars Invested = Net Annual Cost Savings/Escalated CWE

Energy Saved Per Dollars Invested = Net Annual Energy Savings/Escalated CWE

Payback = Escalated CWE/Net Annual Cost Savings

The cost of energy was obtained from each base just before performing the economic analysis. Langley AFB uses only oil and electricity, Minot AFB uses interruptible gas with oil standby and electricity, and Tinker uses gas and electricity.

Number 6 fuel oil at 150,000 BTU/gallon cost Langley AFB 56 cents per gallon in November 1979. Electricity cost Langley 3.5 cents per kilowatt hour consumed, but figures for demand charge were not available. Since none of the ECO's analyzed at Langley caused a kilowatt demand reduction, this information was not needed.

Natural gas cost Minot AFB 21 cents per therm in December 1979. Due to a long-term contract with the local utility, electricity cost Minot one cent per kilowatt hour consumed, and a minimum demand charge of 1.20 dollars per kilowatt demand. Cost for standby fuel oil was not obtained.

Natural gas cost Tinker AFB 19.9 cents per therm in December 1979. Electricity cost experienced a 25 percent increase between November 1979 and December 1979, to a cost of 2.6 cents per kilowatt hour consumed and 2.64 dollars per kilowatt demand. Additional rate increases for gas and electricity are being requested by the local utility.

To determine life cycle cost, a discount rate of 10 percent was used for project costs with a differential escalation rate of 8 percent for oil and gas and 7 percent for electricity in accordance with Air Force guidelines.

The economic life of all modifications was assumed to be 25 years in accordance with ECIP criteria. In some cases, this may be slightly longer than actual life, so an additional analysis was performed assuming a 15-year life cycle. With the exception of infrared heaters, all ECO's which were attractive with a 25-year life cycle remained attractive. Since infrared heaters should last for 25 years, the 25-year analysis used provides reasonable life cycle costs for all modifications considered.

The discounted benefit/cost ratio was computed by dividing the net discounted energy benefits in dollars by the total project cost using the correct differential escalation factors for each fuel. The factor used to compute total discounted benefits was 21.5 for gas and oil and 18.05 for electrical consumption and demand charges.

The energy/cost ratio was calculated by dividing net resource energy saved in millions of BTU by the escalated CWE in thousands of dollars. To determine net raw resource energy saved, gas and oil savings at each hangar were divided by .75 (the assumed overall central plant-efficiency), and electricity saved or consumed to achieve savings in gas or oil was multiplied by 3.4 (11600/3413).

Life cycle cost savings were determined by taking the project cost and subtracting from it the net total discounted benefits.

Energy saved per dollars invested was computed by dividing the net annual energy savings in thousands of BTU by the escalated CWE in dollars.

ENERGY SAVINGS CALCULATIONS

The first step in performing an economic analysis of Energy Conservation Schemes was the determination of net energy savings attributed to the schemes. The following paragraphs provide a detailed description of each modification and the methodology used to calculate energy savings for each of the 14 unique ECO's selected for analysis.

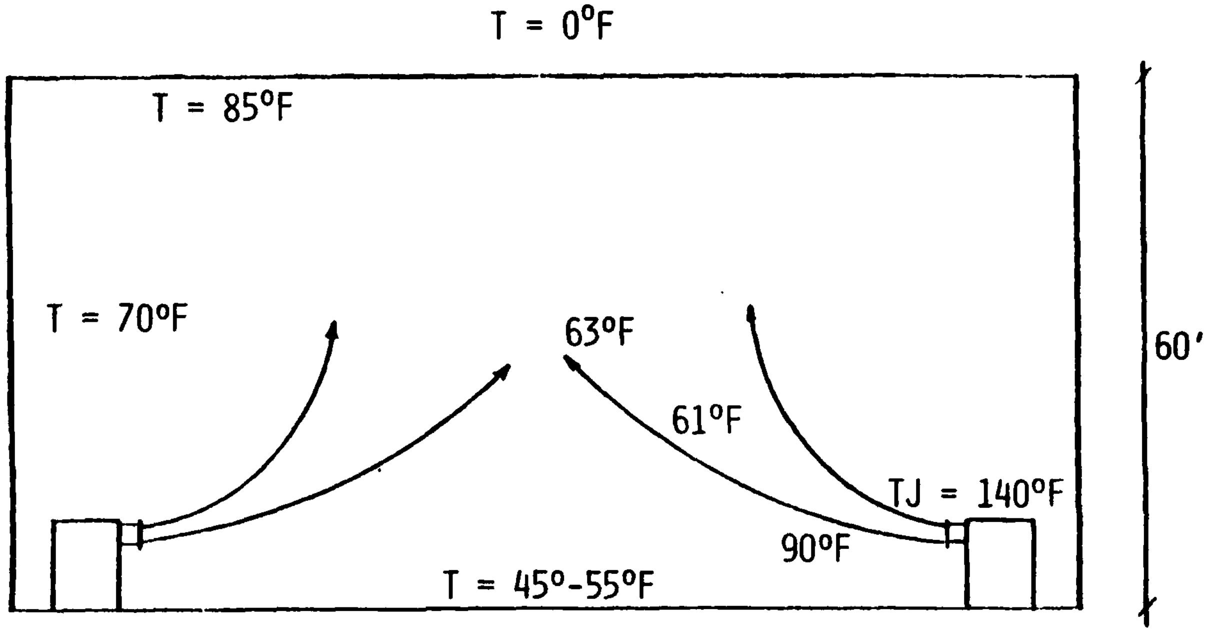
LOWER CEILINGS

Most of the ten hangars at Minot AFB and Tinker AFB have ceiling heights in excess of 60 feet. Thermal stratification in these hangars results in cold temperatures at the floor level and temperatures sometimes higher than 100 degrees F near the roof. These high temperatures cause excessive transmission heat loss through the roof and walls during the heating season. By lowering the ceiling these stratification effects can be substantially reduced. In addition, the ceiling would improve the thermal resistance of the space, further reducing hangar heat losses.

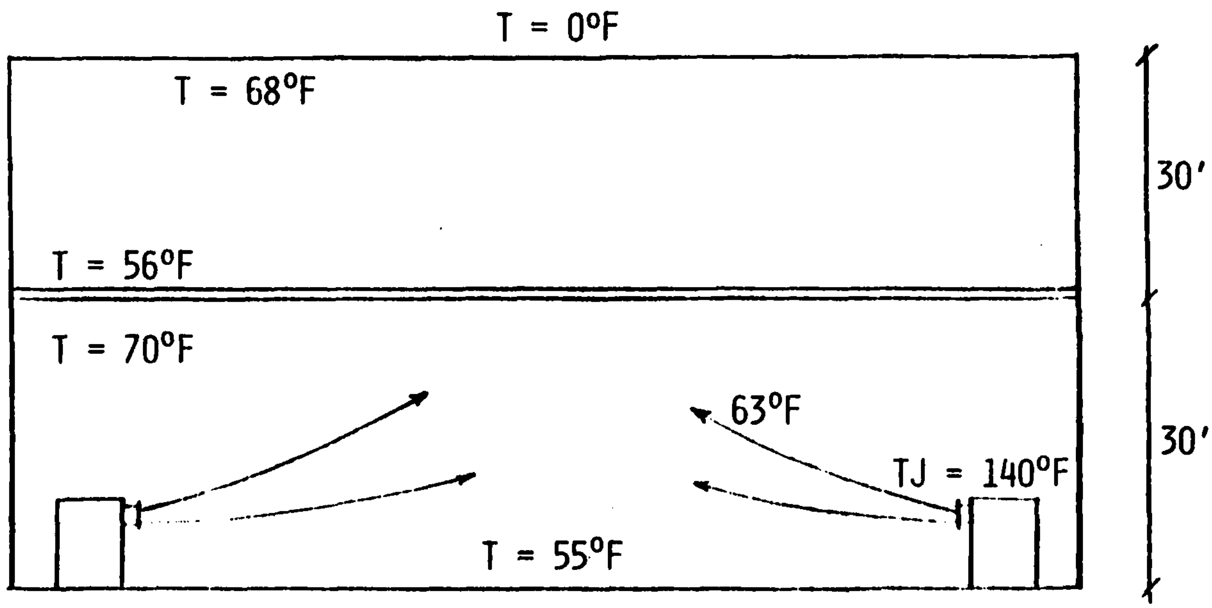
The calculation of savings resulting from lowering ceilings involves the determination of stratification effects in high bay areas of hangars. In addition, the heat transmission through the roof and walls must be calculated. The equation for calculating the temperature as a function of height is $t(h) = t_f = .5h$ where $t(h)$ = temperature at height h, t_f = temperature at the floor, and h = height above the floor in feet. Based on the temperature at the roof and the roof "U" value, the transmission heat loss through the roof and walls is calculated from the equation $Q_T = UA\,\Delta T$, where Q_T = Transmission heat loss in BTUH, U = Roof or wall "U" value, A = Roof or Wall area, and ΔT = the temperature difference between space temperature and outside air temperature. The bin method is then used to estimate the heat loss through the roof and walls during the heating season. (For a discussion of the bin method, see Appendix D.)

The heat loss through the roof is recalculated after the ceiling is added using the following equations: $t(h) = t_{C+1} + .5h$; and $Q = UA\,(t_c - t_{c+1})$; where Q = heat loss through the ceiling, t_c = temperature just below the ceiling and t_{c+1} = temperature just above the ceiling. The first equation evaluates the stratification effects up to the new ceiling height, and the second equation evaluates the heat loss through the ceiling, which include stratification effects above the ceiling. T_{c+1} is calculated by performing a heat balance between heat gain through the ceiling from below and heat loss through the roof and walls assuming similar stratification effects above the ceiling. A computer program was written to calculate the energy savings attributed to lowering ceilings for each hangar using these equations (see Appendix C).

Figure 3 illustrates the effect of lowering the ceiling on a typical hangar whose roof height is 60 feet. Initially, the hangar experiences a 30-degree F stratification effect from floor to roof with several cold spots



STRATIFICATION WITHOUT CEILING



STRATIFICATION WITH CEILING

Figure 3. Lower Ceilings

along the floor. After the ceiling is added, thermal stratification is substantially reduced. Overall transmission heat loss is reduced by over 50 percent. However, while the relative savings are substantial, the total savings per square foot of floor area are small because the structure is assumed to be well insulated. This is in accordance with Air Force criteria in which the required roof "U" value is .05 and the wall "U" value is .07. Of the ten hangars analyzed, only Building 230 at Tinker AFB has no current program to conform to these criteria.

In the case of Building 230, a different problem occurs. The energy savings achieved by lowering the ceiling in the hangar are sufficient to be economically attractive even with the cost of installing a second layer of sprinklers. However, the resulting plenum temperature above the new ceiling would be within approximately 10 degrees F of outdoor air temperature. Supplemental heat would be needed to prevent existing sprinkler lines from freezing. The cost of adding supplemental heat makes this modification unattractive for this building as well.

REMOVE OR REPLACE WINDOWS

Windows in hangar doors and along hangar walls provide natural lighting in the work zone during daylight hours. However, heat loss through these windows throughout both daytime and nighttime hours more than offsets this benefit. In addition, in virtually every hangar analyzed, the work process requires supplemental task lighting. Figure 4 illustrates the extensive glass area (all of which is single pane) of Tinker AFB Building 240. By removing the windows, heat loss can be reduced with a minimal impact on production efficiency.

The equation used to determine energy savings by blocking windows is $(U_1 - U_2)\, A\, \Delta T$, where U_1 = U value of existing windows, U_2 = U value of blocked windows, A = window area, and ΔT = temperature difference between inside air and outside air. The energy savings calculation is similar for each base. The bin method is used to compute total annual energy savings.

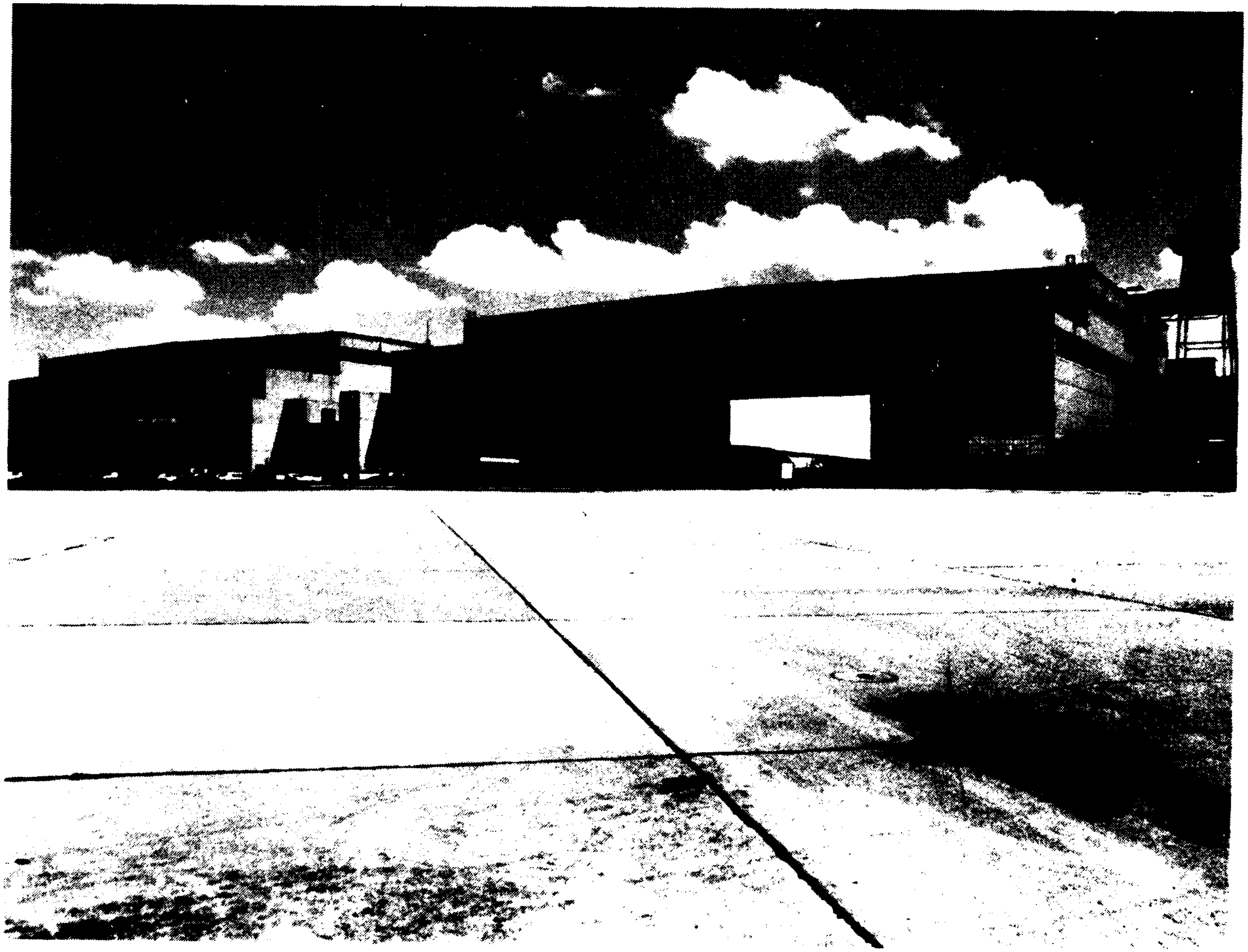


Figure 4. Extensive Glass Area on Building 240, Tinker AFB

The suggested replacement for the removed windows is insulated panels having a U value of .08. These panels can be directly mounted on existing windows and sealed to minimize infiltration.

ADD PORTABLE DOOR SEALS

Infiltration through hangar doors is responsible for much of the heat loss in the hangar. One way to significantly reduce this infiltration is to add portable door seals as shown in Figure 5. The door seal consists of two parts: the floor seal and the vertical seal.

The floor seal consists of a series of 4-inch-diameter foam rubber-filled neoprene strips for each door section which can be easily slid into place by one man. These strips should be flexible enough to conform to irregularities and strong enough to withstand normal abuse.

The vertical seal is a 6-inch-wide neoprene strip with a 10-gauge sheet-metal backing which is attached to the door by hinges at top, middle, and bottom. A spring-loaded latch secures the seal when the door is closed and allows the seal to be moved while the door is being opened or closed. This will help alleviate the problem of deteriorated door seals.

Energy savings attributed to portable door seals assume a half-inch reduction in the gap between the door and the floor and between two adjacent hangar doors. The resulting savings were calculated using ASHRAE techniques for computing infiltration based on average wind velocity and building angle. Using this technique, the average reduction in flow rate in cubic feet per minute (CFM) is computed. Savings at a design temperature are CFM x 1.085 ΔT, where 1.085 is the conversion factor between CFM and BTU per hour per degree F and ΔT is the temperature difference between inside air and outside air. The bin method is used to calculate annual energy savings.

INTERLOCK HEATERS WITH HANGAR DOORS

Operation of unit heaters when hangar doors are open wastes almost all

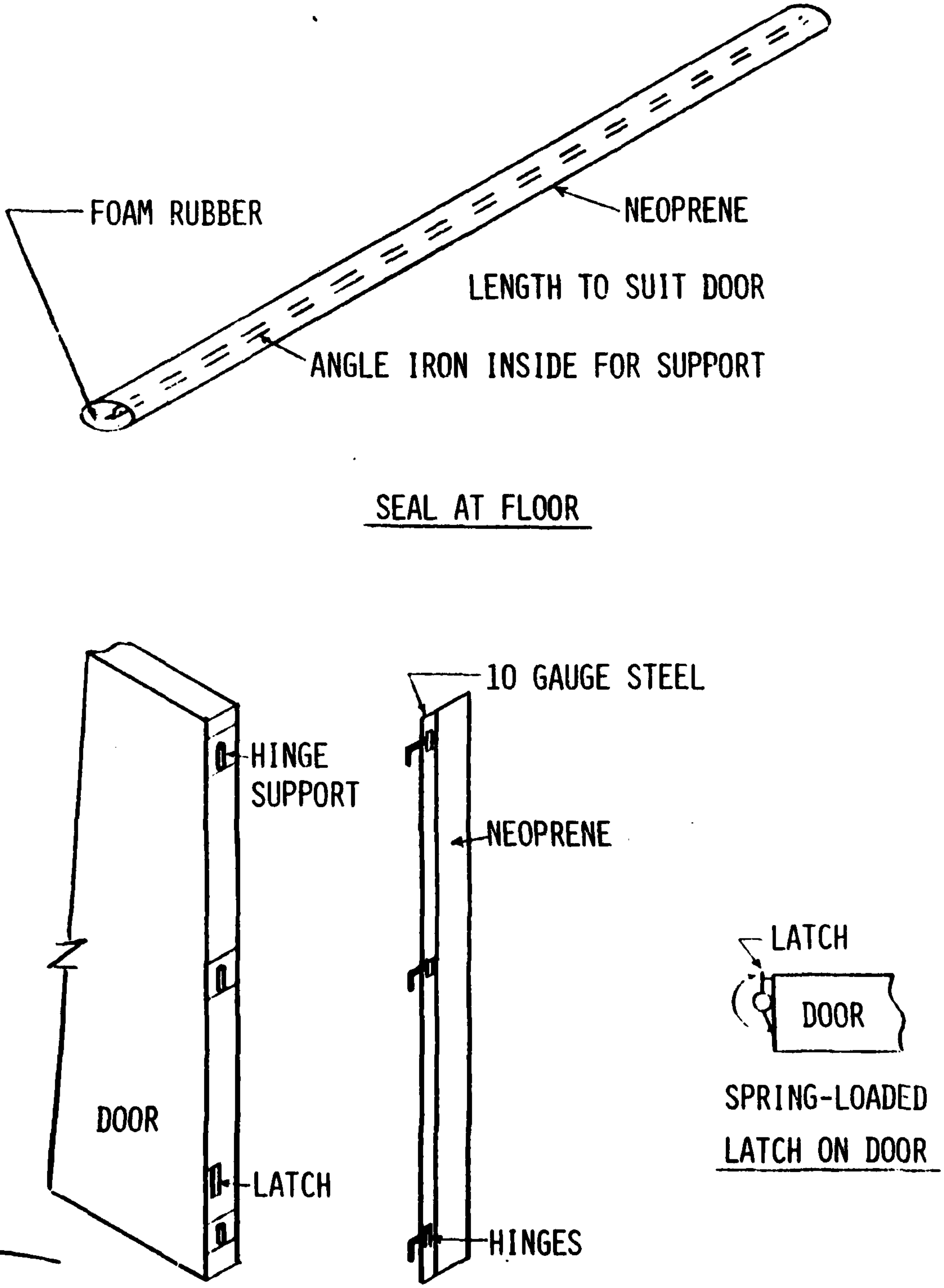


Figure 5. Add Portable Door Seals

of the heat output of the heaters. In some cases, operating the heaters with the doors open causes the heating coil to freeze. By interlocking the heaters with the hangar doors, energy savings can be achieved whenever the hangar doors are opened. The estimated amount of savings will be the heating capacity of the interlocked heaters multiplied by the expected amount of time the doors are opened per heating season.

Currently the unit heaters at Minot AFB are shut off manually whenever the hangar doors are opened in freezing weather because of past experience with frozen heating coils. For this reason, the savings calculated in this report may be higher than actual savings at Minot. Since automatic interlocking is more reliable than manual interlocking, it remains advisable to interlock the heaters at Minot as well as at Tinker and Langley.

ADD POWER FACTOR CORRECTION

Power factor is the ratio of working current to total current in an electrical circuit (KW/KVA). Low power factor is caused by the magnetizing current used in inductive motors to product the flux necessary to run the motor. When the power factor for a site is below a designated level (usually .9), most utilities assess a penalty charge to cover the cost of the KVA generated which does not register on the user's watt meter. Some utilities, such as the one serving Tinker AFB, compute demand charge by dividing the peak KW demand by the lowest power factor recorded in the month.

Two methods of power factor correction are common in building services applications: capacitors and synchronous motors. The preferred method for this case is capacitors because capacitor correction has relatively low material and installation costs. Capacitors generate leading reactive power which offsets the lagging reactive power in the inductive motor. The net result is an improved power factor.

Energy savings from power factor correction occur only to the utility. Savings are calculated by subtracting the site KVA after the power factor has been corrected from the site KVA before correction for each hour of operation. Since these savings are not credited to the base, they were not calculated. Cost savings are relevant only for those utilities which charge for low power factor in computing rates. Otherwise, there are no cost savings.

ADD DESTRATIFICATION FANS

Another way to reduce stratification in high bays of hangars is to add destratification fans near the roof of each hangar. Figure 6 illustrates a typical application of destratification fans. The destratification fans are installed near the ceiling to bring the hot air near the ceiling down to the floor level and thus provide a relatively even temperature profile from the floor to the roof. The fans must provide sufficient velocity to circulate the air to floor, and there must be a sufficient number of fans to provide even coverage throughout the hangar.

Energy savings from destratification fans can be estimated by taking the difference between the transmission heat loss before and after their installation. Although fan horsepower adds heat to the space, electrical input energy is factored differently than steam energy and this factor must appear in the calculation. The bin method is then used to estimate energy savings during the heating season. Stratification after installation of fans is estimated to be 5^{o}F for the calculation. The computer program written to compute these energy savings appears in Appendix C.

USE RADIANT HEATERS (HIGH OR LOW INTENSITY)

Infrared radiant heating systems can efficiently heat large open areas such as hangars and with a substantial amount of energy savings compared to the existing conventional space heating systems. Infrared systems transfer heat by radiation rather than convection. As objects exposed to the primary radiation pattern are heated, they reradiate low-intensity heat or lose heat by convection. This secondary heating effect tends to increase space temperature until it approaches the mean radiant temperature. However, unlike a conventional

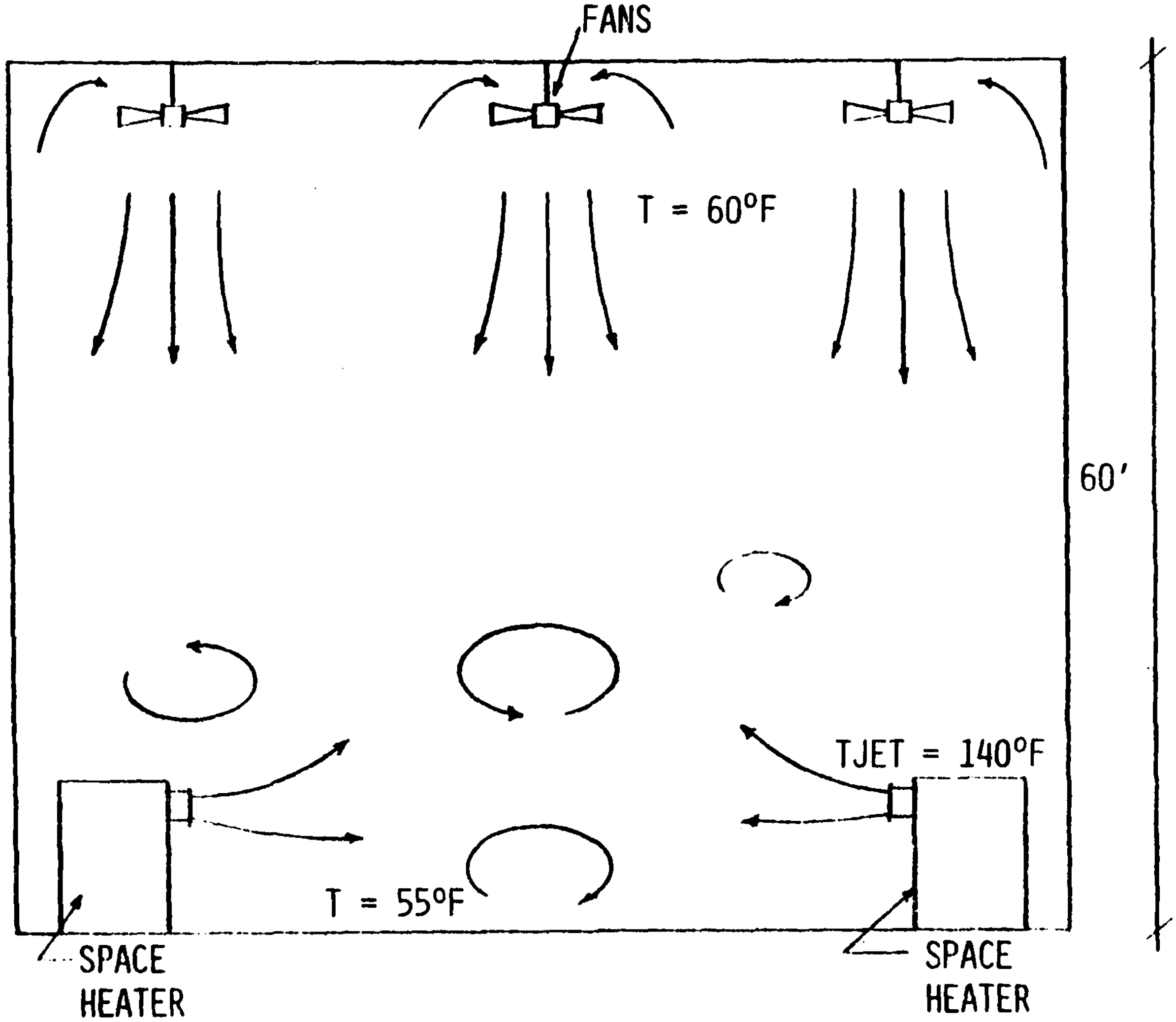


Figure 6. Add Destratification Fans

system, whose dry bulb temperature always exceeds the mean radiant temperature, an infrared system dry bulb temperature is always below the mean radiant temperature. According to ASHRAE,[2] human comfort levels are determined by the arithmetic average of mean radiant and dry-bulb temperatures. When using infrared heaters, equivalent comfort levels are maintained with lower dry bulb temperatures as long as personnel are directly exposed to the primary radiation pattern. As long as radiation is not directed at exterior surfaces, transmission heat loss and energy consumption will be reduced.

Additional advantages of infrared heaters include rapid heating of aircraft, possible reduction in stratification effects, rapid recovery of space temperature after doors are closed, and more even temperature distribution within the space.

Several types of infrared radiant heaters are available. These include five kinds of gas-fired heaters and four kinds of electric heaters.

Electric heaters operate at higher temperatures and so have higher radiation efficiency than gas heaters. However, because of the energy penalty assessed to electricity compared to gas, their feasibility appears to be limited.

High intensity gas-fired heaters are not entirely suitable for installation in hangars. The open flame is undesirable in areas with potentially explosive fuel vapor. Also, great amounts of water vapor are released into the space, causing condensation and rust problems.

A second type of gas-fired infrared heater is a low-intensity heater. The flame can be isolated from the hangar space, and an eductor is used to remove products of combustion. Thus, condensation is not a problem. Although radiant efficiency is somewhat lower than electric and high-intensity gas

[2] American Society of Heating, Refrigerating, and Air Conditioning Engineers, 1977 Handbood of Fundamentals.

heaters, overall thermal efficiency is as high as 90 percent. Thus, low intensity heaters offer the best combination of low cost, high efficiency, and compatibility with hangar operations.

Energy savings resulting from the use of infrared radiant heaters are estimated by subtracting the thermal transmission loss when using infrared from the thermal loss when using conventional heaters, including the energy consumed by existing fans. The bin method is then used to calculate annual savings.

ADD AIR CURTAINS TO VEHICLE DOORS

Vehicle doors are used to provide access to hangars for Aerospace Ground Equipment (AGE) without opening large hangar doors. Typical vehicle doors are roughly 20 feet wide by 20 feet high. These doors are frequently opened throughout the day in many cases and thus cause a large amount of infiltration. One of the ways to reduce infiltration through vehicle doors is to add air curtains to the doors.

An air curtain is a layer of air which is blown across an opening, parallel to the door, to reduce infiltration through that opening. The layer moves at such a velocity and angle that infiltrating air is exactly opposed by the movement of the air curtain. According to ASHRAE[3], infiltration can usually be reduced by about 70 percent when using an air curtain. Figure 7 shows a typical air curtain mounted on a rolling steel vehicle door. Due to the door casing configuration, the best mounting configuration is along the sides of the door.

Energy savings using air curtains can be estimated by subtracting the infiltration heat loss when using air curtains from the infiltration heat loss through the open door. Annual energy savings can then be estimated by determining the frequency of door operation and coincident temperature profile and wind velocity.

[3] ASHRAE 1979 Equipment Handbook

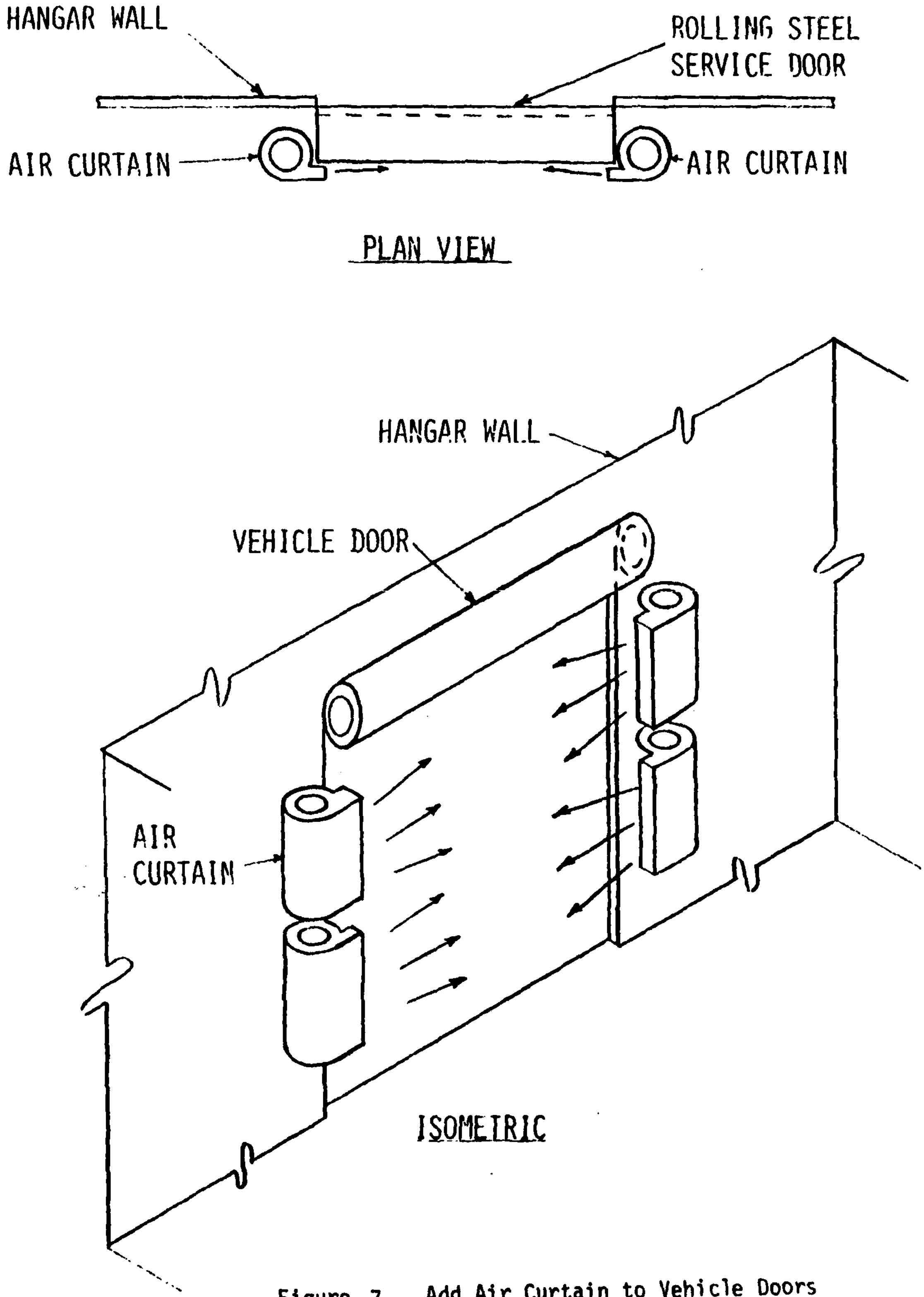


Figure 7. Add Air Curtain to Vehicle Doors

Most data gathered on air curtains refers to refrigeration applications in which the effort is to keep the refrigerated space isloated from the adjacent warm area. In these cases the doors are usually quite small. Relatively little information exists to evaluate the exact effect on a 20-foot by 20-foot opening. For this reason, the values calculated are order-of-magnitude estimates rather than close approximations.

USE VEHICLE DOORS FOR AGE

Movement of aircraft into and out of hangars normally occurs about once a day to once a week depending on the hangar missions. However, the Aerospace Ground Equipment (AGE) such as air compressors, ladders, trucks, and other miscellaneous support equipment moves in and out several times per day.

In many of the hangars, AGE is moved through the main hangar doors rather than through vehicle doors for various reasons. In most cases, infiltration could be reduced substantially whenever AGE is moved merely by using vehicle doors instead of hangar doors for egress.

Energy savings are computed by determining the area open to outside air when using hangar doors for AGE and subtracting from it the area open to outside air when using vehicle doors for AGE. The standard technique for computing infiltration heat loss through the remaining open area provides a rough estimate of savings. The bin method is then used to determine annual savings based on average frequency and duration of door opening.

As with air curtains, the savings attributed to this procedure are only order-of-magnitude estimates. Factors such as wind velocity and frequency and duration of door opening are each imprecise estimates with potential for wide variation. However, the savings estimated are substantial so this modification is worthwhile even if the assumptions used in the calculations are optimistic.

PAINT FLOORS WITH REFLECTIVE PAINT

The standard floor paint for Air Force hangars is a semi-gloss grey paint. The light reflectance of this paint is estimated to be 0.6. To improve the lighting level inside the hangars without increasing the light output, floors should be painted with a lighter-colored, semi-gloss, oil-resistant paint having a light reflectance between 0.8 and 0.9. The suggested paint is an alkyd semi-gloss off-white-colored paint.

Although there are no energy savings directly associated with this ECO, the quality of lighting is improved at relatively low cost. Energy savings are only credited if the current lighting level is maintained by removing additional lights after the floors are painted.

The calculation used to determine average light level before and after painting with reflective paint is the room cavity method described in Section 9 of the 1972 IES Lighting Handbook. Using this method, average lighting levels were improved by 2 to 5 footcandles in the working plane. This could offset lighting level drop due to window removals. However, due to the distribution of lights in most hangars, it is felt that no additional lights could be removed without creating unwanted shadows.

LOWER THE LIGHT FIXTURES

Light fixtures in many of the hangars without ceilings are located in the truss space at the roof. Figure 8 demonstrates this pattern for Building 351 at Langley AFB. However, required clearance height for aircraft and support equipment is usually much lower than this height. Since light intensity varies with the square of the distance between the light source and the object to be lit, lighting levels can be improved without adding new fixtures simply by lowering the fixtures to the minimum acceptable height. By changing lenses, the proper lighting coverage can still be maintained.

As with reflective paint, lowered light fixtures do not directly save energy, but they do improve the quality of lighting. Energy savings are

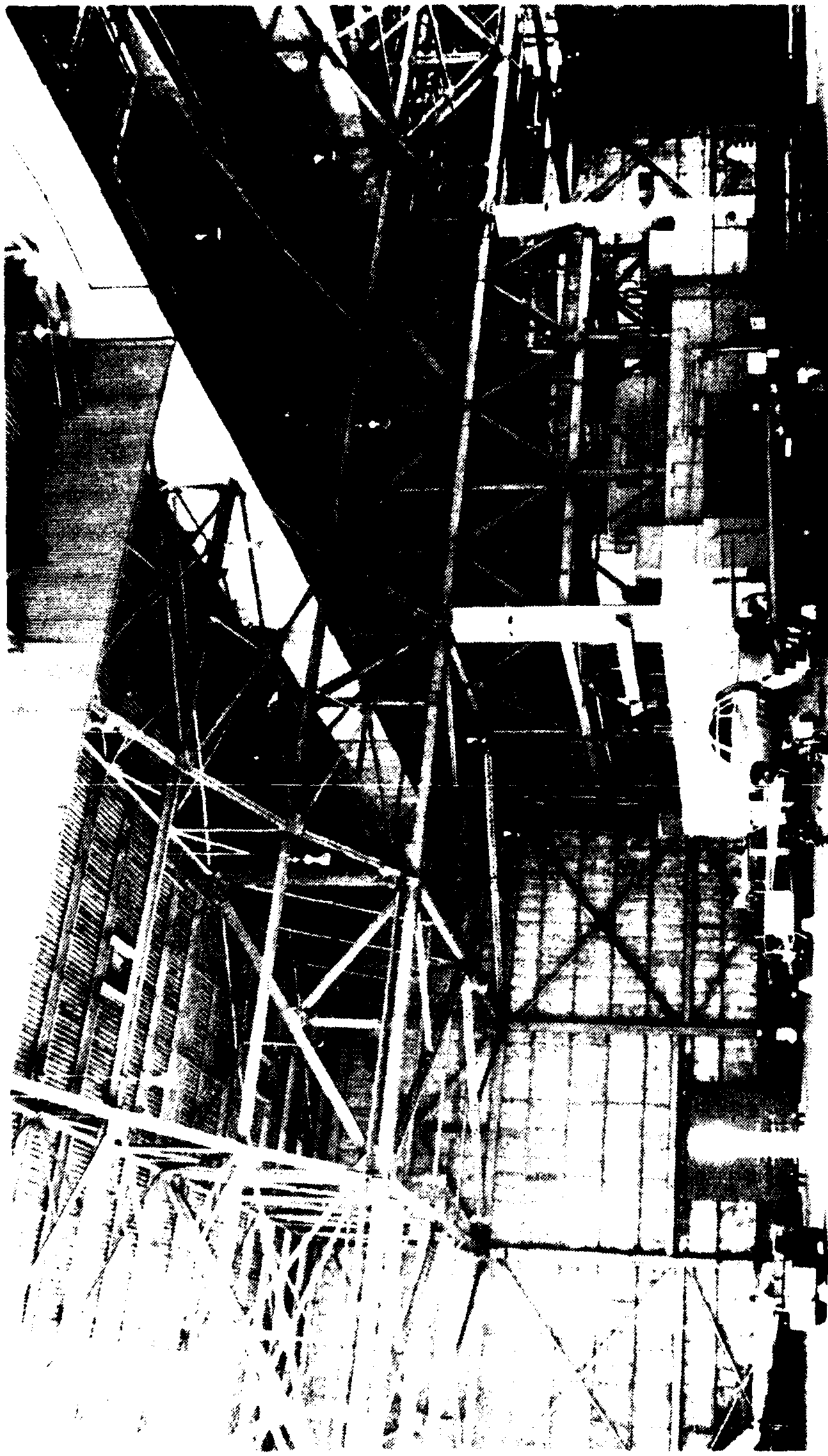


Figure 8. Interior of Building 351, Langley AFB

credited if the existing lighting level can be maintained by eliminating fixtures. As previously discussed, this option does not appear to be possible.

MINIMIZE DEICING OF AIRCRAFT

A common practice at many bases in cold climates is to use building heat to deice aircraft. This occurs because deicing fluid corrodes the electrical wiring, especially on fighter aircraft. This practice uses great quantities of energy for each aircraft deiced in this fashion. If the aircraft requires servicing, the cost is merely the cost of melting the ice. However, whenever the sole purpose is to deice the aircraft, the additional cost is the cost of heating the aircraft to 32^{o}F from its original temperature. Any efforts to minimize the use of heat to deice aircraft will save energy.

Energy savings are calculated by assuming a half-inch layer of ice on the area of the aircraft in the plan view. For an F-15 aircraft, this area is approximately 1000 square feet (608 square feet wing area plus approximately 400 square feet fuselage area). For a B-52, this area is over 5000 square feet (4000 square feet wing area plus over 1000 square feet fuselage area). For each F-15 deiced using building heat, energy consumed is 374,000 BTU. For each B-52 deiced, energy consumed is 1,872,000 BTU. These figures include only the energy consumed by melting ice.

MAXIMUM SUPPLY AIR ΔT OF 25 DEGREES F

In most of the hangars surveyed, the discharge air temperature from the unit heaters was over 100 degrees F. In many cases, the temperature exceeded 140 degrees F. These high discharge temperatures were noted both for floor-mounted horizontal unit heaters and for vertical unit heaters mounted in the truss space. Stratification resulting from these high discharge temperatures can be reduced by decreasing the supply air temperature to 85 degrees F or less.

In order to reduce the supply air temperature to 85 degrees F while simultaneously supplying adequate heating to the work zone, air quantity supplied must increase in proportion with the decrease in temperature. The amount of the increase in CFM used for the energy savings calculation is $CFM_2 = CFM_1 \times (140 - 60) / (85 - 60)$, or $CFM_2 = 3.2 \times CFM_1$, where CFM_2 is the required supply air quantity at 85 degrees F and CFM_1 is the required supply air quantity at 140 degrees F. The increased CFM is supplied by adding new heating units, each of which consumes electrical energy which must be factored into the calculation.

The precise effect of high discharge temperatures on thermal stratification has never been throughly evaluated in this country. The only available comprehensive research performed emanates from Russia. A computer program (Appendix C) was written for floor-mounted heaters based on this research to determine jet temperature and height above floor as a function of outlet velocity, distance from heater, outlet area, and outlet temperature. The results of this program provided the temperature profile previously shown in Figure 3.

While the theoretical equations used above provide some insight into how discharge air temperature affects stratification, no consensus of opinion exists about how stratification develops and what the stratification profile is as a function of height and other variables. Some evidence suggests that most stratification occurs just under the roof, forming a "heat pillow" of warm air. Other empirical data shows immediate and rapid stratification just above the work zone with little additional increase in temperature near the roof. A third approach, the one most often used by engineers, assumes that temperature varies directly as a function of height above the work zone according to the equation $T(h) = T_W + Ch$, where $T(h)$ is space temperature as a function of height, T_W is space temperature in the working zone, and C is the constant determined by engineering judgment, usually 0.5 to 0.75 degrees F per foot of height. C was set at 0.5 for all stratification equations in this report.

Each of the three methods has intuitive appeal for different cases. The heat pillow theory seems reasonable for cases in which high discharge temperatures for horizontal heaters are observed because the jet has little opportunity to destratify. The warm, light air would almost immediately rise toward the roof without mixing. This intuition contradicts the theory used to generate the temperature profile in Figure 3 of this report. However, insufficient supporting data exists to justify using the intuitive heat pillow approach even though it may, in fact, closely correspond to actual conditions in these hangars.

The theory of immediate stratification has both empirical data and intuitive appeal to encourage its use. It appears to be most applicable to vertical-mounted heaters blowing hot air down into the working zone. However, it was not used in this report because it generates the most liberal estimate of stratification and resulting heat losses.

The third approach, linear stratification as a function of height, was used throughout this report to calculate stratification temperatures because it represents the best compromise solution to the problem. Since data on stratification is sorely lacking, this approach seemed to offer the best combination of simplicity and accuracy.

Energy savings resulting from lowering discharge temperatures are calculated by assuming that stratification can be reduced by the amount of the differential in temperature as each jet leaves the work zone. This calculation provides only a rough estimate of the savings, but it was used because it is based on the only available research in the field. As future research is performed, better approximations will be possible. A computer program (Appendix C) was written to perform the energy saving calculations based on the research formulas. Hourly savings were calculated by taking the difference between thermal transmission losses due to stratification from a 140-degree F discharge jet and an 80-degree F discharge jet. The increased electrical horsepower requirements were then added to the electrical load and deducted from the heating load to determine net energy savings.

ADD VEHICLE DOORS

Two of the five hangars surveyed at Tinker AFB currently have no vehicle doors, and a third has no vehicle doors in the vicinity of the hangar doors. As a result, support equipment must be brought into these hangars through the large hangar doors. By adding vehicle doors to these hangars, substantial energy savings can be generated.

The energy savings calculation is identical to the calculation for energy savings by using vehicle doors at Langley AFB and Minot AFB.

RESULTS OF ECONOMIC ANALYSIS

After energy savings were computed for each selected ECO, a detailed economic analysis was performed to determine the attractiveness of each ECO. The estimated cost of each ECO was computed using Means Cost Data for 1979, where appropriate, and manufacturers' cost estimates in other cases. ECO's relating to operations were assigned a cost of one dollar to allow computation of life cycle costs and payback on the computer.

The results of the energy and economic analysis are summarized for each base in the following tables. Tables 5, 6, and 7 summarize results for Langley AFB, Minot AFB and Tinker AFB, respectively. Tables 8, 9, and 10 detail the findings by hangar for Langley AFB, Minot AFB, and Tinker AFB, respectively.

These tables provide all pertinent economic data necessary to evaluate the attractiveness of each ECO for each hangar and further summarize the results of each ECO for each of the three bases. The following paragraphs describe the function of each factor in the tables.

Column 1 lists all the modifications selected for each base. Those ECO's which the analysis showed to be unattractive are listed for future reference.

Column 2 lists the life cycle cost reduction in dollars based on a 25-

year life cycle. Where this cost reduction is listed as none, implementation of that ECO for that base or hangar would result in an increase in life cycle costs.

Column 3 lists the project cost in 1983 dollars. This cost includes the CWE, design costs, SIOH, and contingencies. Project costs for attractive ECO's summarized for each base include costs for only those hangars with Benefit/Cost Ratios above 1.

Column 4 lists the Benefit/Cost Ratio computed by dividing net discounted benefits by project cost. For base summaries it is the total benefits divided by total costs for all hangars.

Columns 5 and 6 list net annual energy savings in million BTU and net annual dollar savings saved per dollars invested for each ECO.

Columns 7 through 10 list dollars saved per dollars invested, dollars saved per dollars invested per square foot, millions of BTU's saved per thousand dollars invested, and millions of BTU's saved per thousand dollars invested per square foot. The figures listed per square foot have been multiplied by 10^6 to facilitate reading the numbers.

Column 11 lists the simple payback in years.

Where savings are listed as "none", the ECO either saved no resource energy or increased net energy consumption. Where columns show NA, the column is not applicable for that hangar. For two cases, ECIP is listed in Column 2, indicating that these modifications are already under consideration as a part of the base ECIP program.

TABLE 5. SUMMARIZED ECONOMIC ANALYSIS FOR LANGLEY AFB

(TOTAL AREA SURVEYED: 281,245 SQUARE FEET)

Modification	Life Cycle Cost Reduction $	1983 Project Cost $	Benefit Cost Ratio	Net Annual Energy Saved Mega BTU	Net Annual Dollars Saved	Dollars Saved Per $ Invested	Dollars Saved X10^6 Per $ Invested Per Sq Ft	Mega BTU Saved Per $1,000 Invested	Mega BTU Saved X10^6 Per $1,000 Invested Per Sq Ft	Simple Payback Years
Remove or Replace Windows	None	406800	0.95	2314	8623	0.02	0.07	7.0	25	50
Paint Floors With Reflective Paint	None	63800	None	None	None	None	None	None	None	None
Add Portable Door Seals	87500	23940	4.6	1386	5137	0.266	0.95	71	254	3.8
Interlock Heaters With Hangar Doors	38700	7060	6.5	571	2120	0.372	1.32	100	350	2.7
Lower Light Fixtures	None	5150	None	None	None	None	None	None	None	None
Supply Air ΔT of 25°F	None	276700	None	None	None	None	None	None	None	None
Add Destratification Fans	157000	36000	5.3	193	8950	0.306	1.10	82	290	3.2
Use Radiant Heaters	None	99400	None	None	None	None	None	None	None	None
Use Vehicle Doors for AGE	42800	0	∞	532	1980	∞	∞	∞	∞	immed.
Minimize Deicing of Aircraft	6000	0	∞	75	285	∞	∞	∞	∞	immed.

TABLE 6. SUMMARIZED ECONOMIC ANALYSIS FOR MINOT AFB

(TOTAL AREA SURVEYED: 136,380 SQUARE FEET)

Modification	Life Cycle Cost Reduction $	1983 Project Cost $	Benefit Cost Ratio	Net Annual Energy Saved Mega BTU	Net Annual Dollars Saved	Dollars Saved Per $ Invested	Dollars Saved $X10^6$ Per $ Invested Per Sq Ft	Mega BTU Saved Per $1,000 Invested	Mega BTU Saved $X10^6$ Per $1,000 Invested Per Sq Ft	Simple Payback Years
Lower Ceilings	None	386500	0.1	1177	2470	0.01	0.07	3.7	27	100
Remove or Replace Windows	5700	5100	2.1	237	500	0.12	0.89	43	318	8.4
Add Portable Door Seals	196000	12100	17	4595	9690	0.99	7.24	468	3430	1.0
Interlock Heaters w/Hangar Doors	45400	10200	5.4	1222	2586	0.31	2.30	149	1090	3.2
Add Power Factor Correction	90300	9500	10.5	0	8450	0.72	5.26	0	0	1.4
Supply Air ΔT of $25^{0}F$	None	121000	None	None	None	None	None	None	None	None
Add Destratification Fans	None	71800	0.2	383	544	0.01	0.07	6.6	47	100
Use Radiant Heaters	102800	315000	1.3	9202	19390	0.076	0.56	36	266	13.1
Add Air Curtains	343000	23000	16	8653	16650	0.9	6.5	376	2766	1.1
Use Vehicle Doors for AGE	216000	0	∞	4776	10080	∞	∞	[illegible]	∞	immed.

TABLE 7. SUMMARIZED ECONOMIC ANALYSIS FOR TINKER AFB

(TOTAL AREA SURVEYED: 1,311,401 SQUARE FEET)

Modification	Life Cycle Cost Reduction $	1983 Project Cost $	Benefit Cost Ratio	Net Annual Energy Saved Mega BTU	Net Annual Dollars Saved	Dollars Saved Per $ Invested	Dollars Saved X10^6 Per $ Invested Per Sq Ft	Mega BTU Saved Per $1,000 Invested	Mega BTU Saved X10^6 Per $1,000 Invested Per Sq Ft	Simple Payback Years
Lower Ceilings	None	2810000	0.7	57600	114500	0.05	0.04	20	15	20
Remove or Replace Windows	None	148400	0.7	2387	4752	0.04	0.03	16	12	25
Paint Floors w/Reflective Paint	None	23830	None	None	None	None	None	None	None	None
Add Vehicle Doors	47200	34200	2.4	1902	3786	0.13	0.10	68	52	7.7
Interlock Heaters w/Hangar Doors	206000	21500	10.6	5546	10500	0.60	0.46	304	230	1.7
Lower Light Fixtures	None	41800	None	None	None	None	None	None	None	None
Add Power Factor Correction	268000	39400	7.8	0	37000	1.16	0.88	0	0	1.1
Supply Air ΔT of 25°F	None	1289000	None	None	None	None	None	None	None	None
Add Destratification Fans	380000	414000	1.9	18180	36900	0.11	0.084	54	41	9
Use Radiant Heaters	None	1265000	0.7	23100	46000	0.04	0.03	22	17	23

TABLE 8. ECONOMIC ANALYSIS BY HANGAR FOR LANGLEY AFB

(A) HANGAR: 338; AREA: 37,430 SQUARE FEET

Modification	Life Cycle Cost Reduction $	1983 Project Cost $	Benefit Cost Ratio	Net Annual Energy Saved Mega BTU	Net Annual Dollars Saved	Dollars Saved Per $ Invested	Dollars Saved X10^6 Per $ Invested Per Sq Ft	Mega BTU Saved Per $1,000 Invested	Mega BTU Saved X10^6 Per $1,000 Invested Per Sq Ft	Simple Payback Years
Remove or Replace Windows	None	24600	0.96	296	1100	0.055	1.5	15	396	18
Paint Floors With Reflective Paint	None	7100	None	None	None	None	None	None	None	None
Add Portable Door Seals	13600	1350	9.19	189	700	0.53	14.1	141	3780	1.9
Interlock Heaters With Hangar Doors	4800	440	11.8	65	240	0.68	18.2	183	4900	1.5
Lower Light Fixtures	ECIP									
Supply Air ΔT of 25°F	None	31000	None	None	None	None	None	None	None	None
Add Destratification Fans	None	20100	0.16	18	117	0.007	0.2	1.1	30	138
Use Radiant Heaters	16000	0.35	None	None	None	None	None	None	None	None
Use Vehicle Doors for AGE	21300	0	∞	266	990	∞	∞	∞	∞	immed.
Minimize Deicing of Aircraft	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA

TABLE 8. ECONOMIC ANALYSIS BY HANGAR FOR LANGLEY AFB (CONTINUED)

(B) HANGAR: 351; AREA: 67,330 SQUARE FEET

Modification	Life Cycle Cost Reduction $	1983 Project Cost $	Benefit Cost Ratio	Net Annual Energy Saved Mega BTU	Net Annual Dollars Saved	Dollars Saved Per $ Invested	Dollars Saved X10^6 Per $ Invested Per Sq Ft	Mega BTU Saved Per $1,000 Invested	Mega BTU Saved X10^6 Per $1,000 Invested Per Sq Ft	Simple Payback Years
Remove or Replace Windows	None	4300	0.84	45	168	0.05	0.7	13	191	21
Paint Floors With Reflective Paint	None	13200	None	None	None	None	None	None	None	None
Add Portable Door Seals	16200	5740	3.8	274	1020	0.22	3.3	59	875	4.5
Interlock Heaters With Hangar Doors	1470	2650	1.5	52	190	0.09	1.3	24	360	11.1
Lower Light Fixtures	None	5100	None	None	None	None	None	None	None	None
Supply Air ΔT of 25°F	None	62000	None	None	None	None	None	None	None	None
Add Destratification Fans	157000	36000	5.3	193	8950	0.31	4.6	82	1212	3.2
Use Radiant Heaters	None	42000	.29	None	None	None	None	None	None	None
Use Vehicle Doors for AGE	21300	0	∞	266	990	∞	∞	∞	∞	immed.
Minimize Deicing of Aircraft	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA

TABLE 8. ECONOMIC ANALYSIS BY HANGAR FOR LANGLEY AFB (CONTINUED)

(C) HANGAR: 752; AREA: 72,725 SQUARE FEET

Modification	Life Cycle Cost Reduction $	1983 Project Cost $	Benefit Cost Ratio	Net Annual Energy Saved Mega BTU	Net Annual Dollars Saved	Dollars Saved Per $ Invested	Dollars Saved X10^6 Per $ Invested Per Sq Ft	Mega BTU Saved Per $1,000 Invested	Mega BTU Saved X10^6 Per $1,000 Invested Per Sq Ft	Simple Payback Years
Remove or Replace Windows	None	67000	0.96	810	3020	0.05	0.8	15	204	18
Paint Floors With Reflective Paint	None	14500	None	None	None	None	None	None	None	None
Add Portable Door Seals	23800	6620	4.6	379	1400	0.26	3.6	71	973	3.8
Interlock Heaters With Hangar Doors	25600	2860	8.2	363	1350	0.47	6.5	127	1750	2.1
Lower Light Fixtures	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
Supply Air ΔT of 25°F	None	76000	None	None	None	None	None	None	None	None
Add Destratification Fans	None	29800	0.09	27	140	0.004	0.1	0.92	12	213
Use Radiant Heaters	None	14700	None	None	None	None	None	None	None	None
Use Vehicle Doors for AGE	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
Minimize Deicing of Aircraft	4000	0	∞	50	190	∞	∞	∞	∞	immed.

TABLE 8. ECONOMIC ANALYSIS BY HANGAR FOR LANGLEY AFB (CONTINUED)

(n) HANGAR: 753; AREA: 62,615 SQUARE FEET

Modification	Life Cycle Cost Reduction $	1983 Project Cost $	Benefit Cost Ratio	Net Annual Energy Saved Mega BTU	Net Annual Dollars Saved	Dollars Saved Per $ Invested	Dollars Saved X10^6 Per $ Invested Per Sq Ft	Mega BTU Saved Per $1,000 Invested	Mega BTU Saved X10^6 Per $1,000 Invested Per Sq Ft	Simple Payback Years
Remove or Replace Windows	None	63000	0.97	770	2870	0.05	0.9	15	240	18
Paint Floors with Reflective Paint	None	14500	None	None	None	None	None	None	None	None
Add Portable Door Seals	23800	6620	4.6	379	1400	0.26	4.2	71	1130	3.8
Interlock Heaters with Hangar Doors	ECIP									
Lower Light Fixtures	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
Supply Air ΔT of 25°F	None	69000	None	None	None	None	None	None	None	None
Add Destratification Fans	None	32300	0.1	30	146	0.005	0.1	1.1	19	179
Use Radiant Heaters	None	14700	None	None	None	None	None	None	None	None
Use Vehicle Doors for AGE	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
Minimize Deicing of Aircraft	2000	0	∞	25	95	∞	∞	∞	∞	immed.

TABLE 8. ECONOMIC ANALYSIS BY HANGAR FOR LANGLEY AFB (CONCLUDED)

(E) HANGAR: 756; AREA: 42.235 SQUARE FEET

Modification	Life Cycle Cost Reduction $	1983 Project Cost $	Benefit Cost Ratio	Net Annual Energy Saved Mega BTU	Net Annual Dollars Saved	Dollars Saved Per $ Invested	Dollars Saved X10^6 Per $ Invested Per Sq Ft	Mega BTU Saved Per $1,000 Invested	Mega BTU Saved X10^6 Per $1,000 Invested Per Sq Ft	Simple Payback Years
Remove or Replace Windows	None	26500	0.963	393	1465	0.05	1.3	15	360	18
Paint Floors With Reflective Paint	None	14500	None	None	None	None	None	None	None	None
Add Portable Door Seals	9980	3310	4.0	165	617	0.23	5.6	62	1502	4.3
Interlock Heaters With Hangar Doors	6840	440	16.5	91	340	0.95	23	254	6180	1
Lower Light Fixtures	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
Supply Air ΔT of 25°F	None	39700	None	None	None	None	None	None	None	None
Add Destratification Fans	None	22200	0.09	16	81	0.004	0.1	0.9	21	220
Use Radiant Heaters	None	12000	None	None	None	None	None	None	None	None
Use Vehicle Doors for AGE	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
Minimize Deicing of Aircraft	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA

TABLE 9. ECONOMIC ANALYSIS BY HANGAR FOR MINOT AFB

(A) HANGAR: 718; AREA: 19,300 SQUARE FEET

Modification	Life Cycle Cost Reduction $	1983 Project Cost $	Benefit Cost Ratio	Net Annual Energy Saved Mega BTU	Net Annual Dollars Saved	Dollars Saved Per $ Invested	Dollars Saved $X10^6$ Per $ Invested Per Sq Ft	Mega BTU Saved Per $1,000 Invested	Mega BTU Saved $X10^6$ Per $1,000 Invested Per Sq Ft	Simple Payback Years
Lower Ceilings	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
Remove or Replace Windows	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
Add Portable Door Seals	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
Interlock Heaters With Hangar Doors	600	1800	1.3	50	106	0.07	3.9	35	1837	13
Add Power Factor Correction	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
Supply Air ΔT of $25^{o}F$	None	20000	None	None	None	None	None	None	None	None
Add Destratification Fans	None	8000	0.2	26	70	0.01	0.6	4	208	92
Use Radiant Heaters	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
Add Air Curtains	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
Use Vehicle Doors for AGE	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA

TABLE 9. ECONOMIC ANALYSIS BY HANGAR FOR MINOT AFB (CONTINUED)

(B) HANGAR: 763; AREA: 39,960 SQUARE FEET

Modification	Life Cycle Cost Reduction $	1983 Project Cost $	Benefit Cost Ratio	Net Annual Energy Saved Mega BTU	Net Annual Dollars Saved	Dollars Saved Per $ Invested	Dollars Saved X10^6 Per $ Invested Per Sq Ft	Mega BTU Saved Per $1,000 Invested	Mega BTU Saved X10^6 Per $1,000 Invested Per Sq Ft	Simple Payback Years
Lower Ceilings	None	132000	0.07	213	450	0.004	0.1	2	50	236
Remove or Replace Windows	4200	3600	2.1	171	360	0.12	3.2	59	1470	8
Add Portable Door Seals	30000	5500	6.4	785	1650	0.37	9.3	175	4400	2.7
Interlock Heaters With Hangar Doors	4600	5300	1.9	218	460	0.11	2.7	51	1270	9.3
Add Power Factor Correction	25600	1000	31	0	1500	2.1	53	0	0	.5
Supply Air ΔT of 25°F	None	38000	None	None	None	None	None	None	None	None
Add Destratification Fans	None	22000	0.08	55	48	0.003	0.1	3	80	357
Use Radiant Heaters	15600	79400	1.2	2096	4400	0.07	1.7	32	815	15
Add Air Curtains	81000	4600	18	2004	3907	1.05	26.5	543	13600	0.9
Use Vehicle Doors for AGE	5000	0	∞	1194	2520	∞	∞	∞	∞	immed.

TABLE 9. ECONOMIC ANALYSIS BY HANGAR FOR MINOT AFB (CONTINUED)

(C) HANGAR: 836; AREA: 17,150 SQUARE FEET

Modification	Life Cycle Cost Reduction $	1983 Project Cost $	Benefit Cost Ratio	Net Annual Energy Saved Mega BTU	Net Annual Dollars Saved	Dollars Saved Per $ Invested	Dollars Saved X10^6 Per $ Invested Per Sq Ft	Mega BTU Saved Per $1,000 Invested	Mega BTU Saved X10^6 Per $1,000 Invested Per Sq Ft	Simple Payback Years
Lower Ceilings	None	56500	0.2	243	500	0.01	0.7	5	309	89
Remove or Replace Windows	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
Add Portable Door Seals	55000	2200	26	1270	2680	1.5	87.5	710	41000	0.67
Interlock Heaters With Hangar Doors	19700	900	23	454	960	1.3	78.2	635	37000	0.75
Add Power Factor Correction	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
Supply Air ΔT of 25^{o}F	None	20000	None	None	None	None	None	None	None	None
Add Destratification Fans	None	9500	0.22	63	86	0.01	0.6	8	476	90
Use Radiant Heaters	26000	44200	1.6	1547	3260	0.09	5.3	43	2524	11
Add Air Curtains	81000	4600	18	2004	3907	1.05	61	543	31600	0.9
Use Vehicle Doors for AGE	50000	0	∞	1194	2520	∞	∞	∞	∞	immed.

TABLE 9. ECONOMIC ANALYSIS BY HANGAR FOR MINOT AFB (CONTINUED)

(D) HANGAR: 837; AREA: 33,250 SQUARE FEET

Modification	Life Cycle Cost Reduction $	1983 Project Cost $	Benefit Cost Ratio	Net Annual Energy Saved Mega BTU	Net Annual Dollars Saved	Dollars Saved Per $ Invested	Dollars Saved X10^6 Per $ Invested Per Sq.Ft.	Mega BTU Saved Per $1,000 Invested	Mega BTU Saved X10^6 Per $1,000 Invested Per Sq.Ft.	Simple Payback Years
Lower Ceilings	None	110000	0.2	420	890	0.01	0.3	5	143	99
Remove or Replace Windows	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
Add Portable Door Seals	55000	2200	26	1270	2680	1.5	45	710	21000	0.67
Interlock Heaters With Hangar Doors	19000	2200	12	460	970	0.7	20	320	9700	1.5
Add Power Factor Correction	31400	2300	14	0	1800	0.98	29	0	0	1
Supply Air ΔT of 25°F	None	34000	None	None	None	None	None	None	None	None
Add Destratification Fans	None	18000	0.3	158	243	0.01	0.5	11	326	60
Use Radiant Heaters	43600	117600	1.4	3555	7500	0.08	2.4	37	1122	13
Add Air Curtains	81000	4600	18	2004	3907	1.05	32	543	16331	0.9
Use Vehicle Doors for AGE	5000	0	∞	1194	2520	∞	∞	∞	∞	immed.

TABLE 9. ECONOMIC ANALYSIS BY HANGAR FOR MINOT AFB (CONCLUDED)
(E) HANGAR: 867; AREA: 26,690 SQUARE FEET

Modification	Life Cycle Cost Reduction $	1983 Project Cost $	Benefit Cost Ratio	Net Annual Energy Saved Mega BTU	Net Annual Dollars Saved	Dollars Saved Per $ Invested	Dollars Saved X10^6 Per $ Invested Per Sq Ft	Mega BTU Saved Per $1,000 Invested	Mega BTU Saved X10^6 Per $1,000 Invested Per Sq Ft	Simple Payback Years
Lower Ceilings	None	88000	0.1	299	630	0.008	0.3	4	157	112
Remove or Replace Windows	1500	1500	2	66	140	0.11	4.4	56	2100	8.4
Add Portable Door Seals	55000	2000	26	1270	2680	1.5	56	710	26000	0.67
Interlock Heaters With Hangar Doors	1400	500	4.1	40	90	0.24	8.9	111	4200	4.2
Add Power Factor Correction	33000	6300	6.2	0	2200	0.43	16	0	0	2.3
Supply Air ΔT of 25°F	None	29000	None	None	None	None	None	None	None	None
Add Destratification Fans	None	14300	0.17	81	97	0.008	0.3	7	262	119
Use Radiant Heaters	17400	74500	1.2	2004	0.07	2.7	34	1261	14	
Add Air Curtains	99000	9200	12	2641	4927	0.67	25	357	13400	1.5
Use Vehicle Doors for AGE	50000	0	∞	1194	2520	∞	∞	∞	∞	immed.

Table 10. ECONOMIC ANALYSIS BY HANGAR FOR TINKER AFB

(A) HANGAR: 230; AREA: 540,821 SQUARE FEET

Modification	Life Cycle Cost Reduction $	1983 Project Cost $	Benefit Cost Ratio	Net Annual Energy Saved Mega BTU	Net Annual Dollars Saved	Dollars Saved Per $ Invested	Dollars Saved X10^6 Per $ Invested Per Sq Ft	Mega BTU Saved Per $1,000 Invested	Mega BTU Saved X10^6 Per $1,000 Invested Per Sq Ft	Simple Payback Years
Lower Ceilings	100000	1500000	1.0	44500	88450	0.06	0.1	30	57	16
Remove or Replace Windows	None	39000	0.7	648	1290	0.04	0.1	20	38	24
Paint Floors With Reflective Paint	None	66000	None	None	None	None	None	None	None	None
Add Vehicle Doors	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
Interlock Heaters With Hangar Doors	2880	6700	1.4	222	440	0.08	0.2	41	76	12
Lower Light Fixtures	None	24600	None	None	None	None	None	None	None	None
Add Power Factor Correction	48000	5200	10.7	0	3070	0.73	1.4	0	0	1.3
Supply Air ΔT of 25°F	None	478000	None	None	None	None	None	None	None	None
Add Destratification Fans	367600	317700	2.1	15442	31952	0.12	0.2	60	111	8
Use Radiant Heaters	None	221000	0.6	3091	6150	0.04	0.1	17	32	29

TABLE 10. ECONOMIC ANALYSIS BY HANGAR FOR TINKER AFB (CONTINUED)

(B) HANGAR: 240; AREA: 181,894 SQUARE FEET

Modification	Life Cycle Cost Reduction $	1983 Project Cost $	Benefit Cost Ratio	Net Annual Energy Saved Mega BTU	Net Annual Dollars Saved	Dollars Saved Per $ Invested	Dollars Saved X10^6 Per $ Invested Per Sq Ft	Mega BTU Saved Per $1,000 Invested	Mega BTU Saved [illegible] Per $1,000 Invested Per Sq Ft	[illegible] Years
Lower Ceilings	None	600000	0.6	8557	17000	0.04	0.2	17	97	[illegible]
Remove or Replace Windows	None	66000	0.6	1023	2037	0.04	0.2	19	105	[illegible]
Paint Floors With Reflective Paint	None	526000	None	None	None	None	None	None	None	None
Add Vehicle Doors	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
Interlock Heaters With Hangar Doors	3000	1760	18	740	1470	1.0	5.7	517	2846	0.97
Lower Light Fixtures	None	30000	None	None	None	None	None	None	None	None
Add Power Factor Correction	59000	8100	8.3	0	3740	0.57	3.1	0	0	1.8
Supply Air ΔT of 25°F	None	200000	None	None	None	None	None	None	None	None
Add Destratification Fans	12930	96350	1.1	2738	4960	0.06	0.3	35	193	16
Use Radiant Heaters	None	221000	0.6	3091	6150	0.04	0.2	17	95	29

TABLE 10. ECONOMIC ANALYSIS BY HANGAR FOR TINKER AFB (CONTINUED)

(C) HANGAR: 1030; AREA: 96,698 SQUARE FEET

Modification	Life Cycle Cost Reduction $	1983 Project Cost $	Benefit Cost Ratio	Net Annual Energy Saved Mega BTU	Net Annual Dollars Saved	Dollars Saved Per $ Invested	Dollars Saved X10^6 Per $ Invested Per Sq Ft	Mega BTU Saved Per $1,000 Invested	Mega BTU Saved X10^6 Per $1,000 Invested Per Sq Ft	Simple Payback Years
Lower Ceilings	None	260000	0.2	1905	3800	0.01	0.2	7	76	68
Remove or Replace Windows	None	43400	0.7	716	1425	0.04	0.1	20	63	24
Paint Floors With Reflective Paint	None	23800	0.55	348	780	0.04	0.4	18	186	25
Add Vehicle Doors	20300	6850	4	634	1262	0.22	2.4	114	1184	4.4
Interlock Heaters With Hangar Doors	27000	2650	11	691	1375	0.64	6.6	322	3335	1.5
Lower Light Fixtures	None	32300	None	None	None	None	None	None	None	None
Add Power Factor Correction	118000	5300	23	0	6850	1.6	16.5	0	0	.6
Supply Air [illegible] 25°F	None	105000	None	None	None	None	None	None	None	None
Add Destratification Fans	None	52000	0.3	497	737	0.02	0.2	12	123	56
Use Radiant Heaters	None	102000	0.6	1440	2870	0.04	0.4	17	178	29

TABLE 10. ECONOMIC ANALYSIS BY HANGAR FOR TINKER AFB (CONTINUED)

(D) HANGAR: 2122; AREA: 323,509 SQUARE FEET

Modification	Life Cycle Cost Reduction $	1983 Project Cost $	Benefit Cost Ratio	Net Annual Energy Saved Mega BTU	Net Annual Dollars Saved	Dollars Saved Per $ Invested	Dollars Saved X10^6 Per $ Invested Per Sq Ft	Mega BTU Saved Per $1,000 Invested	Mega BTU Saved X10^6 Per $1,000 Invested Per Sq Ft	Simple Payback Years
Lower Ceilings	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
Remove or Replace Windows	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
Paint Floors With Reflective Paint	None	344000	None	None	None	None	None	None	None	None
Add Vehicle Doors	13500	14000	2	634	1262	0.11	0.4	57	177	8.8
Interlock Heaters With Hangar Doors	25000	5300	5.7	711	1415	0.33	1.0	166	512	3.0
Lower Light Fixtures	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
Add Power Factor Correction	254000	9850	27	0	14700	1.8	5.7	0	0	0.54
Supply Air ΔT of 25^{o}F	None	286000	None	None	None	None	None	None	None	None
Add Destratification Fans	None	171000	None	None	None	None	None	None	None	None
Use Radiant Heaters	None	588000	0.9	13046	25960	0.05	0.2	27	84	18

TABLE 10. ECONOMIC ANALYSIS BY HANGAR FOR TINKER AFB (CONCLUDED)

(E) HANGAR: 3102; AREA: 168,479 SQUARE FEET

Modification	Life Cycle Cost Reduction $	1983 Project Cost $	Benefit Cost Ratio	Net Annual Energy Saved Mega BTU	Net Annual Dollars Saved	Dollars Saved Per $ Invested	Dollars Saved X10^6 Per $ Invested Per Sq Ft	Mega BTU Saved Per $1,000 Invested	Mega BTU Saved X10^6 Per $1,000 Invested Per Sq Ft	Simple Payback Years
Lower Ceilings	None	450000	0.2	2655	5285	0.01	0.1	6	35	85
Remove or Replace Windows	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
Paint Floors With Reflective Paint	None	45080	None	None	None	None	None	None	None	None
Add Vestibule Doors	13500	13700	2	634	1262	0.11	0.7	57	340	8.8
Interlock Heaters With Hangar Doors	121000	5300	24	2964	5900	1.4	8.2	691	4103	0.7
Lower Light Fixtures	None	12400	None	None	None	None	None	None	None	None
Add Power Factor Correction	149000	11100	14	0	8930	1.0	5.9	0	0	1.0
Supply Air [illegible]	None	220000	None	None	None	None	None	None	None	None
Add Destratification Fans	None	89500	0.5	1265	2075	0.03	0.2	17	103	35
Use Radiant Heaters	None	133000	0.8	2455	4885	0.05	0.3	23	136	22

SURVEY RESULTS

Many interesting and unusual problems were discussed during the surveys. This section addresses some of the recurrent difficulties and categorical defects observed at each base.

The most common problem observed at each base was high infiltration through the entire structure. This includes under and around hangar doors and through the walls and perimeter as illustrated in Figure 9. Note especially the large opening along the floor. Infiltration probably represents the single largest source of heat loss in the hangars. Since most infiltration comes through the large hangar doors, efforts to reduce this infiltration through the use of proper door seals should prove highly beneficial. The door seals observed were in many cases in a state of disrepair. Base personnel have noted that the expected life of a door seal has been two years or less. An improved seal design would be extremely desirable to reduce infiltration.

Hangar door operation presents another unusual problem. Many hangar doors are motor-operated and others are opened and closed manually. In two cases, the doors open vertically (Tinker, Building 3102 and Minot, Building 718). The remainder open horizontally using tracks at the top and bottom of the door. The hangar door design in most cases represents the best combination of strength, durability, and ease of opening. However, either method of opening the doors, i.e., manually or by motor operation, results in some dissatisfaction. In cases of manual operation, productivity drops each time doors are opened because up to six people are used to open the doors. Only one or two operators would be necessary if the doors were motor operated. Also, some of the heavier doors remain open in cold weather because they are too heavy to close easily. In cases of motor-operated doors, the mechanism often uses a chain-gear operator with one motor for five door sections. The chain often breaks, especially in colder weather. As a result, the door is stuck in that position until the chain is fixed, a procedure which often takes up to several days to complete. Since each of these two methods has different drawbacks, the type of door closer selected should be determined by analyzing individual hangar requirements with input from the operating personnel.

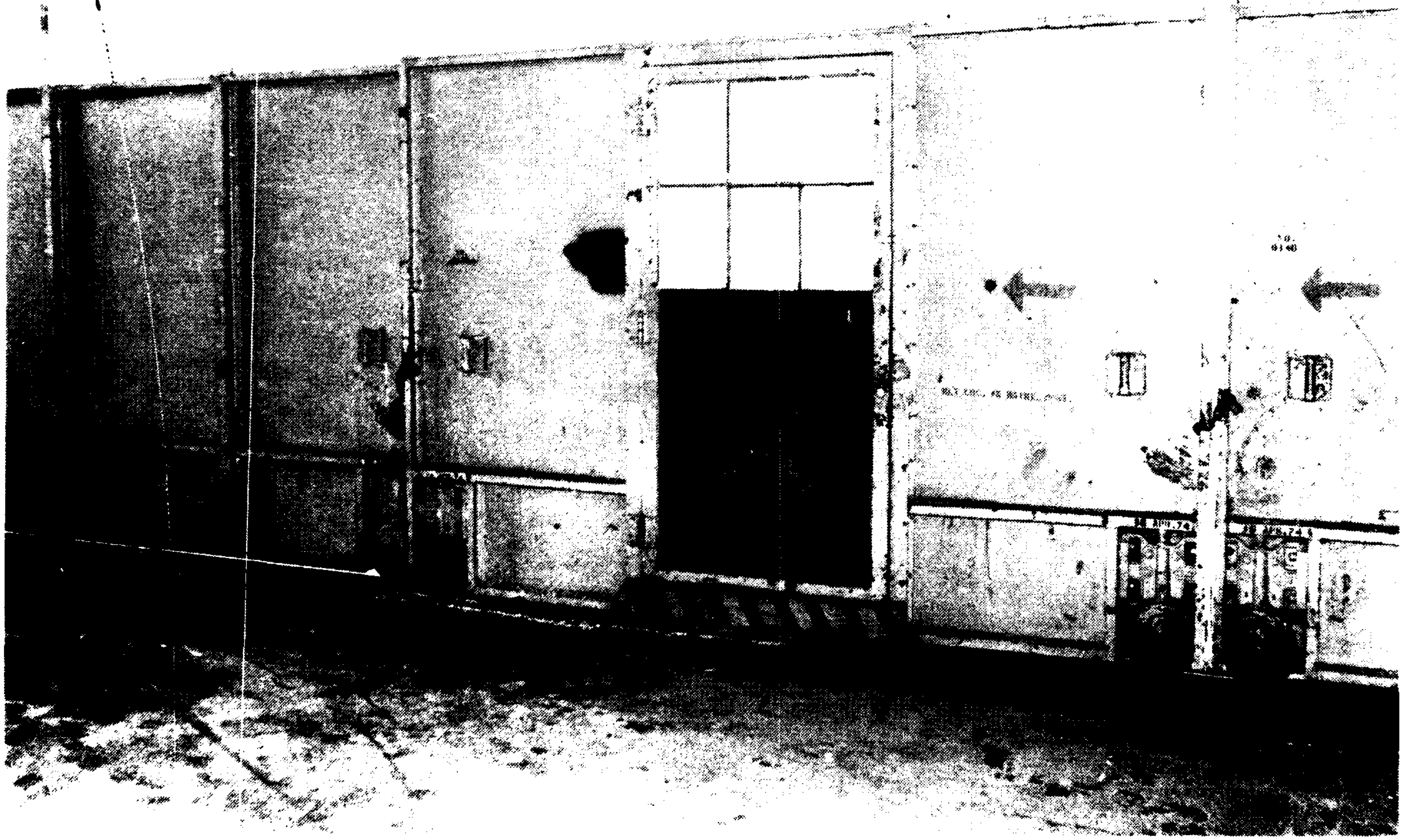


Figure 9. Infiltration Through Typical Hangar Door, 753, Langley AFB

Deicing of aircraft presents a problem for fighter aircraft such as the F-106 and F-15. The use of deicing fluid is prohibited on these aricraft because the fluid is extremely corrosive to wiring on the electronics inside the aircraft skin. For this reason the aircraft are often deiced using building heat. Alternate methods of deicing should be considered to save energy.

For various reasons the building heating systems often fail to maintain adequate space temperatures for several hours after a hangar door is opened. Space temperatures as low as 38 degrees F have been noted by operating personnel on several occasions. In the case of Building 756 at Langley AFB, it takes up to 48 hours after a hangar door is opened to bring the space temperature up to 60 degrees F. It appears that heating systems in most hangars are somewhat undersized. Figure 10 illustrates a typical floor-mounted space heater with horizontal steam coil.

In Minot AFB Building 836 and Tinker AFB Building 2122, production processes such as application of fuel cell sealant require that the temperature of the surface at the point of application be above 70 degrees F. Portable electric heaters are often used to supplement the space heaters, especially in Building 2122, to allow the sealant to cure properly. Even with this supplemental heat, the operating personnel experience a reduction in productivity of up to 50 percent in winter. Special consideration regarding heating systems should be given to those hangars which incorporate specialized processes. The decreased energy costs achieved through certain conservation efforts may be more than offset by the costs of a reduction in production efficiency.

Many of the hangars surveyed had ceiling heights in excess of 70 feet at the high point. In many cases, the ceiling height was up to 40 feet higher than the height required to properly service aircraft. Lowering ceilings appeared to be a desirable and useful modification. Unfortunately, each of the hangars at Tinker AFB and Minot AFB contain a wet sprinkler system with sprinklers located along the high point of the building. In order to lower ceilings in these hangars, a second layer of sprinklers would be needed at

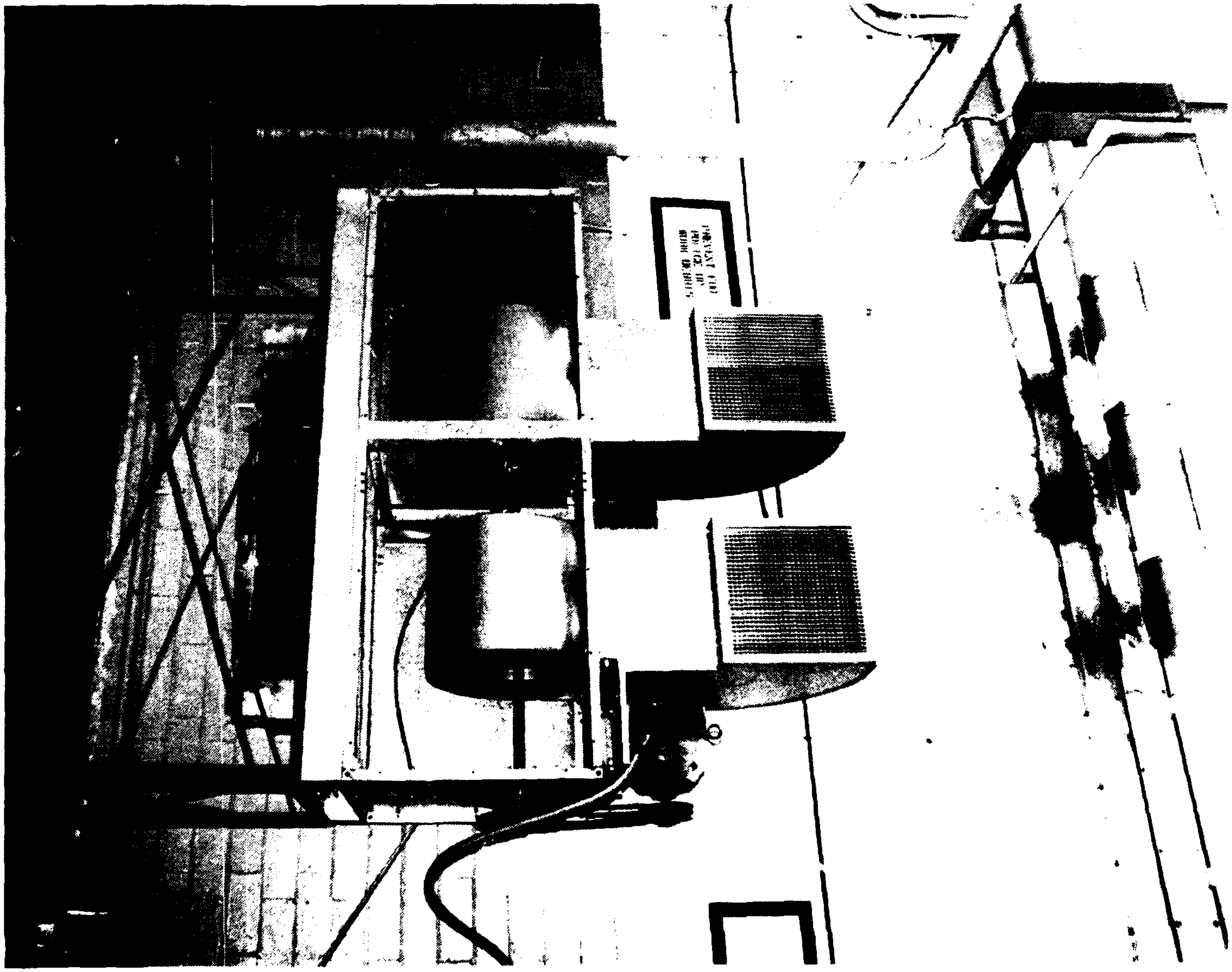


Figure 10. Typical Floor-Mounted Space Heater, Building 752, Langley AFB

the new ceiling level. The cost of these sprinklers amounts to a significant percentage of the cost of the lowered ceiling and reduces the feasibility of this modification.

One unusual problem associated with the high ceilings in hangars is pigeons. The truss space apparently makes an ideal nesting area for the birds, and environmental regulations prohibit their extermination. As a result, aircraft and people in these hangars are subject to an annoying problem. Although the pigeon problem appears at first to be a humorous situation, it is potentially serious in that pigeon droppings can corrode aircraft surfaces causing potentially serious damage. Lowering the ceilings would probably discourage the pigeons and improve working conditions in these hangars.

Several of the hangars with high bays such as Tinker AFB Building 230, shown in Figure 11, reported serious stratification problems. Temperatures in excess of 100 degrees F in the truss space have been recorded at Tinker AFB in the middle of winter while at the same time floor temperatures were 55 degrees F. High temperatures caused by stratification result in excessive transmission heat loss through the walls and roof. Destratification fans represent a potentially attractive measure to reduct this stratification.

Base personnel at Minot AFB have suggested using Building 867 as a test building to compare energy consumption before and after ECO's are implemented. The building currently has no metering and would require full instrumentation of energy systems to record consumption. Building 867 is shown in Figure 12.

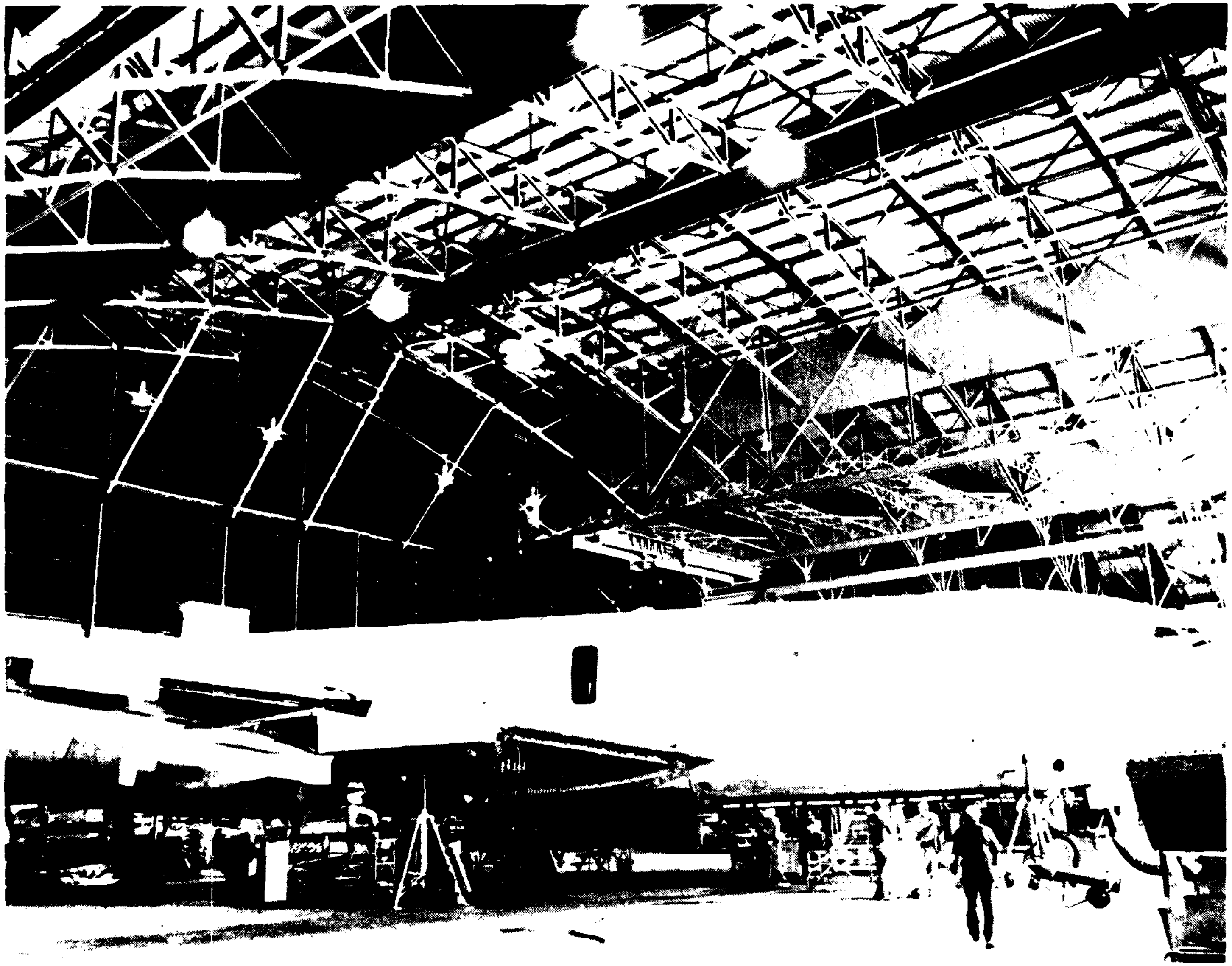


Figure 11. Interior of Building 230, Tinker AFB

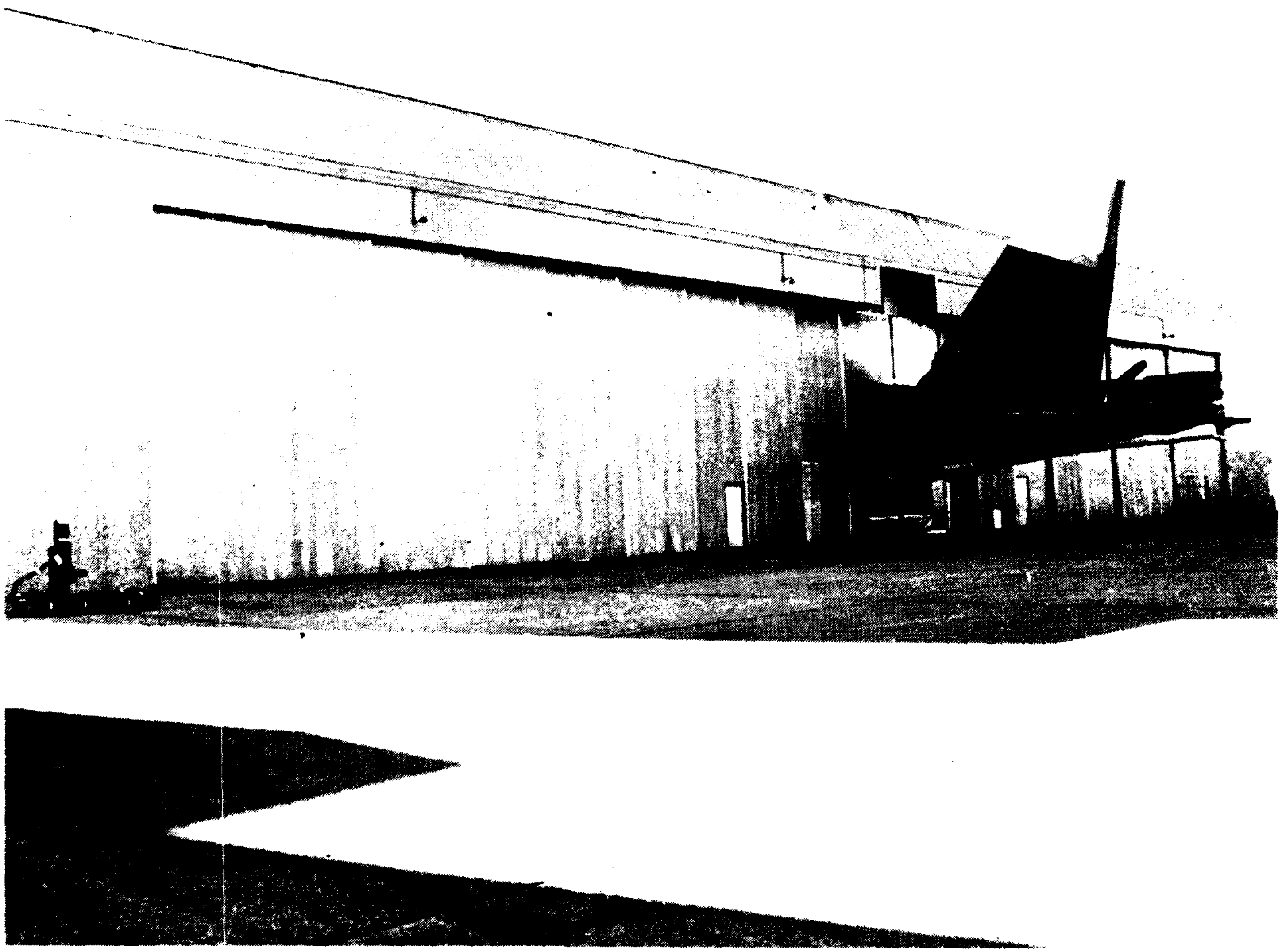


Figure 12. Building 867, Minot AFB

SECTION V

CONCLUSIONS AND RECOMMENDATIONS

GENERAL

Table 11 summarizes the economic analysis of each ECO studied for each hangar. This table shows that many of the ECO's analyzed are economically attractive for several hangars. Those ECO's which were shown to be economically attractive are denoted by an A. Those which were analyzed and are economically unattractive are marked with a U. Those hangars to which a selected ECO did not apply were denoted by NA (Not Applicable). Those ECO's which were not selected for a given hangar are marked with NS (Not Selected). Those ECO's which have been evaluated as a part of ECIP are marked with an E.

DESIGN TEMPERATURE

The Air Force design criteria calls for a 55-degree F design space temperature for aircraft hangars during the heating season. Because of this low design temperature, some of the modifications are economically unattractive, especially at Langley AFB. Modifications such as adding infrared heaters, lowering ceilings, and removing windows would be more attractive if the design temperature were 70 degrees F.

COST OF ENERGY

Energy costs for fossil fuels and electricity are still relatively inexpensive at all three bases. This factor also contributes to the poor feasibility of some ECO's. However, the substantial increases in energy costs observed recently should make several of the currently unattractive ECO's more economically desirable by 1985. These ECO's include removing windows, using gas-fired infrared heaters at Tinker, lowering ceilings (in poorly insulated hangars), and destratification fans.

TABLE 11. SUMMARY OF ENERGY CONSERVATION OPPORTUNITIES

MODIFICATION	L338	L351	L752	L753	L756	M718	M763	M836	M837	M867	T230	T240	T1030	T2122	T3102
REMOVE WINDOWS	U	U	U	U	U	E	A	NA	NA	A	U	U	NA	U	NA
PORTABLE DOOR SEALS	A	A	A	A	A	NA	A	A	A	A	NS	NS	NS	NS	NS
INTERLOCK HEATERS	A	A	A	E	A	A	A	A	A	A	A	A	A	A	A
SUPPLY AIR AT 85°F	U	U	U	U	U	U	U	U	U	U	U	U	U	U	U
DESTRATIFICATION FANS	U	A	U	U	U	U	U	U	U	U	A	A	U	U	U
RADIANT HEATERS	U	U	U	U	U	NA	A	A	A	A	U	U	U	U	U
USE VEHICLE DOORS FOR AGE	A	A	NA	NA	NA	NA	A	A	A	A	NS	NS	NS	NS	NS
LOWER LIGHTS	E	U	NA	NA	NA	NS	NS	NS	NS	NS	U	U	U	NA	U
REFLECTIVE PAINT	U	U	U	U	U	NS	NS	NS	NS	NS	U	U	U	U	U
MINIMIZE DEICING OF AIRCRAFT	NS	NA	A	A	NA	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
LOWER CEILING	NS	NS	NS	NS	NS	NA	U	U	U	U	U	U	U	U	U
POWER FACTOR CORRECTION	NS	NS	NS	NS	NS	NA	A	NA	A	A	A	A	A	A	A
AIR CURTAINS	NS	NS	NS	NS	NS	NA	A	A	A	A	NS	NS	NS	NS	NS
ADD VEHICLE DOOR	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NA	NA	A	A	A

NA = NOT APPLICABLE
NS = NOT STUDIED
E = PART OF ECIP PROGRAM

A = ECONOMICALLY ATTRACTIVE ECO
U = ECONOMICALLY UNATTRACTIVE ECO

REMOVE OR REPLACE WINDOWS

Blocking up windows can be accomplished in several ways. The method chosen for this study, i.e., adding insulated panels, proved to be too expensive to be cost effective in the milder climates at Tinker AFB and Langley AFB. However, the energy savings attributed to this modification are great, and it is possible that less expensive methods of blocking the windows can be used successfully. Therefore, it is recommended that requests for bids to block the windows be issued to see if the cost can be reduced. From the data developed in this report, a new analysis can then be quickly performed to re-evaluate this ECO for each hangar. It is felt that these bids will show that this ECO is cost effective for most bases.

The economic analysis of removing windows at Minot AFB was performed even though Minot is currently engaging in a window replacement program. This analysis was done in order to provide the USAF with economic data for bases with similar climates to Minot AFB. The results show that blocking windows in the colder climates is economically attractive even with the low cost of energy.

ADD PORTABLE DOOR SEALS

Since infiltration is the most important factor in energy consumption in hangars, major efforts should continue to be directed toward reducing infiltration. The portable door seals analyzed represent a good and inexpensive method of reducing infiltration and should be installed at each base. In addition, base personnel should be encouraged to reduce infiltration by properly sealing openings.

INTERLOCK HEATERS WITH HANGAR DOORS

Heaters located in the vicinity of hangar doors should be interlocked to shut off automatically when hangar doors are open. However, these interlocks will always be easy to bypass, so workers should be instructed not to tamper with the operation of these heaters under risk of penalty or this modification will not succeed.

ADD AIR CURTAINS TO VEHICLE DOORS

Air curtains are difficult to evaluate because little theoretical data exists about actual performance. The savings attributed to air curtains in this report are based on average wind velocities over the heating season and appear to be optimistically high. Nevertheless, the analysis shows theoretically excellent results, and it is recommended that air curtains be installed on a test basis at both Minot AFB and Tinker AFB. After empirical data is gathered at each base, a decision can be made about installing units at all bases.

USE INFRARED RADIANT HEATERS

Infrared heating seems to be ideally suited to hangars for several reasons. First, rapid recovery improves productivity. Second, equivalent comfort levels can be maintained with lower temperatures. Third, aircraft will be warmer. Fourth, stratification will be reduced.

It is recommended that low-intensity gas-fired infrared heaters be tested on at least one hangar at Minot AFB and installed in other hangars if the test results are successful. Building 867 is suggested as the test building at Minot AFB. It must be noted that the DOD's current gas policy discourages the use of gas-fired devices. Special variance must be obtained to use the recommended heaters. Another observation is that the use of infrared heaters will reduce energy savings due to interlocking heaters and using destratification fans. Any building using infrared heat should not use destratification fans but should continue to interlock the heaters with hangar doors.

ADD DESTRATIFICATION FANS

Destratification fans offer the best low-cost solution currently available to the problem of stratification. However, stratification theory is sorely lacking, and the total number of fans required is an estimated rather than a calculable value. For these reasons, a theoretical analysis cannot fully evaluate the true impact of these fans. Testimonies from satisfied users indicate that the figures generated in this report are probably conservative. Therefore, an empirical evaluation of this ECO is the best way to determine its value. It is recommended that these fans be installed in at least one high bay structure at Tinker AFB and Langley AFB. Since Building 240 at Tinker AFB has two identical bays, one should be outfitted with fans to test their effectiveness. Building 351 is the only high bay hangar surveyed at Langley AFB, so fans should be installed there as well.

USE AND ADD VEHICLE DOORS FOR AGE

Although base personnel have the incentive to use vehicle doors in cold weather, they are sometimes forced to use hangar doors because equipment is blocking the vehicle doors. Personnel should be strongly encouraged to keep vehicle doors clear and use them instead of hangar doors whenever possible.

In cases where vehicle doors do not exist, it is economical to install them and encourage personnel to use them.

ADD POWER FACTOR CORRECTION

Power factor correction using capacitors is attractive where utilities charge for poor power factor such as at Tinker AFB. Even though synchronous motors are used extensively at most Air Force Bases, synchronous motors can be shut off. Since demand charges are based on the lowest power factor, capacitors remain the most useful method of power factor correction.

MINIMIZE DEICING USING BUILDING HEAT

For every F-15 which is deiced by means other than building heat, 374,000 BTU's are saved. Therefore, efforts should be directed to finding an economical alternative to using building heat to deice aircraft.

LOWERING CEILINGS

Although lowering ceilings appears to be an intuitively attractive ECO, three factors make it economically unfeasible. First, most of the buildings analyzed were or are in the process of becoming well-insulated, so the total savings by lowering the ceilings is fairly small. Second, fire protection systems at Minot AFB and Tinker AFB would need a second, very expensive layer of sprinklers if a false ceiling were installed. These additional sprinklers make the cost prohibitive in all except Building 230 at Tinker AFB which is poorly insulated. Third, at Building 230, if a false ceiling were installed, the attic temperature would fall low enough to freeze the sprinkler pipes. Therefore, the only case in which lowering a ceiling would be attractive is a poorly insulated high bay with no fire protection requirements.

LOWERING LIGHTS AND PAINTING WITH REFLECTIVE PAINT

Because of past delamping efforts and the generally wide spacing of lights in hangars, lowering lights and painting with reflective paint do not allow any additional delamping while still maintaining current lighting levels. Therefore, lights should be lowered only when replacing old fixtures with High Pressure Sodium fixtures. Floors should be painted with reflective paint only when repainting as a part of scheduled maintenance.

SUPPLY AIR ΔT OF 25 DEGREES F

Since significant additional air must be supplied to reduce the supply air temperature and still heat the space, this ECO actually uses more raw source energy than it saves (due to the increase in electricity consumption) and is totally unacceptable in all cases.

SUMMARY

The ECO's recommended for implementation are as follows: remove windows, add portable door seals; interlock heaters; add air curtains; use infrared heaters; add destratification fans; use and add vehicle doors; add power factor correction; and minimize deicing of aircraft.

APPENDIX A

LIST OF POTENTIAL ENERGY CONSERVATION OPPORTUNITIES

TYPES:

- A - ARCHITECTURAL
- E - ELECTRICAL
- M - MECHANICAL
- O - OPERATIONS
- S - STRUCTURAL

BASES

- L - LANGLEY
- M - MINOT
- T - TINKER

TYPE	MODIFICATION	APPLICABLE BUILDINGS	BUILDINGS COVERED BY BEAP
A	LOWER CEILING	L752, 338, 351 M763, 836, 837, T230, 240, 2122, 3102	-
A	BLOCK UP HANGAR DOORS	L752	-
A	ADD DOOR CLOSERS TO MAN DOORS	L752	-
A	REMOVE WINDOWS	ALL	-
A	REPLACE REMAINING WINDOWS	ALL	-
A	INSULATE WALLS AND CEILING	ALL	ALL EXCEPT L753, T1030, 3102
A	REPAIR AND REPLACE SEALS	ALL	ALL
A	PAINT FLOORS TO REFLECT LIGHT	ALL EXCEPT M836, 837	-

TYPE	MODIFICATION	APPLICABLE BUILDINGS	BUILDINGS COVERED BY BEAP
A	PROVIDE OPERABLE WINDOWS TO REDUCE A/C REQUIRED	M763 T1030	-
A	ADD VEHICLE DOORS	T230, 240, 1030, 3102	-
A	LOWER CEILING IN PARTS SUPPLY AREA	L756 T230	-
A	ADD SMALL WINDOW TO HANGAR DOOR TO CHECK AGE STATUS	M763	-
A	IMPROVE AIRCRAFT TAIL OPENING SEAL	M836, 867	-
A	CHANGE MAN DOOR TO SLIDING TYPE DOOR	M837	-
A	REDUCE HEIGHT OF VEHICLE DOORS	M867	-
A	ADD DOOR JAMBS TO KEEP HANGAR DOORS CLOSED IN WIND	ALL AT MINOT	-
A	ADD PORTABLE DOOR SEALS	ALL	-
A	PAINT INSIDE WITH LIGHT COLORED EPOXY	ALL	-
A	PAINT OUTSIDE WITH A DARK COLOR PAINT	ALL	-
A	ADD INSULATED WINDOWS COVERS	ALL	-
A	CHANGE TO INSULATED SKYLIGHTS	ALL	-
A	USE DOUBLE OR TRIPLE GLAZED WINDOWS	ALL	-
A	ADD STRIP DOORS TO VEHICLE DOORS	ALL	-

APPENDIX A

LIST OF POTENTIAL
ENERGY CONSERVATION OPPORTUNITIES

TYPES: A - ARCHITECTURAL
E - ELECTRICAL
M - MECHANICAL
O - OPERATIONS
S - STRUCTURAL

BASES L - LANGLEY
M - MINOT
T - TINKER

TYPE	MODIFICATION	APPLICABLE BUILDINGS	BUILDINGS COVERED BY BEAP
A	LOWER CEILING	L752, 338, 351 M763, 836, 837, T230, 240, 2122, 3102	-
A	BLOCK UP HANGAR DOORS	L752	-
A	ADD DOOR CLOSERS TO MAN DOORS	L752	-
A	REMOVE WINDOWS	ALL	-
A	REPLACE REMAINING WINDOWS	ALL	-
A	INSULATE WALLS AND CEILING	ALL	ALL EXCEPT L753, T1030, 3102
A	REPAIR AND REPLACE SEALS	ALL	ALL
A	PAINT FLOORS TO REFLECT LIGHT	ALL EXCEPT M836, 837	-

TYPE	MODIFICATION	APPLICABLE BUILDINGS	BUILDINGS COVERED BY BEAP
A	PROVIDE OPERABLE WINDOWS TO REDUCE A/C REQUIRED	M763 T1030	-
A	ADD VEHICLE DOORS	T230, 240, 1030, 3102	-
A	LOWER CEILING IN PARTS SUPPLY AREA	L756 T230	-
A	ADD SMALL WINDOW TO HANGAR DOOR TO CHECK AGE STATUS	M763	-
A	IMPROVE AIRCRAFT TAIL OPENING SEAL	M836, 867	-
A	CHANGE MAN DOOR TO SLIDING TYPE DOOR	M837	-
A	REDUCE HEIGHT OF VEHICLE DOORS	M867	-
A	ADD DOOR JAMBS TO KEEP HANGAR DOORS CLOSED IN WIND	ALL AT MINOT	-
A	ADD PORTABLE DOOR SEALS	ALL	-
A	PAINT INSIDE WITH LIGHT COLORED EPOXY	ALL	-
A	PAINT OUTSIDE WITH A DARK COLOR PAINT	ALL	-
A	ADD INSULATED WINDOWS COVERS	ALL	-
A	CHANGE TO INSULATED SKYLIGHTS	ALL	-
A	USE DOUBLE OR TRIPLE GLAZED WINDOWS	ALL	-
A	ADD STRIP DOORS TO VEHICLE DOORS	ALL	-

TYPE	MODIFICATION	APPLICABLE BUILDINGS	BUILDINGS COVERED BY BEAP
A	CONFORM SHAPE OF DOOR OPENING TO SHAPE OF CRAFT	ALL	-
A	REPLACE HANGAR DOORS WITH TIGHTER DOORS	ALL AT LANGLEY	-
A	INSULATE OFFICES	L351	L351
E	USE HIGH EFFICIENCY MOTORS	ALL	-
E	CHANGE TO MOTORIZED DOORS	L752, 753, 756 T1030, 2122	-
E	CHANGE TO HPS LIGHTS	ALL	ALL
E	INTERLOCK HEATERS AND IMPROVED SWITCHING	ALL AT LANGLEY AND TINKER	ALL AT TINKER
E	INTERLOCK TAIL DOOR WITH MAIN DOOR	M837	-
E	USE WIND-POWERED GENERATORS	ALL	-
E	USE ELECTRONIC BALLASTS	ALL OFFICES	-
E	INVESTIGATE POLARIZED LENSES FOR OFFICE LIGHTS	ALL OFFICES	-
E	SHUT OFF TRANSFORMERS WHENEVER POSSIBLE	ALL	-
E	LOWER LIGHTING FIXTURES AND CHANGE TO MORE EFFICIENT LENSES	ALL	-
E	ADD POWER FACTOR CORRECTION	ALL	-

TYPE	MODIFICATION	APPLICABLE BUILDINGS	BUILDINGS COVERED BY BEAP
E,M	INVESTIGATE COGENERATION	ALL	-
E	INSTALL TIMERS ON LIGHTS	L351	L351
E	INVESTIGATE PHOTO-VOLTAIC CELLS	ALL	-
M	INVESTIGATE UNDER-GROUND HEAT STORAGE	ALL	-
M	RECLAIM CONDENSER HEAT FROM AIR CONDITIONING UNITS	L752, 753, 756	-
M	INCREASE HOT WATER ΔT TO REDUCE FLOW RATE	ALL AT MINOT	-
M	ADD AIR CURTAINS TO VEHICLE DOORS	ALL	-
M	PERFORM INFRA-RED SCAN TO SPOT MAJOR HEAT LOSS AREAS	ALL	-
M	REPLACE EXISTING AIR CONDITIONING SYSTEMS AND ADD ECONOMIZER	L338	L338
M	REPLACE FOUR SMALL FLOOR MOUNTED UNIT HEATERS WITH LARGER CAPACITY HEATERS	L338	L338
M	SUPPLY AIR ΔT OF 25^{o}F MAX.	ALL	-
M	RELOCATE R. A. GRILLES AWAY FROM WALL	L752, 753	-
M	CHANGE TO FLOOR MOUNTED HEATERS	L756 M836, 837	-

TYPE	MODIFICATION	APPLICABLE BUILDINGS	BUILDINGS COVERED BY BEAP
M	ADD DESTRATIFICATION FANS	ALL	-
M	IMPROVE BOILER WATER TREATMENT	L351, 338	-
M,E	ADD ENERGY MONITORING DEVICES	ALL	-
M	CONTROL STEAM HEAT IN OFFICES	L338 T1030	-
M	IMPROVE BUILDING TEMERPATURE TO ALLOW PROPER APPLICATION OF SEALANT	M763 T2122	-
M	ADD TURBINE VENTILATORS FOR SUMMER-COVER DURING WINTER	T2122	-
M	ADD NIGHT SETBACK CONTROLS	ALL	L338, 756 All AT TINKER
M	ADD HEAT TO PAINT AREA	M763	-
M	IMPROVE RADIANT FLOOR HEATER CONTROLS	ALL AT MINOT	-
M	USE FLEXIBLE DUCT FOR OVERHEAD HEATERS TO DUCT FOR WARM AIR TO FLOOR	M837	-
M	REPAIR INSULATION ON PIPING	ALL	-
M	USE SOLAR HEATING WITH STORAGE	ALL	-
M	O_2 ANALYZER AND TURBULATORS FOR BOILERS	L338, 351	-
M	USE LOW INTENSITY RADIANT HEATERS	ALL	-

TYPE	MODIFICATION	APPLICABLE BUILDINGS	BUILDINGS COVERED BY BEAP
M	PREHEAT BOILER COMBUSTION AIR WITH CEILING AIR	L338, 351	-
M	INVESTIGATE CENTRAL COMPRESSED AIR FOR ENGINE STARTING	ALL	-
M	INSULATE HOT AIR DUCTS ABOVE CEILINGS	T2122	-
M	INVESTIGATE TASK HEATING	ALL	-
M	USE HIGHER EFFICIENCY V-BELTS ON DRIVES	A11	-
M	INSULATE ELECTRONIC COOKING EQUIPMENT	M718, T2122	-
M	REDUCE WATER FAUCET FLOW RATES	ALL	-
M	ADD REFLECTORS OUT-SIDE WINDOWS TO IN-CREASE SOLAR EFFECT	ALL	-
M	INSTALL NEW HEATER DESIGNED TO OPERATE ON DEMAND ONLY	L351	L351
M	CHANGE OFFICE AIR CONDITIONING SYSTEM TO SPLIT SYSTEM	L752	L752
M	PROVIDE RETURN AIR DUCTS TO FLOOR MOUNT-ED HEATERS TO CIRCULATE CEILING AIR	M837	M837
O	SHUT OFF LIGHTS ABOVE OFFICES	L756	-
O	USE VEHICLE DOORS FOR AGE	ALL	-

TYPE	MODIFICATION	APPLICABLE BUILDINGS	BUILDINGS COVERED BY BEAP
O	INCREASE MAINTENANCE SCHEDULE	ALL	-
O	MINIMIZE DE-ICING OF AIRCRAFT BY BUILDING HEATCOVER AIRCRAFT BEFORE FOUL WEATHER	ALL	-
O	SCHEDULE REMOVAL OF AIRCRAFT DURING GRAVEYARD SHIFT	ALL	-
O	BUY REDUNDANT AGE SO AGE CAN STAY INSIDE	T230	-
O	PRESENT SEMINARS OF ENERGY CONSERVATION FOR HANGAR PERSONNEL	ALL	-
O	DEVELOP SHUTDOWN OPERATING PROCEDURES	ALL	-
O	CONSOLIDATE OPERATIONS INTO FEWER HANGARS	L752, 753	
O	USE GROUP RELAMPING OF FLUORESCENT TUBES TO INCREASE LIGHT LEVEL FOR SAME ENERGY	ALL OFFICES	-
O	RECLAIM WASTE OIL FOR USE AS FUEL	ALL	-
O	FIX ROOF LEAKS	ALL AT LANGLEY AND TINKER	-
O	CONNECT TO ENERGY MANAGEMENT CONTROL SYSTEM (EMCS)	T3102	T3102
S	USE EXTERIOR COWLING TO IMPROVE SUMMER CIRCULATION	T2122	-

APPENDIX B

FORM A-1, ECIP ECONOMIC ANALYSIS SUMMARY

Location: ______________________________ FY __________
Project: ____

Economic Life: _____ Yrs. Date Prepared __________ Prepared by __________

COSTS

1. Non-recurring Initial Capital Costs:
   - a CWE $ __________
   - b. Design $ __________
   - c. ______________________ $ __________
   - d. Total $ __________

BENEFITS

2. Recurring Benefit/Cost Differential Other Than Energy:
   - a. Annual Labor Decrease (+)/Increase (-) $ ______ /Yr.
   - b. Annual Material Decrease (+)/Increase (-) $ ______ /Yr.
   - c. Other Annual Decrease (+)/Increase (-) $ ______ /Yr.
   - d. Total Costs $ ______ /Yr.
   - e. 10% Discount Factor $ __________
   - f. Discounted Recurring Cost (d x e) $ __________
3. Recurring Energy Benefit/Costs:
   - a. Type of Fuel: __________
     - (1) Annual Energy Decrease (+)/Increase (-) ______ MBTU
     - (2) Cost per MBTU $ ______ /MBTU
     - (3) Annual Dollar Decrease/Increase ((1)x(2)) $ ______ /Yr.
     - (4) Differential Escalation Rate (___%) Factor __________
     - (5) Discounted Dollar Decrease/Increase (3)x(4) $ __________
   - b. Type of Fuel: __________
     - (1) Annual Energy Decrease (+)/Increase (-) ______ MBTU
     - (2) Cost per MBTU $ ______ /MBTU
     - (3) Annual Dollar Decrease/Increase ((1)x(2)) $ ______ /Yr.
     - (4) Differential Escalation Rate (___%) Factor __________
     - (5) Discounted Dollar Decrease/Increase ((3)x(4)) $ __________
   - c. Type of Fuel: __________
     - (1) Annual Energy Decrease (+)/Increase (-) ______ MBTU
     - (2) Cost per MBTU $ ______ /MBTU
     - (3) Annual Dollar Decrease/Increase ((1)x(2)) $ ______ /Yr.
     - (4) Differential Escalation Rate (___%) Factor __________
     - (5) Discounted Dollar Decrease/Increase ((3)x(4)) $ __________
   - d. Discounted Energy Benefits (3a(5)+3b(5)+3c(5)
4. Total Benefits (Sum 2f + 3d) $ __________
5. Discounted Benefit/Cost Ratio (Line 4÷Line 1d) $ __________
6. Total Annual Energy Savings (3a(1)+3b(1)+3c(1)) __________
7. E/C Ratio (Line 6 ÷ Line 1a/1000) __________
8. Annual $ Savings (2d+3a(3)+3b(3)+3c(3)) $ __________
9. Pay-back Period ((Line 1a - Salvage) : Line 8) __________

APPENDIX C

COMPUTER PROGRAMS DEVELOPED FOR THIS PROJECT

C-1 Calculation of Stratification Effects

```
      DIMENSION TITLE (10), TROOM (4), UC (4)
      DATA TROOM /55.,60.,65.,70./
      DATA UC /.08,.2,.4,1.0/
      DO 10 K=1,11
      WRITE ( 6,100 )
100   FORMAT (1H1)
      READ (5,25) (TITLE(I),I=1,10)
 25   FORMAT (10A4)
      WRITE (6,25) (TITLE(I),I=1,10)
     READ ( 5,* ) UR,ANGLE,HC,HR,TO,UW,
    * AW,AC,STRAT,EFLH
      DO 10 J=1,4
      DO 10 L=1,4
      WRITE (6,20) UR,ANGLE,HR,TO,UW,AW,UC(J),AC,STRAT,TROOM(L),EFLH
 20   FORMAT (/////,11X,'UR =',F5.2,2X,'ANGLE =',F5.2,5X,
    1 'HR=',F5.2,5X,'TO =',F6.2,/,11X,'UW =',F5.2,5X,
    2 'AW =',F10.1,5X,'UC =',F5.2,5X,'AC =',F10.1,/,11X,
    3 'STRAT =',F5.2,5X,'TROOM =',F7.2,5X,'EFLH =',F10.1)
C
C     UR    = U VALUE OF THE ROOF
C     ANGLE = PITCH ANGLE OF THE ROOF
C     HR    = HEIGHT OF THE ROOM
C     HC    = HEIGHT ABOVE THE CEILING
C     TO    = DESIGN OUTSIDE TEMPERATURE
C     UW    = U VALUE OF THE WALLS
C     AW    = AREA OF THE WALLS
C     UC    = U VALUE OF THE CEILING
C     AC    = AREA OF THE CEILING
C     STRAT = STRATIFICATION COEFFICIENT
C     TROOM = ROOM TEMPERATURE AT 5 FEET ABOVE FLOOR
C     EFLH  = EQUIVALENT FULL LOAD HOURS
C
     TC=TROOM(L)+STRAT*(HR-5.)
     UAR=UR*AC/COS(ANGLE)
     UAW=UW*AW*(HC/(HR+HC))
     UAC=UC(J)*AC
     UARW=UAR+UAW
     UATOT=UARW+UAC
     UAWL=UW*AW*(HR/(HR+HC))
     TCEIL=(UAC*TC-(STRAT*HC-TO)*UARW+.5*STRAT*HC*UAW)/UATOT
     TROOF=TCEIL+STRAT*HC
     TWALL=TCEIL+.5*STRAT*HC
     TTOP=TC+STRAT*HC
     QCEIL=UAC*(TC-TCEIL)
     QWALL=UAWL*(TROOM(L)+.5*STRAT*HR-TO)
     QTOT1=QCEIL+QWALL
     QROOF=UAR*(TTOP-TO)
     QWALS=UW*AW*((TTOP+TROOM(L))/2.-TO)
```

```
      QTOT2=QROOF+QWALS
      DELTAQ=(QTOT2-QTOT1)*EFLH/1000000.
      WRITE(6,12) TCEIL, TROOF,TWALL,TTOP,QCEIL,QWALL,QTOT1,
     1            QROOF,QWALS,QTOT2,DELTAQ
12    FORMAT (//,11X,'CEILING TEMPERATURE =',F5.1,10X,
     1 'ROOF TEMPERATURE =',F5.1,//,11X,'WALL TEMPERATURE =',F5.1,
     2 10X,'STRAT ROOF TEMPERATURE =',F5.1,//,11X,'CEILING ',
     3 'HEAT LOSS =',F10.1,8X,'WALL HEAT LOSS BELOW CEILING =',F10.1,
     4 //,11X,'TOTAL HEAT LOSS WITH CEILING =',F10.1,5X,
     5 'ROOF HEAT LOSS WITHOUT CEILING =',F10.1,//,11X,
     6 'WALL HEAT LOSS WITHOUT CEILING =',F10.1,5X,'TOTAL HEAT
     7 LOSS WITHOUT CEILING =',F10.1,//,11X,'ANNUAL SAVINGS DUE TO ',
     8 'CEILING =',F10.1,2X,'MILLION BTUS PER YEAR')
10    CONTINUE
      STOP
      END
```

C-2 Calculation of Jet Temperature Profile

```
C   THE EQUATIONS FOR JET TRAJECTORY,VELOCITY AND TEMPERATURE WERE
C   DEVELOPED BY :
C          1. G.N.ABRAMOVICH,TURBULENT FREE JETS OF FLUID AND GAS
C                                          GOSENERGOSDAT,MOSCOW,1948
C          2. P.N.KAMENEV,HEATING AND VENTILATION
C                                          STROISDAT,MOSCOW,1959
C
C    INSIDE TEMP. IS 55.0 F=12.7 C,COEF.TURBULENT.=0.12
C
       DIMENSION X(9),YM(9),VXM(9),TXM(9)
       DATA X/2.,5.,10.,15.,20.,25.,30.,40.,50./
C
C   DIAMETER
       D=18.
     1 D1=D*0.0254
C
C    VELOCITY
       V=1000.
     2 V1=V*0.0051
C
C   ANGLE
       A=0.
C
C   OUTLET TEMPERATURE
     3 T=80.
C
C   LENGTH
     4 DO 5 IX=1,9
       XX=X(IX)*0.3048
C
C
       T1=273.+(T-32.)*0.555
       T2=285.7
C
C    ARCHIMEDES CRITERIA
C
       AR=9.81*D1/V1**2*(T1-T2)/T2
C
       C=A/57.3
       C1=SIN(C)
       C2=COS(C)
       C3=C1/C2
C
C    HEIGHT AS A FUNCTION OF DISTANCE
C
       Y=XX*C3+0.63*D1*0.204*AR*(T1/T2)**.5*(XX/D1/2)**2.73
C
       ZX=(XX**2+Y**2)**.5
C
C    VELOCITY AS A FUNCTION OF DISTANCE
C
       VX=V1*0.48/(0.12*XX/D1+0.145)
```

```
C TEMPERATURE AS A FUNCTION OF DISTANCE
C
      TX=T2+0.226*(T1-T2)/(.12*X/D1+0.145)-273
C
      YM(IX)=Y*3.281
      VXM(IX)=VX*1.9E-3
      TXM(IX)=TX*1.8+32.
C     WRITE(6,200)D,D1,V,V1,A,T,T1,XX,T1,T2,AR,C1,C2,C3,Y,VX,TX,
C    *YM(IX),VXM(IX),TXM(IX)
C 200 FORMAT(' D,D1,[illegible]',10F10.2,/,8X,10F10.2)
C
    5 CONTINUE
      C4=C1*(-1.)
      IF(AR.LT..0001.AND.C4.LT..0001)GO TO 12
C     X0=0.
C     XB=0
C     YB=0.
C     GO TO 15
C
C DISTANCE AT WHICH JET LEAVES WORKING ZONE
C
   12 X0=1.28*D1*C2*C4**.57/.403/AR**.57/(T1/T2)**.286*3.281
C
C THE EXTREMUM POINT OF JET
C
      XB=X0*0.562
      YB=.456*D1*C4**2.757/.403/AR**.57/(T1/T2)**.286*(-3.281)
C
   15 WRITE(6,100)D,V,A,T,X0,XB,YB,(X(I),I=1,9),(YM(I),I=1,9),
     *(VXM(I),I=1,9),(TXM(I),I=1,9)
C
  100 FORMAT('   ',120('*'),/,' D=',F4.0,' IN  V=',F5.0,' FPM  A=',F5.0,
     *'  T=',F5.0,'  X0=',F5.0,'  XB=',F5.0,'  YB=',F5.0,/,' X   =',9F11.3,
     */,' Y    =',9F11.3,/,' V(X)=',9F11.3,/,' T(X)=',9F11.3)
      IF(T.GT.150.)GO TO 6
      T=T+20.
      GO TO 4
C
    6 IF(A.LT.-38.)GO TO 7
      A=A-20.
      GO TO 3
C
    7 IF(V.GT.1800.)GO TO 8
      V=V+500.
      GO TO 2
C
    8 IF(D.GT.28.)GO TO 9
      D=D+12.
      GO TO 1
C
    9 STOP
      END
```

C-3 Calculation of Jet Stratification Effects

```
      DIMENSION TJET(3), TITLE(10), QLOSS(3), TNOZ(3)
      DATA TNOZ /80.,120.,140./
      DATA TJET /56.,60.5,63.8/
      DO 10 M=1,15
      WRITE (6,15)
15    FORMAT (1H1)
      READ (5,25) (TITLE(I),I=1,10)
25    FORMAT (10A4)
      WRITE (6,25) (TITLE(I),I=1,10)
      READ (5,*) UR,UW,HW,AR,AW,PITCH,STRAT,TO,EFLH
      DO 20 J=1,3
      WRITE (6,35) UR,UW,HW,AR,AW,PITCH,STRAT,TO,TNOZ(J),TJET(J),EFLH
35    FORMAT (//,11X,'UR =',F6.2,5X,'UW =',F6.2,5X,'HR =',
     1 F6.2,/,11X,'AR =',F10.1,5X,'AW =',F10.1,5X,'PITCH =',F6.2,5X,
     2 'STRAT =',F6.2,/,11X,'TO =',F6.2,5X,'TNOZ =',F6.2,5X,'TJET =',
     3 F6.2,5X,'EFLH =',F10.1)
      QLOSS(J)=UR*AR/COS(PITCH)*(TJET(J)+STRAT*(HW-7)-TO)
     1 +UW*AW*(TJET(J)+.5*STRAT*(HW-7)-TO)
20    CONTINUE
      Q3V801=(QLOSS(3)-QLOSS(1))*EFLH/1000000.
      Q2V801=(QLOSS(2)-QLOSS(1))*EFLH/1000000.
      WRITE (6,45) (QLOSS(K),K=1,3),Q3V801,Q2V801
45    FORMAT(//,11X,'HEAT LOSS WITH 80 DEG JET =',F10.1,//,11X,
     1 'HEAT LOSS WITH 120 DEG JET =',F10.1,//,11X,
     2 'HEAT LOSS WITH 140 DEG JET =',F10.1,//,11X,
     3 'HEAT SAVED 80 VS 140 DEG JET =',F10.1,2X,'MMBTU/YEAR',//,11X,
     4 'HEAT SAVED 80 VS 120 DEG JET =',F10.1,2X,'MMBTU/YEAR')
10    CONTINUE
      STOP
      END
```

C-4 Calculation of Effect of Destratification Fans

```
      DIMENSION TITLE (10)
      DO 10 M=1,15
      WRITE (6,15)
15    FORMAT (1H1)
      READ (5,25) (TITLE(I),I=1,10)
25    FORMAT (10A4)
      WRITE (6,25) (TITLE(I),I=1,10)
      READ (5,*) UR,UW,HW,AR,AW,PITCH,STRAT,TO,TROOM,EFLH
      WRITE (6,35) UR,UW,HW,AR,AW,PITCH,STRAT,TO,TROOM,EFLH
35    FORMAT (//,11X,'UR =',F6.2,5X,'UW =',F6.2,5X,'HW =',F6.2,
     1 //,11X,'AR =',F10.1,5X,'AW =',F10.1,5X,'PITCH =',F6.2,//,11X,
     2 'STRAT =',F6.2,5X,'TO =',F6.2,5X,'TROOM =',F6.2,5X,'EFLH =',
     3 F10.1)
      QLOSS1=UR*AR/COS(PITCH)*(TROOM + STRAT*(HW-5.)-TO) +
     1 UW*AW*(TROOM + .5*STRAT*(HW-5.)-TO)
      QLOSS2=UR*AR/COS(PITCH)*(TROOM + 5. - TO)+UW*AW*(TROOM + 2.5-TO)
      DELTAQ=(QLOSS1-QLOSS2)*EFLH/1000000.
      WRITE (6,45) QLOSS1,QLOSS2,DELTAQ
45    FORMAT(///,11X,'HEAT LOSS WITHOUT FANS =',F10.1,//11X,
     1 'HEAT LOSS WITH FANS ON =',F10.1,//,11X,'HEAT SAVED BY USING ',
     2 'DESTRATIFICATION FANS =',F10.1,' MMBTU PER YEAR')
10    CONTINUE
      STOP
      END
```

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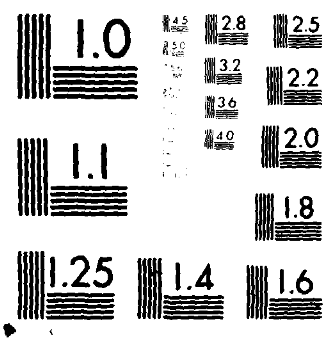

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C-5 Economic Analysis of ECO's

```
      DIMENSION TITLE (20), TMOD(20)
      DO 100 M=1,15
      READ (5,20) (TITLE(I),I=1,20)
20    FORMAT     (20A4)
      WRITE(6,25)(TITLE(I),I=1,20)
25    FORMAT (1H1,///,20A4)
      READ (5,*) NUM,AREA,COIL,CGAS,CELEC,DEL
      WRITE (6,35) AREA,COIL,CGAS,CELEC,DEL
35    FORMAT (//,11X,5F15.4,//)
      DO 100 N=1,NUM
      READ (5,20) (TMOD(I),I=1,20)
      WRITE (6,28) (TITLE(I),I=1,20),(TMOD(L),L=1,20)
28    FORMAT (1H1,///,20X,20A4,//,20X,20A4)
      READ (5,*) COST,ENOIL,ENGAS,ENEL,FFCOR
      WRITE (6,45) COST,ENOIL,ENGAS,ENEL,FFCOR
45    FORMAT (//,11X,'PROJECT COST = $',F10.2,5X,'OIL SAVED =',F10.1,
     1 ' KBTU/YR',//,11X,'GAS SAVED =',F10.1,' KBTU/YR',5X,
     2 'ELECTRICITY SAVED =',F10.1,' KBTU/YR',//,11X,'FFCOR =',F10.1,
     3 ' KW')
      ESCOST=COST*1.06**3
      TCOST=COST*1.471
      TOIL=ENOIL/.75
      TGAS=ENGAS/.7
      TOTEL=ENEL*11600./3413.
      SAOIL=TOIL*COIL
      SAGAS=TGAS*CGAS
      SAEL=ENEL*CELEC
      SAFF=FFCOR*DEL
      DISOIL=SAOIL*13.112
      DISGAS=SAGAS*13.112
      DISEL=SAEL*12.237
      DISFF=SAFF*12.237
      DISTOT=DISOIL+DISGAS+DISEL+DISFF
      BCRAT=DISTOT/TCOST
      ENTOT=TOIL+TGAS+TOTEL
      ECRAT=ENTOT/ESCOST
      SAVGS=SAOIL+SAGAS+SAEL+SAFF
      IF (SAVGS.EQ.0.) SAVGS=SAVGS+1.
      TOTLCC=(1-BCRAT)*1.191*COST
      PAYBAC=ESCOST/SAVGS
      COVERC=1./PAYBAC
      SAVSF=COVERC/AREA
      ENSF=ECRAT/AREA
      WRITE (6,52) ESCOST
      WRITE (6,55) TCOST,TOIL,TGAS,TOTEL,SAOIL,SAGAS,SAEL,SAFF
      WRITE (6,63)DISOIL,DISGAS,DISEL,DISFF,DISTOT,BCRAT,ENTOT
      WRITE (6,75) ECRAT,SAVGS,TOTLCC,PAYBAC
      WRITE (6,83) SAVSF,ENSF,COVERC
```

```
52    FORMAT (//,11X,'ESCALATED CWE = $',F10.2)
55    FORMAT (//,11X,'PROJECT COST = $',F13.2,5X,'OIL SAVED =',
     1 F10.1,' KBTU',5X,'GAS SAVED =',F10.1,' KBTU',//,11X,
     2 'ELECTRICITY SAVED =',F10.1,' KBTU',5X,'OIL SAVED = $',
     3 F12.2,5X,'GAS SAVED = $',F12.2,//,11X,'ELECTRICITY SAVED = $',
     4 F12.2,5X,'DEMAND CHARGE REDUCTION = $',F10.2,5X)
65    FORMAT ( //,11X,'DISCOUNTED ',
     5 'OIL BENEFITS = $',F12.2,//,11X,'DISCOUNTED GAS BENEFITS = $',
     6 F12.2,5X,'DISCOUNTED ELECTRICITY BENEFITS = $',F12.2,5X,//,11X,
     7 'DISCOUNTED DEMAND BENEFITS = $',F12.2,//,11X,'TOTAL DISCOUNTE',
     8 'D BENEFITS = $',F14.2,5X,'BENEFIT/COST RATIO =',F10.3,//,6X,
     9 5X,'TOTAL ANNUAL ENERGY SAVINGS =',F13.2,' KBTU/YR')
75    FORMAT (//,11X,'E/C RATIO = ',
     * F15.2,5X,'TOTAL ANNUAL COST SAVINGS = $',F13.2,
     1 //,11X,'LIFE CYCLE COST = $',F13.2,5X,'PAYBACK =',F6.2,' YEARS')
85    FORMAT(//,11X,'COST RATIO PER SF =',F15.7,' $/$/SF',//,11X,
     1 'E/C RATIO PER SF =',F15.7,' KBTU/$/SF',//,11X,'COST RATIO =',
     2 F15.7,' $ PER $')
100   CONTINUE
      STOP
      END
```

APPENDIX D

BIN METHOD OF ESTIMATING ANNUAL ENERGY CONSUMPTION

The bin method of estimating annual energy consumption uses data contained in AFM 88-29, Engineering Weather Data, published in 1978. This data is simply the number of hours in which the outside air temperature at a given location is observed in each temperature bin. Temperature bins are divided into 5-degree F increments. Observation hours in each bin are summarized for the year and subdivided into months and time of day for more detailed estimates.

Each modification analyzed in this report assumes a constant indoor air temperature. Thermal heat losses are assumed to vary linearly with outdoor air temperature. Thus, by determining the heat loss at some arbitrary design outside air temperature, an estimate of annual energy consumption can be made. The method chosen in this report is the equivalent full load hour (EFLH) method. The procedure is listed below.

Once design indoor and outdoor air temperatures are determined, the hourly heat loss in BTUH at those temperatures is calculated. Because this heat loss varies linearly with outside air temperature, hourly heat loss in each temperature bin is a linear fraction of the design heat loss. For example, if indoor design temperature is 55 degrees F and outdoor design temperature is 5 degrees F, the hourly heat loss at 30 degrees F outdoor air temperature is one-half of the design heat loss. A fraction of full load is thus assigned to each temperature bin. By multiplying the hours of observation in that bin by the fraction of full load assigned to the bin, the number of EFLH is established for the entire temperature profile. The total EFLH for the heating season is obtained by adding the EFLH in each bin. The total EFLH is then multiplied by the design heat loss to estimate total annual heat loss.

For Langley AFB, design temperatures were T_R = 55 degrees F, T_o = 0 degrees F. Based on these temperatures, EFLH = 918.8 hours.

For Minot AFB, T_R = 55 degrees F, T_o = -30 degrees F, and EFLH = 2008.2 hours.

For Tinker AFB, T_R = 55 degrees F, T_o = -10 degrees F, and EFLH = 840.7 hours.

Note that EFLH depends on the chosen design temperatures. Different indoor or outdoor design temperatures will directly affect the number of EFLH.

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