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DOE/NASA CONTRACTOR REPORT

DOE/NASA CR-150533

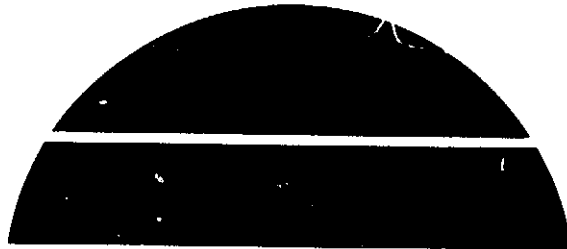# SITE DEPENDENT FACTORS AFFECTING THE ECONOMIC FEASIBILITY OF SOLAR POWERED ABSORPTION COOLING

U.S. Department of Energy

Solar Energy

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16. ABSTRACT

A procedure has been developed to evaluate the cost effectiveness of combining an absorption cycle chiller with a solar energy system. A basic assumption of the procedure is that a solar energy system exists for meeting the heating load of the building, and that the building must be cooled. The decision to be made is to either cool the building with a conventional vapor compression cycle chiller or to use the existing solar energy system to provide a heat input to the absorption chiller. Two methods of meeting the cooling load not supplied by solar energy were considered. In the first method, heat is supplied to the absorption chiller by a boiler using fossil fuel. In the second method, the load not met by solar energy is met by a conventional vapor compression chiller. In addition, the procedure can consider waste heat as another form of auxiliary energy.

Commercial applications of solar cooling with an absorption chiller were found to be more cost effective than the residential applications. In general, it was found that the larger the chiller, the more economically feasible it would be. Also, it was found that a conventional vapor compression chiller is a viable alternative for the auxiliary cooling source, especially for the larger chillers.

The results of the analysis gives a relative rating of the sites considered as to their economic feasibility of solar cooling. Before a final judgment is made on the cost effectiveness of a particular site, the influence of all parameters must be determined.

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I. INTRODUCTION

In response to a MSFC Technical Directive (Number 13) under the SIMS program, a study was performed to investigate the site independent factors affecting the economic feasibility of the cooling of buildings using an absorption cycle chiller with part of its input requirements supplied by a solar energy system. The factors which favor the operation of the absorption unit were identified and their influence on the economics was determined. After the important factors had been identified, various sites were selected to determine which combinations of the important factors would result in an overall favorable economic outlook. The study considered the application of 3, 25, and 100 ton absorption units. In addition, the following methods were considered for the auxiliary cooling system: 1) auxiliary heat is supplied to the absorption unit by a natural gas fired boiler, 2) auxiliary cooling is supplied directly to the load by a conventional electric vapor compression chiller, and 3) auxiliary heat is supplied to the absorption unit by excess process (waste) heat.

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II. STUDY APPROACH

A procedure was developed to determine if the cooling of a building with an absorption cycle chiller and a solar energy system can be justified by a savings of both energy resources and capital. This procedure involves several assumptions which are discussed in this section as the procedure is presented. The major assumption is in determining the relevancy of the acquisition/installation cost of the solar energy system. For reasons that are elaborated later in this section, it has been assumed that the following situation exists: the decision has been made to supply part of the heating load of the building with solar energy and in addition the building must be cooled. Therefore as long as the size of the system does not have to be increased, or the collector technology has to be changed, the costs of the components used by the solar heating system (collectors, storage, auxiliary heating subsystem, etc.) are irrelevant and are not chargeable to the cooling decision. The only relevant costs are the cost of the chillers, the cost of energy, and costs which are affected by the investment required for cooling. This basic assumption is a foundation of the procedure and its necessity and value can be seen as the procedure is developed.

The procedure is comprised of three steps. The first involves determining what percent of the cooling load that the solar energy system must provide in order that the system's requirement for energy resources will not be increased. (It is possible using a solar powered absorption cycle chiller to use more conventional energy than if cooling with conventional means). This requirement is presented as the Energy Savings Criteria in Secion II.A. The second step of the procedure determines what percent of the cooling load can be supplied by the solar energy system that was designed to meet the heating load. Comparison with the minimum solar cooling fraction from the first step then determines if energy resources will be saved. The method used to determine the system capability for meeting the building cooling load is presented in Section II.B. If it is shown that the system is capable of saving energy resources, the last step is to determine if the system will also result in savings of capital for the owner. The Economic Evaluation is presented in Section III.C. and is based on life-cycle cost using the present value method. If the system will result in savings of both energy resources

and capital then the system represents a practical application of cooling a building using an absorption chiller and a solar energy system. For commercial applications if the system capability is less than that required based on economics the difference can be used as a requirement for excess process (waste) energy.

The process requires as inputs several parameters that are site dependent. These site dependent parameters are: building heating and cooling loads, the available insolation for both heating and cooling, and the cost of utilities. The cost of utilities used in the analysis was obtained from the appropriate utility company for each location in the fourth quarter of 1976. The other site dependent parameters where obtained from monthly long term averages based on measurements made by the National Weather Service. Appendix A presents a procedure for using this monthly data to determine the annual building heating and cooling loads and also the insolation available for both heating and cooling.

In addition to the site dependent parameters, the procedure requires several inputs that were not considered to be site dependent. Examples of these parameters are fuel escalation rate, discount rate, mortgage interest rate, life of the system, and repair and maintenance costs. Although many of the parameters that were considered site independent can significantly effect the system's economics, these parameters were not varied. Typical values of these parameters were selected and used throughout the analysis. This is consistent with the scope of the study--to look at relative merits of sites for solar cooling. After a site has been tentatively selected for a solar heating and cooling application these site independent parameters must be varied to determine their influence on the systems's economics.

A. ENERGY SAVINGS CRITERIA[1]

The overall goal of the Energy Research and Development Administration National Plan for Solar Heating and Cooling is to "stimulate the creation of a viable industrial and commercial capability to produce and distribute solar heating and cooling systems and thereby reduce the demand on present fuel supplies through wide spread application." This goal requires that any solar energy system require less energy to operate than the conventional system. The energy requirements can be determined in absolute terms, but for comparison purposes they will be determined based on a common point of origin, (i.e., consumption compared for the same energy resource). The energy required by the conventional cooling system, E_C, to satisfy a given cooling load, Q_C can be written as:

$$E_C = \frac{Q_C}{\eta_C COP_C} \hspace{3cm} (1)$$

where: η_C = Energy conversion efficiency to the point of origin for the conventional cooling system, and

COP_C = Coefficient of performance of the conventional cooling system.

The energy required by the solar energy system, E_S, to satisfy a given cooling load, Q_C, can be written as:

$$E_S = \frac{(1-F)Q_C}{\eta_{AF} COP_{AF}} + \frac{(1-F)Q_C}{\eta_{AE} COP_{AE}} + \frac{FQ_C}{\eta_{SE} COP_{SE}} + \frac{FQ_C}{\eta_{SE} COP_S COP_A}, \hspace{1cm} (2)$$

where: F = Fraction of the cooling load satisfied by solar energy, and

η_{AF} = Energy conversion efficiency to the point of origin for the fossil energy requirements of the auxiliary cooling subsystem.

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[1] For a detailed discussion of the Energy Savings Criteria see: Littles, J. W. and Cody, J. C.; "Considerations for Performance Evaluation of Solar Heating and Cooling Systems", NASA TM X-64969, November 14, 1975.

COP_{AF} = Coefficient of performance of the auxiliary cooling subsystem based on fossil energy requirements,

η_{AE} = Energy conversion efficiency to the point of origin for the electrical energy requirements of the auxiliary cooling subsystem,

COP_{AE} = Coefficient of performance of the auxiliary cooling subsystem based on electrical energy requirements,

η_{SE} = Energy conversion efficiency to the point of origin for the electrical energy requirements of the solar energy system,

COP_{SE} = Coefficient of performance of the solar cooling subsystem based on electrical energy requirements,

COP_A = Coefficient of performance of the solar cooling subsystem based on thermal energy requirements, and

COP_S = Coefficient of performance of the solar collector and storage subsystem based on the energy delivered to the solar cooling subsystem and electrical energy required to deliver that energy.

Equations (1) and (2) can be used to determine a minimum fraction of the load that must be satisfied by solar energy to ensure that the solar energy system does not require more energy to satisfy a given cooling load than a conventional system. Combining the two equations the minimum solar fraction to save energy, F_{MIN}, can be written as:

$$F_{MIN} = \frac{\dfrac{1}{\eta_C COP_C} - \dfrac{1}{\eta_{AF} COP_{AF}} - \dfrac{1}{\eta_{AE} COP_{AE}}}{\dfrac{1}{\eta_S COP_{SE}} + \dfrac{1}{\eta_{SE} COP_S COP_A} - \dfrac{1}{\eta_{AF} COP_{AF}} - \dfrac{1}{\eta_{AE} COP_{AE}}} \qquad (3)$$

Equation (3) has been used to determine the minimum fraction of the load that must be satisfied by solar energy to insure energy savings for 3 ton, 25 ton, and 100 ton absorption chillers. Two auxiliary cooling subsystems were considered. In the first method the portion of the load not satisfied by solar energy is satisfied by heating the generator water with fossil energy. In the second

method the portion of the load not satisfied by solar energy is satisfied by a conventional vapor compression chiller. The minimum solar fractions for 3 ton, 25 ton, and 100 ton chillers are given in Table I. It was assumed that the absorption chiller operated at 75 percent of its rated capacity when fired by solar energy and at its rated capacity when fired by fossil energy. For the vapor compression auxiliary cooling subsystem the minimum solar fraction to ensure energy savings is zero if:

$$\frac{1}{COP_A COP_S} + \frac{1}{COP_{SE}} \geq \frac{1}{COP_C}.$$

It has been assumed that this limitation is met and that the minimum solar fraction for a vapor compression auxiliary cooling subsystem is zero.

B. SYSTEM CAPABILITY

In the economic evaluation of any solar energy system it is difficult to precisely predict the relevant cost due to the immature state of the market and the industry. The consideration of the costs of the components of the solar energy system other than the chiller and related hardware were eliminated from this study by assuming that the cost of the solar heating system was covered by the heating requirements. This is a major assumption but it is necessary in order that an economic criteria may be realistically established. Solar heating systems are being installed; therefore, the assumption was made that the building in question has a solar heating system and requires cooling. The question then can be stated: should the cooling load be met by the conventional unit or should the cooling load be met with an absorption unit with part of its input supplied by the solar energy system? Thus, the actual assumption is that the solar collectors, storage tank, and the auxiliary heating system have already been justified and the decision to be made is how to provide the required cooling. A major point, however, is that only a certain size of solar energy system and collector type has been justified by the heating criteria. If this size of collector type is not adequate to supply the cooling requirements any increase in size must be justified by the cooling decision. For the purposes of this study it was assumed that the solar energy system size and collector type was limited to that justified by the heating requirements.

Table I. Minimum Solar Fraction to Insure Energy Savings for Fossil Auxiliary

Chiller Size (Tons)	COP_{AE}	COP_{SE}	Minimum Solar Fraction
3	10.55	7.91	50
25	14.65	11.00	46
100	17.58	13.18	44

Assumptions: $\eta_C = \eta_{AE} = \eta_{SE} = 0.30$

$$\eta_{AF} = 0.50$$

$$COP_C = 2.0$$

$$COP_{AF} = 0.65$$

$$COP_A = 0.65$$

$$COP_S = 150$$

If the assumption is made that solar heating system will provide a given percentage of the heating load, the corresponding collector area can be found approximately by:

$$A \simeq \frac{F_H Q_H}{EFF_H I_H} \tag{4}$$

where:

A = Collector area,

F_H = Fraction of heating load satisfied by solar energy,

Q_H = Annual heating load,

EFF_H = Solar energy system (collector and storage) efficiency during heating season, and

I_H = Insolation available during heating season.

Equation (4) is an approximation and cannot be used for high solar fractions because the available solar energy is out of phase with the load (April's high solar energy is not available to satisfy January's high heating load). Equation (4) will predict a collector area that is less than will be required given a collector efficiency, a solar heating fraction, the available solar energy and the heating load. The size of the error will increase as the solar heating fraction increases; therefore, the use of Equation (4) should therefore be limited to low (≤ 0.5) solar fractions.

A corresponding expression can be developed to determine the precent of the cooling load that can be met with a given collector area.

$$F_C \simeq \frac{EFF_C I_C}{Q_C/COP_A} A \tag{5}$$

where:

F_C = Fraction of cooling load satisfied by solar energy,

EFF_C = Solar energy system (collector and storage) efficiency during cooling season,

I_C = Insolation available during cooling season,

Q_C = Annual cooling load, and

COP_A = Absorption chiller coefficient of performance.

Equation (5) is more exact than equation (4) because the load is more in phase with the available energy.

The two previous equations can be combined to relate the various factors.

$$\frac{F_C}{F_H} \simeq \frac{EFF_C I_C}{EFF_H I_H} \frac{Q_H}{Q_C/COP_A} \qquad (6)$$

Equation (6) has been plotted in Figure 1. By inspecting Figure 1 and Equation (6) some site factors which are favorable to solar cooling by satisfying a large fraction of the cooling load with solar energy can be determined. These favorable site factors are:

1) A high heating load relative to the cooling load,

2) A high collector efficiency during the cooling season relative to the heating season,

3) A high insolation during the summer relative to the insolation in the winter,

4) A higher chiller COP, and

5) A high percent solar heating. (It should be remembered that the higher the percent solar heating the greater the error in Equation (4).)

Although the equations are approximations, they will predict a solar cooling fraction for a given set of conditions (solar heating fraction, system efficiencies for heating and cooling, and monthly available energy and loads) that is less than the actual capability of the system. These equations are conservative because of the phase difference between the available energy and the load. For heating the load is out of phase with the available energy, therefore for a given solar heating fraction a collector area will be predicted which is too small. For cooling the available energy is in phase with the load and the predicted solar cooling fraction will agree with the actual solar cooling fraction. Therefore the use of the equations will predict a collector area that is too small to provide the given solar heating fraction and when the collector area is increased to provide the desired solar heating fraction the solar cooling fraction will increase. The technique has been verified with detailed computer runs which for a given collector area predicted a solar heating fraction less than would be predicted by the technique and a solar cooling fraction approximately equal to the fraction predicted by the technique.
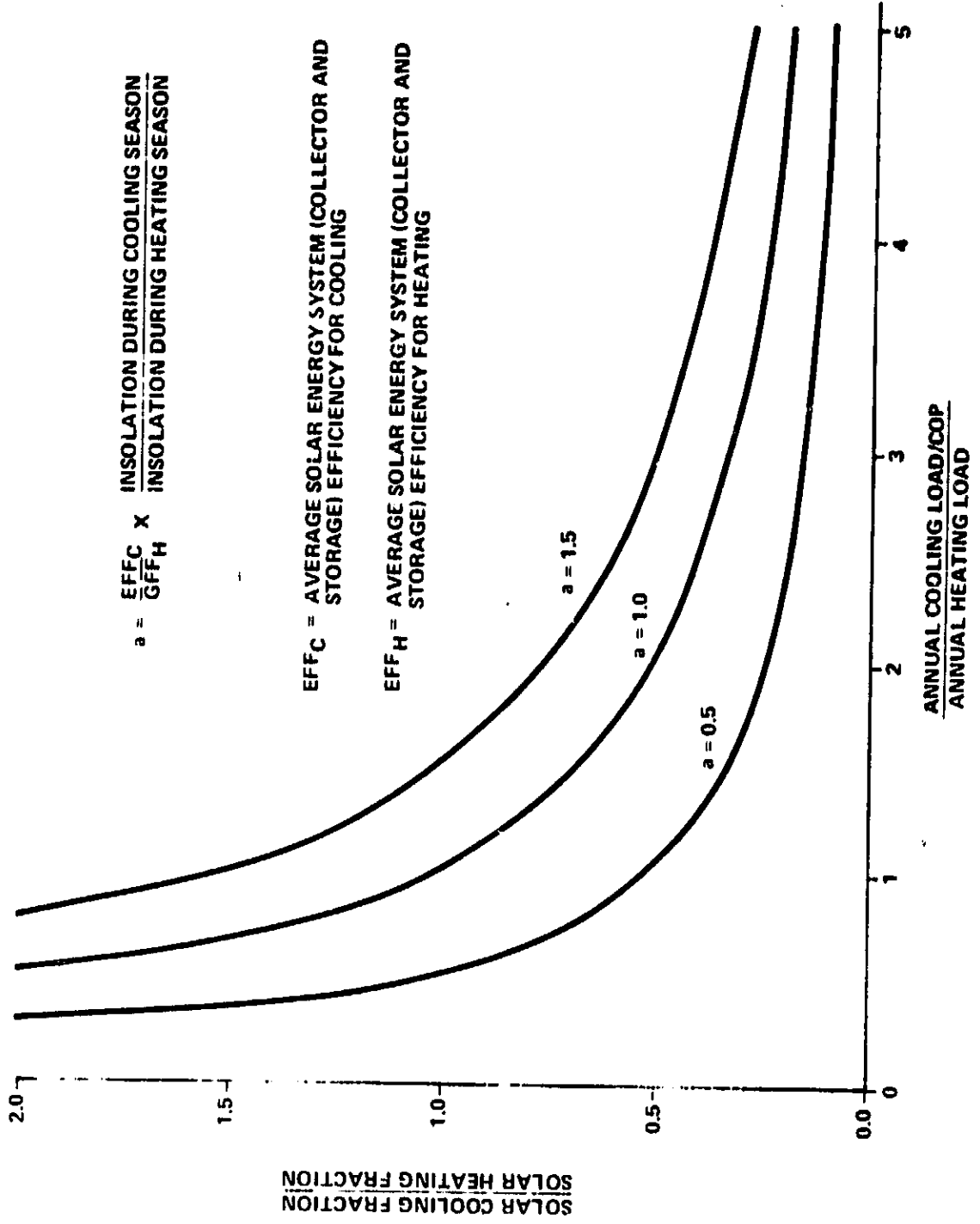
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Figure 1. Solar Energy System Capability

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C. ECONOMIC EVALUATION

Life-cycle cost analysis must be used if economic decisions are to made accurately. For this the present value method of life-cycle costing was selected. In the previous section the assumption was made that a solar energy system exists for heating the building and that the system can also provide cooling by the addition of an absorption chiller and the appropriate interconnecting hardware. This assumption allows the consideration of only the incremental costs of the solar chiller subsystem over the cost of the conventional vapor compression chiller. The present value of the incremental costs is a function of the initial incremental· costs and all future incremental costs. The present value of the incremental savings is a function of the load, the coefficients of performances of the subsystems, the utility rate structures, and the fraction of the load satisfied by solar energy. The present value of the incremental cost of solar cooling can be equated to the present value of the savings of solar cooling to determine the minimum fraction of the load that must be satisfied by solar energy for the system to break even economically.

The present value of the incremental costs of solar powered absorption cooling is comprised of the sum of the present value of all incremental costs incurred as a result of the decision during the life of the system. The present value of the cost of the incremental cooling investment, $(P.V.)_C$, can be written as:

$$(P.V.)_C = xC + P.V.(P) + (1-t_i)P.V.(I) + (1-t_i)P.V.(P.T.) + (1-t_o)P.V.(M)$$
$$+ (1-t_o)P.V.(IN) - (1-t_o)P.V.(D) - P.V.(S) \tag{7}$$

where: C = Incremental cooling investment,

x = Fractional down payment,

$P.V.(P)$ = Present value of incremental principal payments,

$P.V.(I)$ = Present value of incremental interest payments,

$P.V.(P.T.)$ = Present value of incremental property taxes,

$P.V.(M)$ = Present value of incremental repair and maintenance costs,

$P.V.(IN)$ = Present value of incremental insurance costs,

$P.V.(D)$ = Present value of incremental depreciation deductions,

$P.V.(S)$ = Present value of incremental salvage income,

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t_i = Incremental tax rate for interest and tax deductions[2], and

t_o = Incremental tax rate for operating expense deductions[2].

The present value of the increment principal payments, P.V.(P), can be written as:

$$P.V.(P) = \sum_{j=1}^{N} \frac{i(1-x)C}{(1+r)^j} \left| \frac{(1+i)^{j-1}}{1-(1+i)^{-N}} - (1+i)^{j-1} \right| \tag{8}$$

and present value of the incremental interest payments, P.V.(I), can be written as:

$$P.V.(I) = \sum_{j=1}^{N} \frac{i(1-x)C}{(1+r)^j} \left\{ (1+i)^{j-1} + \frac{1-(1+i)^{j-1}}{1-(1+i)^{-N}} \right\}$$

where: i = Annual mortgage interest rate,

N = Number of years of mortgage, and

r = Discount rate

If it is assumed for residential applications that the total value of the building appreciates at the inflation rate of the economy and the value of the cooling equipment remains a fixed proportion of the value of the building, then the value of the cooling equipment for property taxes inflates at the rate of the economy. For commercial applications it is assumed that the equipment is depreciated for property taxes by the sum of the years digits method, therefore the present value of the incremental property taxes, P.V.(P.T.), can be written as:

$$P.V.(P.T.) = \gamma \sum_{j=1}^{M} pC \left(\frac{1+e}{1+r} \right)^j + (\gamma-1) \sum_{j=1}^{L} pC \frac{2(L+1-j)}{L(L+1)} \left(\frac{1}{1+r} \right)^j \tag{10}$$

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[2]It has been assumed that the incremental tax rate of the owner does not change during the life of the system.

where: γ = 1 for residential applications,

γ = 0 for commercial applications,

M = Useful life of the equipment,

p = Property tax rate based on total value of equipment,

e = Inflation rate of the economy, and

L = Life time of the equipment for depreciation.

If it is assumed that the repair and maintenance costs inflate at the rate of the economy, the present value of the incremental repair and maintenance costs, P.V.(M), can be written as:

$$P.V.(M) = \sum_{j=1}^{M} mC \left(\frac{1+e}{1+r} \right)^{j} \tag{11}$$

where: m = Repair and maintenance cost for year zero as a fraction of the cost of the equipment.

Assuming that the insurance costs inflate at the rate of the economy, the present value of the incremental insurance costs, P.V.(IN), can be written as:

$$P.V.(IN) = \sum_{j=1}^{M} kC \left(\frac{1+e}{1+r} \right)^{j} \tag{12}$$

where: k = Insurance cost for year zero as a fraction of the cost of the equipment.

The present value of the incremental depreciation deductions, P.V.(D), for commercial applications using the sum of the years digits can be written as:

$$P.V.(D) = \sum_{j=1}^{L} (1-\gamma)C \; \frac{2(L+1-j)}{L(L+1)} \left(\frac{1}{1+r} \right) \tag{13}$$

The present value of the increment salvage income, P.V.(S) can be written as:

$$P.V.(S) = sC \left(\frac{1}{1+r}\right)^M \tag{14}$$

where: s = Salvage value of the equipment at year M as a fraction of value of the equipment at year zero.

The present value of the incremental savings is equal to the difference between the present value of the utility costs of cooling with the conventional vapor compression chiller and the present value of the utility costs of cooling with the solar powered absorption chiller. The present value of the incremental savings, $(P.V.)_S$, can be written as:

$$(P.V.)_S = (1-t_o) \; P.V.(Q_C) - (1-t_o) \; P.V.(Q_S) - (1-t_o)P.V.(Q_{SC}) \tag{15}$$

$$-(1-t_o)P.V.(Q_{AE}) - (1-t_o)P.V.(Q_{AF})$$

where: $P.V.(Q_C)$ = Present value of conventional cooling energy cost,

$P.V.(Q_S)$ = Present value of solar collector and storage electrical energy cost during cooling season,

$P.V.(Q_{SC})$ = Present value of solar cooling electrical energy cost,

$P.V.(Q_{AE})$ = Present value of auxiliary cooling electrical energy cost, and

$P.V.(Q_{AF})$ = Present value of auxiliary cooling fuel energy cost.

The present value of the conventional cooling energy cost, $P.V.(Q_C)$, can be written as:

$$P.V.(Q_C) = \sum_{j=1}^{M} \frac{Q_C}{COP_C} \; u_C \left(\frac{1+f_C}{1+r}\right)^j \tag{16}$$

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where: Q_C = Annual equipment cooling load,

        COP_C = Conventional chiller coefficient of performance,

        U_C = Incremental utility cost for the conventional chiller, and

        f_C = Escalation rate of U_C.

The present value of the solar collector and storage electrical energy cost during the cooling season, $P.V.(Q_S)$, can be written as:

$$P.V.(Q_S) = \sum_{j=1}^{M} F \frac{Q_C}{COP_S COP_A} U_S \left(\frac{1+f_S}{1+r}\right)^j \tag{17}$$

where: F = Solar fraction of annual cooling load,

        COP_S = Solar energy system coefficient of performance during the cooling system[3],

        COP_A = Thermal coefficient of performance of the absorption chiller,

        U_S = Incremental electrical utility cost for the solar energy system, and

        f_S = Escalation rate of U_S.

The present value of the solar cooling electrical energy cost, $P.V.(Q_{SC})$, can be written as:

$$P.V.(Q_{SC}) = \sum_{j=1}^{M} F \frac{Q_C}{COP_{SE}} U_{SE} \left(\frac{1+f_{SE}}{1+r}\right)^j \tag{18}$$

where: COP_{SE} = Electrical coefficient of performance of the solar cooling subsystem[4],

        U_{SE} = Incremental electrical utility cost for the solar cooling subsystem, and

        f_{SE} = Escalation rate of U_{SE}.

[3] COP_S = solar energy delivered to the solar cooling subsystem from storage during the cooling season/collector electrical energy during the cooling season.

[4] COP_{SE} = average thermal output of the solar cooling subsystem/solar cooling subsystem electrical energy requirements.

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The present value of the auxiliary cooling electrical energy cost, P.V.(Q_{AE}), can be written as:

$$P.V.(Q_{AE}) = \sum_{j=1}^{M} (1-F) \frac{Q_C}{COP_{AE}} U_{AE} \left(\frac{1+f_{AE}}{1+r}\right)^j \qquad (19)$$

where

COP_{AE} = Electrical coefficient of performance of the auxiliary cooling subsystem,

U_{AE} = Incremental electrical utility cost for the auxiliary cooling subsystem, and

f_{AE} = Escalation rate of U_{AE}.

The present value of the auxiliary cooling fuel energy cost, P.V.(Q_{AF}), can be written as:

$$P.V.(Q_{AF}) = \beta \sum_{j=1}^{M} (1-F) \frac{Q_C}{\eta_{AF} COP_{AF}} U_{AF} \left(\frac{1+f_{AF}}{1+r}\right)^j \qquad (20)$$

where:

β = 0 for electrical energy source for auxiliary cooling,

β = 1 for fuel energy scurve for auxiliary cooling,

η_{AF} = Auxiliary cooling subsystem thermal conversion efficiency,

COP_{AF} = Thermal coefficient of performances of the auxiliary cooling subsystem,

U_{AF} = Incremental fuel utility cost for the auxiliary cooling subsystem, and

f_{AF} = Escalation rate of U_{AF}.

Equation (7) can be equated to Equation (15) and the minimum fraction of the load that must be supplied by solar energy for the owner of the system to break-even economically. If this minimum economic fraction is less than the system's capability and in addition energy will be saved, then the system is economically feasible. The minimum fraction of the cooling load that must be satisfied by solar energy is a function of both site dependent parameters and site independent parameters.

In the following section the economic feasibility of solar powered absorption cooling has been evaluated for several sites. In making this evaluation typical values were selected for the site independent parameters, therefore the values of the minimum solar fraction for each site should only be interpreted as the midpoint of a range and not as absolutes. These values are useful to predict which sites will probably be more cost effective than others by making relative comparisons.

III. RESULTS

The procedure presented in Section II was used to evaluate the feasibility of meeting the cooling load of buildings in various locations using an absorption cycle chiller and a solar energy system. Buildings that are characterized by a peak cooling load of 3, 25, and 100 tons were considered in this phase of the study. Two different methods of meeting the cooling load not met by the solar energy system and the absorption chiller were evaluated. In the first method the auxiliary load was met by firing the absorption chiller with a boiler using natural gas. In the second method the auxiliary load was met by a conventional vapor compression chiller. The economies of a typical home owner were used in the 3-ton applications, and the economies of a commercial building owner/occupant were used in the 25- and 100-ton applications.

The results for the various locations and applications considered are presented in Tables II through VII. In each table are the site dependent factors and the solar fraction of the cooling load for each of the three criteria (energy savings, system capability, and economic breakeven). Below each table are the site independent parameters used for the particular application. The cost and performance of the absorption chillers used in the analysis are representative of those that are currently available. The point of origin for the energy conversion efficiency for electricity assumes an electrical generating plant using fossil energy. The efficiencies for the solar energy system for heating and cooling are those that can be expected from a two cover non-selective surface collector. In each table is the collector area required to satisfy 50% of the heating load with solar energy and also the solar fraction of the cooling load that can be satisfied with the collector area. From Table II and Table III it is seen that based on the assumptions shown that a location was not found that could satisfy all three criteria for a 3-ton residential application of solar cooling with either a fossil source for auxiliary energy or a conventional vapor compression chiller for auxiliary energy. Therefore, it can be concluded that based on the ground rules of the study, residential applications of solar absorption cooling are not currently economically attractive. However, some site dependent factors have been identified which make some sites more amenable (or less undesirable) than others. These factors are:

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Table II. Solar Fractions for Three-Ton Residential Applications with Fossil Auxiliary

City	I_H (10^6 Btu/ ft² yr)	I_C (10^6 Btu/ ft² yr)	Q_H (10^6 Btu/yr)	Q_C (10^6 Btu/yr)	A (Ft²)	Electrical Energy Cost ($/$10^6$ Btu)	Fossil Energy Cost ($/$10^6$ Btu)	Solar Fraction of Cooling Load		
								Energy Savings	System Capability	Economic Breakeven
Albuquerque	0.483	0.318	125	39.2	378	7.41	2.07	0.50	0.40	>1.00
Birmingham	0.266	0.311	84.7	57.4	456	8.62	2.12	0.50	0.32	0.76
Fort Worth	0.249	0.352	58.8	63.9	337	7.32	2.16	0.50	0.24	0.82
Kansas City	0.328	0.249	139	38.4	608	10.25	1.59	0.50	0.51	0.77
Nashville	0.264	0.275	106	48.8	577	8.38	2.78	0.50	0.42	0.89
Omaha	0.348	0.219	180	35.0	740	9.44	1.65	0.50	0.60	>1.00
Salt Lake City	0.436	0.205	178	27.6	584	9.32	2.64	0.50	0.56	>1.00
Washington	0.294	0.239	135	45.3	654	12.51	1.97	0.50	0.45	0.54
Wichita	0.353	0.241	119	42.5	482	8.14	1.80	0.50	0.35	0.92

Site Independent Parameters:

Collector Tilt = Latitude

$\eta_C = \eta_{AE} = \eta_{SE} = 0.30$

$\eta_{AF} = 0.60$

$COP_C = 2$

$COP_A = COP_{AF} = 0.65$

$COP_S = 150$

$COP_{AE} = 10.55$

$COP_{SE} = 7.91$

$EFF_C = 0.20$

$EFF_H = 0.35$

$F_H = 0.50$

$C = \$2,800$

$x = 0.20$

$i = 0.08$

$N = 20$

$M = 20$

$s = 0$

$e = 0.06$

$r = 0.08$

$t_1 = 0.30$

$p = 0.01$

$m = 0.025$

$k = 0.005$

$f_C = f_S = f_{SE} = f_{AE} = f_{AF} = 0.14$

Table III. Solar Fractions for Three-Ton Residential Application with Vapor Compression Auxiliary

City	I_H (10⁶ Btu/ ft² yr)	I_C (10⁶ Btu/ ft² yr)	Q_H (10⁶ Btu/yr)	Q_C (10⁶ Btu/yr)	A (Ft²)	Electrical Energy Cost ($/10⁶ Btu)	Solar Fraction of Cooling Load		
	I_H (10⁶ Btu/ ft² yr)	I_C (10⁶ Btu/ ft² yr)	Q_H (10⁶ Btu/yr)	Q_C (10⁶ Btu/yr)	A (Ft²)		Energy Savings	System Capability	Economic Break-even
Albuquerque	0.483	0.316	128	39.1	378	7.41	0	0.40	>1.00
Birmingham	0.256	0.311	84.7	57.4	456	3.62	0	0.32	0.38
Fort Worth	0.249	0.352	58.8	63.9	337	5.56	0	0.34	>1.00
Kansas City	0.328	0.249	139	38.4	602	10.25	0	0.51	>1.00
Nashville	0.264	0.275	106	43.8	577	6.33	0	0.42	>1.00
Omaha	0.348	0.219	180	35.0	740	8.44	0	0.40	>1.00
Salt Lake City	0.436	0.205	178	27.6	534	9.32	0	0.55	>1.00
Washington	0.294	0.239	135	45.3	654	12.51	0	0.45	0.77
Wichita	0.353	0.241	119	42.5	432	8.14	0	0.35	>1.00

Site Independent Parameters:

Collector Tilt = Latitude

$n_C = n_{AE} = n_{SE} = 0.30$
$n_{AF} = 0.60$
$COP_C = 2$
$COP_A = COP_{AF} = 0.65$
$COP_S = 150$
$COP_{AE} = 10.55$
$COP_{SE} = 7.91$
$EFF_C = 0.20$
$EFF_H = 0.35$
$F_H = 0.50$

$C = \$4,000$
$x = 0.20$
$i = 0.08$
$N = 20$
$M = 20$

$s = 0$
$e = 0.06$

$r = 0.38$
$t_1 = 0.30$
$p = 0.01$

$m = 0.025$
$k = 0.005$
$f_C = f_S = f_{SE} = f_{AE} = f_{AF} = 0.14$

1. A high heating load relative to the cooling load,

2. A high collector efficiency during the cooling season relative to the heating season,

3. A high insolation during the summer relative to the insolation in the winter,

4. A high absorption chiller COP,

5. A high percent solar heating,

6. A high cost for conventional energy, and

7. A low cost for auxiliary energy.

From the sites that were considered in the study, Washington and Kansas City would be the most favorable although not cost effective. Due to the nature of the study and the many assumptions that were made, an individual decision to cool or not to cool with a solar powered absorption chiller should not be inferred from the results. Rather the study should be considered as a guide to things to be considered. An update of the assumptions peculiar to a particular installation should be made as well as the sensitivities to key non-site dependent assumptions (i.e., fuel escalation rate, period of analysis, etc.) whenever a specific site is to be analyzed.

For the commerical applications, two references temperatures were used for the load calculations. The reference temperature is a measure of the energy dissipated internally to the building by electrical devices and people. A reference temperature of 65°F is commonly used for residential applications, but for commercial applications the reference temperature can be much lower. Two values were used for each location considered for a commercial application of solar cooling. The lower reference temperature for each site considered was determined by reducing the reference temperature in increments of 10°F (starting for 65°F) until the system capability was reduced to approximately 30%. A further reduction was not made because it was felt that a solar fraction of less than 30% could not be justified. The higher reference temperature was set 10°F higher than the lower reference temperature.

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The results for the commercial applications are presented in Tables IV through VII. In addition to the site dependent data that was presented for the residential applications and the reference temperature for the load calculations another site dependent parameter is presented. This parameter is the waste energy requirement to satisfy the three criteria. It is assumed that for commercial applications that excess process heat in the form of waste energy is available as a by-product product of a manufacturing process. If all three criteria were not met, the annual waste energy requirements were determined. These waste energy requirements are assumed to be available at the chiller's rated generator temperature.

For the 25-ton commercial applications, all sites considered were feasible using the higher reference temperature for both fossil and conventional auxiliary. It should be remembered that very few commercial applications will have a load reference temperature of 65°F. For a 55°F reference temperature, Minneapolis is the only site considered that is feasible, based on the given assumption for fossil auxiliary without the use of waste energy. All sites are feasible for a load reference temperature of 55°F if a conventional vapor compression chiller is used as the auxiliary source, and Minneapolis still meets the criteria with a load reference temperature of 45°F. The results indicate that a 25-ton commercial application is more feasible than a 3-ton residential application and that a city with a high heating load, such as Minneapolis, and a conventional vapor compression auxiliary is the best location.

The results for the 100-ton commercial applications were essentially the same as the 25-ton commercial application with the exception of the economic break even. Because of the lower incremental cost per ton of the larger chiller, the fraction of the cooling load that must be satisfied with solar energy to break even economically was substantially reduced. This reduction will allow application with lower load reference temperature to be feasible for the 100-ton application than the 25-ton application. Therefore, it can be stated that in general the larger chillers will be more cost effective than the smaller chillers.

Table IV. Solar Fractions for 25-Ton Commercial Application with Fossil Auxiliary

City	T_{REF} (°F)	L_H (10^6 Btu / ft² yr)	L_C (10^6 Btu / ft² yr)	Q_H (10^6 Btu/yr)	Q_C (10^6 Btu/yr)	A (ft²)	Electrical Energy Cost ($/$10^6$ Btu)	Fossil Energy Cost ($/$10^6$ Btu)	Solar Fraction of Cooling Load — Energy Savings	System Capability	Economic Break-even	Waste Energy Requirements (10^6 Btu/yr)
Columbus	65	0.335	0.194	1790	353	7537	10.03	2.21	0.46	0.74	0.40	0
Columbus	55	0.232	0.297	1315	989	6549	10.03	2.16	0.46	0.37	0.29	95.4
Kansas City	65	0.330	0.247	1135	294	4530	6.35	1.28	0.46	0.54	0.40	0
Kansas City	55	0.330	0.346	585	662	4252	6.35	1.28	0.46	0.29	0.27	173.1
Minneapolis	55	0.281	0.239	1678	500	8539	10.40	1.55	0.46	0.53	0.03	0
Minneapolis	45	0.202	0.318	1089	1036	7714	10.40	1.55	0.46	0.32	0.09	216.7
Omaha	65	0.350	0.277	1490	227	6082	7.13	1.32	0.46	0.62	0.33	0
Omaha	55	0.252	0.315	954	647	5413	7.13	1.31	0.46	0.34	0.19	119.4
Washington	65	0.296	0.237	1481	370	7139	8.73	1.64	0.46	0.59	0.25	0
Washington	55	0.207	0.327	935	825	6659	8.73	1.59	0.46	0.34	0.15	152.3

Site Independent Parameters:

Collector Tilt = Latitude

$\eta_C = \eta_{AE} = \eta_{SE} = 0.30$
$\eta_{AF} = 0.60$

$COP_C = 2$

$COP_A = COP_{AF} = 0.65$

$COP_S = 150$

$COP_{AE} = 10.55$

$COP_{SE} = 7.91$

$EFF_C = 0.20$

$EFF_H = 0.35$

$F_H = 0.50$

$C = \$6,000$

$x = 0.20$

$i = 0.08$

$N = 20$

$M = 20$

$s = 0$

$e = 0.06$

$r = 0.08$

$t_1 = t_o = 0.48$

$\bar{p} = 0.01$

$m = 0.025$

$k = 0.005$

$f_C = f_S = f_{SE} = f_{AE} = f_{AF} = 0.14$

Table V. Solar Fractions for 25-Ton Commercial Application with Conventional Auxiliary

City	T_{EF} (°F)	L_H (10^6 Btu/ ft² yr)	I_c (10^6 Btu/ ft² yr)	Q_H (10^6 Btu/yr)	Q_C (10^6 Btu/yr)	A (Ft²)	Electrical Energy Cost ($/$10^6$ Btu)	Solar Fraction of Cooling Load			Waste Energy Requirements (10^6 Btu/yr)
								Energy Savings	System Capability	Economic Break-even	
Columbus	65	0.335	0.194	1790	258	7637	10.03	0	0.74	0.39	0
Columbus	55	0.232	0.297	1079	689	6649	10.03	0	0.37	0.15	0
Kansas City	65	0.330	0.247	1138	294	4930	6.35	0	0.54	0.54	0
Kansas City	55	0.230	0.346	635	662	4252	6.35	0	0.29	0.24	0
Minneapolis	55	0.281	0.239	1678	550	8539	10.40	0	0.53	0.19	0
Minneapolis	45	0.202	0.318	1089	1006	7714	10.40	0	0.32	0.10	0
Omaha	65	0.350	0.217	1490	227	5082	7.13	0	0.62	0.48	0
Omaha	55	0.252	0.315	954	647	5413	7.13	0	0.34	0.33	0
Washington	65	0.295	0.237	1481	370	7139	8.73	0	0.59	0.27	0
Washington	55	0.237	0.327	963	825	6659	8.73	0	0.34	0.22	0

0   0.34   0.22   0

0   0

Site Independent Parameters:

Collector Tilt = Latitude

$\eta_C = \eta_{AE} = \eta_{SE} = 0.30 \quad \eta_{AF} = 0.60$

$COP_C = 2$

$COP_A = COP_{AF} = 0.65$

$COP_S = 150$

$COP_{AE} = 10.55$

$COP_{SE} = 7.91$

$EFF_C = 0.20$

$EFF_H = 0.35$

$F_H = 0.50$

$C = \$12,000$

$x = 0.20$

$i = 0.08$

$N = 20$

$M = 20$

$s = 0$

$e = 0.06$

$r = 0.08$

$t_i = t_o = 0.48$

$p = 0.01$

$m = 0.025$

$k = 0.005$

$f_C = f_S = f_{SE} = f_{AE} = f_{AF} = 0.14$

Table VI. Solar Fractions for 100-Ton Commercial Application with Fossil Auxiliary

City	T_{REF} (°F)	I_H (10^6 Btu/ ft^2 yr)	I_C (10^6 Btu/ ft^2 yr)	q_H (10^6 Btu/yr)	q_C (10^6 Btu/yr)	A (Ft^2)	Electrical Energy Cost ($/$10^6$ Btu)	Fossil Energy Cost ($/$10^5$ Btu)	Solar Fraction of Cooling Load			Waste Energy Require- ments (10^5 Btu/yr)
									Energy Savings	System Capa- bility	Economic Break- even	
Columbus	65	0.335	0.194	7161	1033	30543	10.03	2.14	0.44	0.74	0.26	0
Columbus	55	0.232	0.297	4315	2759	26596	10.03	2.14	0.44	0.37	0.22	237.0
Kansas City	65	0.330	0.247	4552	1175	19720	5.35	1.27	0.44	0.54	0.23	0
Kansas City	55	0.230	0.346	2740	2548	17008	6.35	1.27	0.44	0.29	0.18	611.1
Minneapolis	55	0.281	0.239	6714	2031	34155	10.40	1.55	0.44	0.53	0.13	0
Minneapolis	45	0.202	0.318	4357	4025	30358	10.40	1.55	0.44	0.32	0.15	743.1
Omaha	65	0.350	0.227	5960	1108	24327	7.13	1.29	0.44	0.62	0.14	0
Omaha	55	0.252	0.315	3818	2590	21550	7.13	1.29	0.44	0.34	0.09	399.5
Washington	65	0.296	0.237	5923	1480	23554	8.73	1.54	0.44	0.59	0.08	0
Washington	55	0.207	0.327	3851	3302	25635	8.73	1.53	0.44	0.34	0.04	503.0

Site Independent Parameters:

Collector Tilt = Latitude

$n_C = n_{AE} = n_{SE} = 0.30$
$n_{AF} = 0.60$

$COP_C = 2$
$COP_A = COP_{AF} = 0.65$
$COP_S = 150$
$COP_{AE} = 10.55$
$COP_{AE} = 7.91$
$EFF_C = 0.20$
$EFF_{SE} = 0.35$
$F_H = 0.50$

$C = \$6,000$
$x = 0.20$
$i = 0.08$
$N = 20$
$M = 20$

$s = 0$
$e = 0.06$
$r = 0.08$
$t_1 = t_0 = 0.48$
$p = 0.01$
$m = 0.025$
$k = 0.005$
$f_C = f_S = f_{SE} = f_{AE} = f_{AF} = 0.14$

Table VII. Solar Fractions for 100-Ton Commercial Application with Conventional Auxiliary

City	T_{REF} (°F)	I_H (10^6 Btu/ ft² yr)	I_C (10^6 Btu/ ft² yr)	Q_H (10^6 Btu/yr)	Q_C (10^6 Btu/yr)	A (Ft²)	Electrical Energy Cost ($/$10^6$ Btu)	Solar Fraction of Cooling Load Energy Savings	System Capability	Economic Break-even	Waste Energy Requirements (10^6 Btu/yr)
Columbus	65	0.335	0.194	7161	1033	30548	10.03	0	0.74	0.20	0
Columbus	55	0.232	0.297	4315	2758	26596	10.03	0	0.37	0.07	0
Kansas City	65	0.330	0.247	4552	1175	19720	6.35	0	0.54	0.27	0
Kansas City	55	0.230	0.346	2740	2648	17008	6.35	0	0.29	0.12	0
Minneapolis	55	0.281	0.239	6714	2001	34155	10.40	0	0.53	0.10	0
Minneapolis	45	0.202	0.318	4357	4025	30858	10.40	0	0.32	0.07	0
Omaha	65	0.350	0.217	5960	1108	24327	7.13	0	0.62	0.26	0
Omaha	55	0.252	0.315	3818	2590	21650	7.13	0	0.34	0.11	0
Washington	65	0.296	0.237	5923	1480	28554	8.73	0	0.59	0.16	0
Washington	55	0.207	0.327	3851	3302	26635	8.73	0	0.34	0.07	0

Site Independent Parameters:

Collector Tilt = Latitude

$\eta_C = \eta_{AE} = \eta_{SE} = 0.30$
$\eta_{AF} = 0.60$
$COP_C = 2$
$COP_A = COP_{AF} = 0.65$
$COP_S = 150$
$COP_{AE} = 10.55$
$COP_{SE} = 7.91$
$EFF_C = 0.20$
$EFF_H = 0.35$
$F_H = 0.50$

$C = \$25,000$
$x = 0.20$
$i = 0.08$
$N = 20$
$M = 20$
$s = 0$
$e = 0.06$
$r = 0.08$
$t_i = t_o = 0.48$
$p = 0.01$
$m = 0.025$
$k = 0.005$
$f_C = f_S = f_{SE} = f_{AE} = f_{AF} = 0.14$

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IV. SUMMARY

A procedure has been developed to evaluate the cost effectiveness of combining
an absorption cycle chiller with a solar energy system. A basic assumption
of the procedure is that a solar energy system exists for meeting the heating
load of the building and the building must be cooled. The decision to be
made is to either cool the building with a conventional vapor compression cycle
chiller or to use the existing solar energy system to provide a heat input to
the absorption chiller. Two methods of meeting the cooling load not supplied
by solar energy were considered. In the first method, heat is supplied to the
absorption chiller by a boiler using fossil fuel. In the second method, the
load not met by solar energy is met by a conventional vapor compression chiller.
In addition, the procedure can consider waste heat as another form of auxiliary
energy.

The procedure was used to determine which sites are attractive for solar cooling
with an absorption chiller. During the analysis site independent parameters were
held constant so that the influence of the site dependent parameters could be
determined. Typical values were selected for these site indepenent parameters.
The results of the analysis, therefore, gives a relative rating of the sites
considered as to their economic feasibility of solar cooling. Before a final
judgment is made on the cost effectiveness of a particular site, the influence
of all parameters should be determined.

The results of the analysis indicates, based on the ground rules of the study
and the assumptions that were made, that residential applications of solar powered
absorption cooling are not currently economically attractive. However, of the
sites considered, Washington and Kansas City are the most favored although not
cost effective. Again, it must be emphasized that the results are valid only
considering the guidelines and the assumptions made and that the general results
should not be used for specific installations. Rather, specific data should be
gathered and the analysis repeated.

Commercial applications of solar cooling with an absorption chiller were found
to be more cost effective than the residential applications. Although all of

the commerical applications that were considered were found to be cost effective, the lower reference temperature applications using fossil auxiliary were found not to result in energy savings. Because of the variations in the internally generated energy in a commercial application, any proposed application should be reviewed based on its own merits to determine if it saves energy and is also cost effective. In general, it was found that the larger the chiller, the more economically feasible it would be. Also, it was found that a conventional vapor compression chiller is a viable alternative for the auxiliary cooling source, especially for the larger chillers.

A - collector area

C - incremental cooling investment

COP_A - coefficient of performance of the solar cooling subsystem based on thermal energy requirements

COP_{AE} - coefficient of performance of the auxiliary cooling subsystem based on electrical energy requirements

COP_{AF} - coefficient of performance of the auxiliary cooling subsystem based on fossil energy requirements

COP_C - Coefficient of performance of the conventional cooling system

COP_S - coefficient of performance of the solar collector and storage subsystem based on the energy delivered to the solar cooling subsystem and electrical energy required to deliver that energy

COP_{SE} - coefficient of performance of the solar cooling subsystem based on electrical energy requirements

e - inflation rate of the economy

E_C - conventional cooling system energy requirements

E_S - solar energy system energy requirements

EFF_C - solar energy system (collector and storage) efficiency during cooling season

EFF_H - solar energy system (collector and storage) efficiency during heating season

f_{AE} - escalation rate of U_{AE}

f_{AF} - escalation rate of U_{AF}

f_C - escalation rate of U_C

f_S - escalation rate of U_S

f_{SE} - escalation rate of U_{SE}

F or F_C - fraction of cooling load satisfied by solar energy

F_H - fraction of heating load satisfied by solar energy

F_{MIN} - fraction of the cooling load that must be satisfied with solar energy to save energy resources

i – annual mortgage interest rate

I_C – insulation available during cooling season

I_H – insulation available during heating season

j – summation variable

k – insurance cost for year zero as a fraction of the cost of the equipment

L – life time of the equipment for depreciation

m – repair and maintenance cost for year zero as a fraction of the cost of the equipment

M – useful life of the equipment

N – number of years of mortgage

p – property tax rate based on total value of equipment

$(P.V.)_C$ – present value of the cost of the incremental cooling investment

$(P.V.)_S$ – present value of the savings from the incremental cooling investment

$P.V.(D)$ – present value of incremental depreciation deductions

$P.V.(I)$ – present value of incremental interest payments

$P.V.(IN)$ – present value of incremental insurance costs

$P.V.(M)$ – present value of incremental repair and maintenance costs

$P.V.(P)$ – present value of incremental principal payments

$P.V.(P.T.)$ – present value of incremental property taxes

$P.V.(Q_{AE})$ – present value of auxiliary cooling electrical energy cost

$P.V.(Q_{AF})$ – present value of auxiliary cooling fuel energy cost

$P.V.(Q_C)$ – present value of conventional cooling energy cost

$P.V.(Q_S)$ – present value of solar collector and storage electrical energy cost during cooling season

$P.V.(Q_{SC})$ – present value of solar cooling electrical energy cost

$P.V.(S)$ – present value of incremental salvage income

Q_C – annual equipment vooling load

Q_H – annual heating load

r – discount rate

s – salvage value of the equipment at year M as a fraction of the value of the equipment at year zero

t_i – incremental tax rate for interest and tax deductions

t_o – incremental tax rate for operating expense deductions

T_{REF} – reference temperature (building equilibrium temperature) for load calculations

U_{AE} – incremental electrical utility cost for the auxiliary cooling subsystem

U_{AF} – incremental fuel utility cost for the auxiliary cooling subsystem

U_C – incremental utility cost for the conventional chiller

U_S – incremental electrical utility cost for the solar energy system

U_{SE} – incremental electrical utility cost for the solar cooling system

β – 0 for electrical energy source for auxiliary cooling

β – 1 for fuel energy source for auxiliary cooling

γ – 0 for commercial applications

γ – 1 for residential applications

η_{AE} – energy conversion efficiency to the point of origin for the electrical energy requirements of the auxiliary cooling subsystem

η_{AF} – energy conversion efficiency to the point of origin for the fossil energy requirements of the auxiliary cooling subsystem

η_C – energy conversion efficiency to the point of origin for the conventional system

η_{SE} – energy conversion efficiency to the point of origin for the electrical energy requirements of the solar energy system.

APPENDIX

Determination of Building Loads and Available Insolation

A procedure is presented to determine the heating and cooling loads of a building and the amount of insolation available for meeting each of the loads. The procedure requires as inputs:

T_D — Cooling design temperature, °F

T_R — Reference temperature for load calculation, °F

CAP — Cooling capacity of the chiller, BTU/hr

I_n — Monthly insolation on the tilted collector, BTU/Ft^2 month

$TMAX_n$ — Monthly daily maximum temperature, °F

$TMIN_n$ — Monthly daily minimum temperature, °F

The steps of the procedure are:

1. Determine the building heat loss coefficient, UA,

$$UA = \frac{CAP}{T_D - T_R} \text{ , BTU/Hr°F}$$

2. Determine the monthly cooling degree days, CDD, [1]

If $T_R > TMAX_n$

$$CDD_n = 0$$

If $TMAX_n > T_R > TMIN_n$

$$CDD_n = \left(\frac{TMAX_n - T_R}{TMAX_n - TMIN_n} \right) \left(\frac{TMAX_n - T_R}{2} \right) N_n$$

where N_n = number of days in the month

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[1] If $T_R = 65$°F the monthly degree days published by the National Weather Service can be used.

If $T_R < TMIN_n$

$$CDD_n = \left\{ \left(\frac{TMAX_n + TMIN_n}{2} \right) - T_R \right\} N_n$$

3. Determine the monthly heating degree days, HDD,[1]

If $T_R < T_{MIN_n}$

$$HDD_n = 0$$

If $TMAX_n > T_R > TMIN_n$

$$HDD_n = \left\{ 1 - \left(\frac{TMAX_n - T_R}{TMAX_n - TMIN_n} \right) \right\} \left(\frac{T_R - TMIN_n}{2} \right) N_n$$

If $T_R > TMAX_n$

$$HDD_n = \left\{ T_R - \left(\frac{TMAX_n + TMIN_n}{2} \right) \right\} N_n$$

4. Determine the monthly cooling load, $CLOAD_n$,

$$CLOAD_n = 24\ CDD_n UA,\ BTU/Month$$

5. Determine the monthly heating load, $HLOAD_n$,

$$HLOAD_n = 24\ HDD_n UA,\ BTU/Month$$

6. Determine the yearly cooling load, $CLOAD_T$,

$$CLOAD_T = \sum_{n=1}^{12} CLOAD_n,\ BTU/Year$$

[1] If $T_R - 65°F$ the monthly degree days published by the National Weather Service can be used.

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7. Determine the yearly heating load, $HLOAD_T$,

$$HLOAD_T = \sum_{n=1}^{12} HLOAD_n \text{ , BTU/Year}$$

8. Determine the yearly insolation available for cooling, $CSOL_T$,

$$CSOL_T = \sum_{n=1}^{12} \gamma_n I_n \text{ , BTU/Year Ft}^2$$

where $\gamma_n = \dfrac{CDD_n}{CDD_n + HDD_n}$

9. Determine the yearly insolation available for heating, $HSOL_T$,

$$HSOL_T = \sum_{n=1}^{12} \beta_n I_n, \text{ BTU/Year Ft}^2$$

where $\beta_n = \dfrac{HDD_n}{CDD_n + HDD_n}$