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OVERVIEW OF SYSTEMS ANALYSIS, MARKET ASSESSMENT, AND CONTROLS WORK

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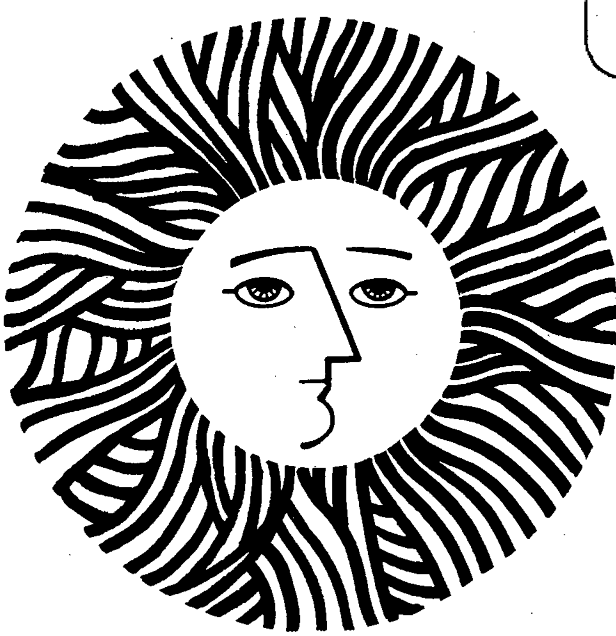

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DISCLAIMER

OVERVIEW OF SYSTEMS ANALYSIS, MARKET ASSESSMENT, AND CONTROLS WORK*

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OBJECTIVE

The major goal of the DOE Systems analysis effort is to define the most fruitful areas for R&D activity in support of private industry's efforts to develop competitive solar space conditioning systems. This includes: establishing the operational requirements of advanced space cooling systems and subsystems; establishing cost and performance goals for these systems; and identifying and recommending systems, subsystems, components and materials requiring research and development activities. Advanced space conditioning systems include heat pumps, desiccant subsystems, absorption chillers, and Rankine driven chillers. In FY 1982 these systems analysis efforts will be coordinated by DOE/SAN.

BACKGROUND

The development activities for systems analysis have been centered in the national laboratories with assistance from outside contractors. Principal areas of responsibility have been: Collector development, LANL; Storage subsystems, ANL; Desiccant systems, SERI; Heat pumps, BNL; and Absorption and Rankine systems, LBL. Major outside contractors have included: University of Wisconsin, development of TRNSYS and desiccant

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systems studies; Colorado State University, system testing and evaluation; and Science Applications, Inc., computer modeling of storage, heat pump, and chiller configurations for commercial and residential buildings.

TECHNICAL ACCOMPLISHMENTS

Heat Pump Analysis. The technical responsibility for the solar assisted heat pump (SAHP) program has been at Brookhaven National Laboratory (BNL). The basic SAHP concept is to collect solar energy at temperatures in the 50 ^{o}F to 90 ^{o}F range, and to use this collected thermal energy as the source for a heat pump. Extensive simulation of heat pump systems has been conducted by SAI [1].

Cost performance goals have been developed by BNL for solar/heat pump systems using simple payback, positive cash flow, and life cycle costing [2]. BNL established an incremental-system-cost to first-year-fuel-savings ratio of ten as a goal. A ratio of ten is consistent with a 5% fuel escalation rate above inflation and a payback period of slightly less than 10 years. They then established the characteristics of typical systems in southern, central, and northern climatic zones.

Systems analysis at SERI has examined the performance of heat pump water heaters [3,4]. Other analyses at SERI have included the verification of building simulation code predictions against analytic models for simplified buildings [5], spectral analysis as a method of characterizing weather patterns for building energy analysis [6], and analysis of seasonal energy storage for heating [7].

Desiccant Cooling Analysis. Technical responsibility for the desiccant cooling program has been at the Solar Energy Research Institute (SERI). Although the theory behind the use of desiccants has long been known and understood, the development of desiccant cooling systems is still at the stage of applied research. Only since emphasis has been placed on conservation of non-renewable energy sources and the application of solar energy have desiccant systems become potential candidates for the space cooling of residential and commercial buildings. A considerable amount of research and development is needed before marketable desiccant cooling systems become available. In humid climates a hybrid configuration with a "conventional" air conditioning system supplemented with desiccant dehumidification may be attractive. Research and analysis are currently under way to optimize the performance of desiccant systems.[8,9,10]

Absorption and Rankine Cooling Analysis. The technical responsibility for the absorption and Rankine cooling program has been at Lawrence Berkeley Laboratory (LBL). LBL has developed a methodology to determine cost and performance goals for absorption and Rankine cooling/heating systems [11,12] based on determining the value of future energy savings from the solar system. The energy savings are determined from simulation analysis. A scenario is adopted which assumes a first entry into the market place in the year 1986 and a 20 % market penetration by the year 2000.

A solar cooling or cooling/heating system is taken to be cost-effective when the incremental solar system cost is equal to (or less than) the present value of the energy savings. The present value over the life of the system (20 years) of the fuel saved by an active solar system has been calculated and is a function of the fuel escalation rates and the expected real return on investment.

The economic performance requirement for a solar system can be expressed in terms of payback period, the number of year for the undiscounted system savings to equal the incremental cost of the solar system over that of a conventional system that provides the same service. A market assessment performed by OR/MS Dialogue [13] has developed a relationship between payback period and market acceptance of a product. If payback period is shorter, that product is more acceptable. Based on their assessment, significant market penetration (20%) would be achieved with a payback period of the order of 9 years. The payback period is closely related to the real return on investment which is dependent on the assumed rates for general inflation and fuel escalation.

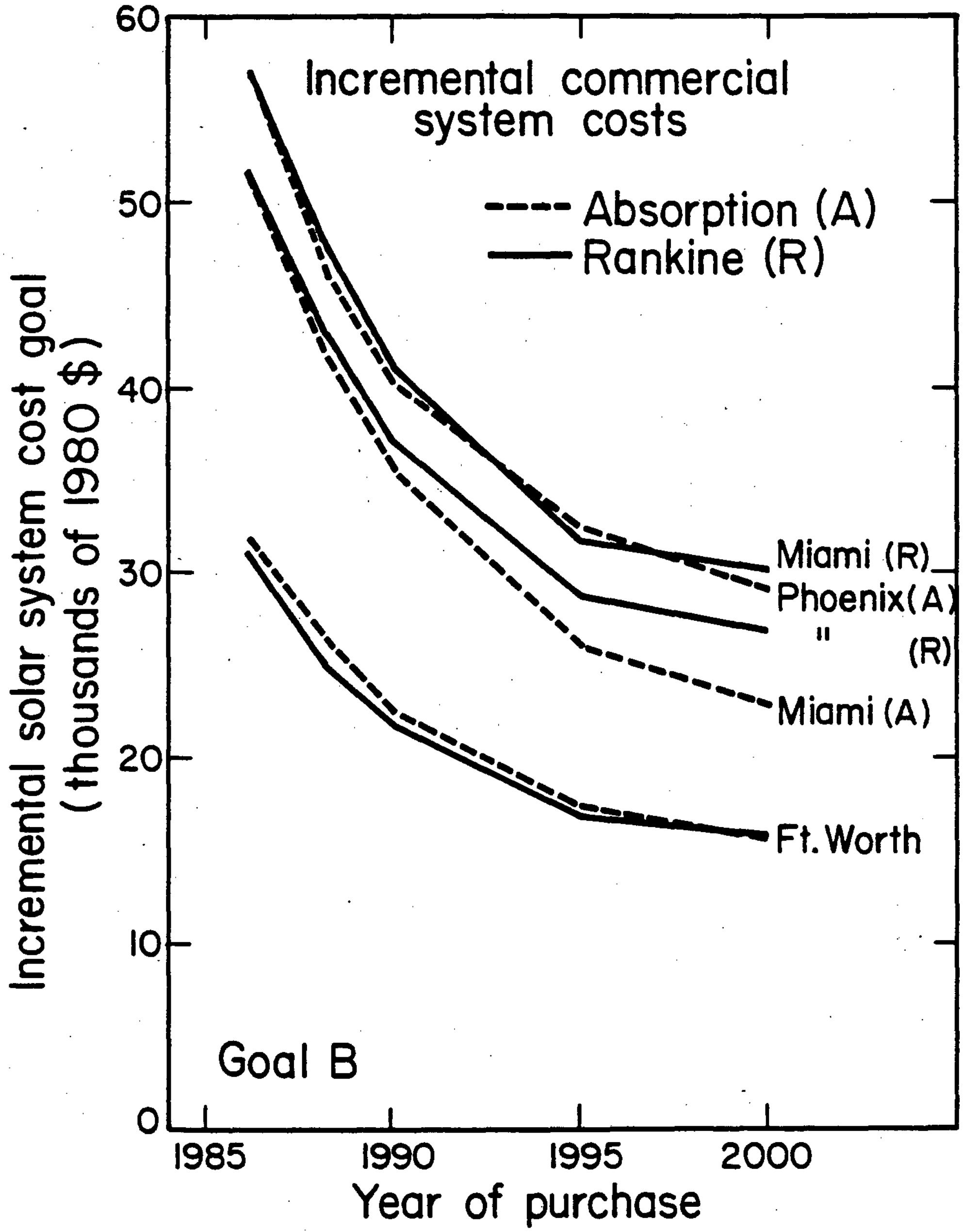
The HVAC industry generally considers a 3 to 5 year payback on incremental investment as necessary to justify new, more efficient products. However, HVAC equipment is designed to last for a significant fraction of the building life. As energy costs increase, other factors such as increased energy consciousness, civic responsibility in conserving energy, and protection from disruption of the fuel supply should make the longer payback periods acceptable for energy conserving equipment.

Market analysis is also required to establish size and geographic distribution of the market. A cooling market assessment by Planco, Inc. [14,15], concludes that the total residential market in the South and West (the "Sun belt") will remain about 2 million units per year from now until the year 2000.

Annual system simulations of the thermal performance of active solar Rankine and absorption cooling/heating systems have been conducted by SAI using TRNSYS.[16,17]. These calculations have been carried out for residential solar cooling/heating systems in four cities (Fort Worth, Phoenix, Miami, and Washington, D.C.) and for commercial solar cooling-only systems in three cities (Fort Worth, Phoenix, and Miami) that are representative of the cooling market. Three types of systems have been evaluated: residential 3 ton absorption (ARKLA), commercial 25 ton absorption (ARKLA), and commercial 25 ton Rankine (AiResearch).

These initial analyses by SAI, OR/MS Dialogue, and Planco have been incorporated into the methodology developed by LBL, thereby generating preliminary cost goals for solar cooling systems. Combining the calculation of the incremental solar system cost as a function of real return on investment with the real return on investment goals as a function of year, incremental system cost goals as a function of year have been generated for commercial solar cooling systems and are displayed Figure 1. Similar analysis has been performed for residential solar cooling/heating systems.

Figure 1. Incremental solar system cost goals (1980$) without tax credits as a function of year of purchase for 25 ton commercial cooling systems in three cities to achieve a 20% market penetration by the year 2000(Goal B).



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National Energy Savings. With estimates of the energy savings in each region for typically sized systems, the anticipated market penetration, and the geographic distribution of the market, estimates of the annual and cumulative energy savings from solar can be made. A very crude estimate indicates that if 20% of the new and retrofit air conditioning market is solar in the year 2000 the annual energy savings will be on the order of 0.14 quad. More work remains to be done to improve the accuracy of this estimate, perhaps using an energy forecasting model such as that developed at Oak Ridge National Laboratory [18].

Meeting Cost and Performance Goals. Once cost goals have been established, scenarios must be developed based on current costs [19] and projections of performance improvements and cost reductions, to establish when the cost goals can be met. Since the cost goals decrease over time (see Fig. 1) to stimulate market acceptance, the projected costs must decrease accordingly. Critical requirements in the solar cooling program are that collector costs relative to performance be reduced, that chiller performance be improved, that intelligent control strategies be used, and that system reliability be established.

Present costs of solar cooling systems are high, which is characteristic for costs of first generation products of an emerging technology. A projected absorption chiller cost of approximately $1000/ton (or even $2000/ton for Rankine units) is low enough to be acceptable even in a mature solar cooling industry, if accompanied by: 1) sufficiently low costs for the collectors and other system components, and 2) high enough chiller efficiency to reduce the size of the collector area. Today's installed collector costs of \$25 to \$40/ft^2 for evacuated tube and trough collectors must clearly be reduced to make solar cooling cost effective.

For the high temperature, high COP future scenario, either evacuated tubes with reflectors or trough collectors will likely be used. Collector manufacturing costs of $14/ft^2 have been projected [20] for evacuated tube concentrating collectors. A key to low cost collectors is the use of lightweight and inexpensive materials. The Low Cost Collector Program has recently projected[21] the manufacturing cost of a trough collector with a lightweight reflector and iron pipe absorber at $6-8/ft^2. A recent evaluation of the potential for cost reduction indicates that with automation and a production volume of greater than 200,000 panels per year in a single facility, the cost of evacuated tube collectors can be reduced to $6.50/ft^2 [22].

It may be possible to achieve system and subsystem cost goals using current chiller technology, with a COP of 0.7 and operating temperatures below 200^{o}F, if very low cost (installed cost of $6/ft^2 or less) good performance collectors can be developed. Work underway at Brookhaven National Laboratory is directed towards developing such collectors [23].

Recent Simulation Analysis. More recent simulation analysis nearing completion by SAI is examining the use of an Arkla 25 ton absorption chiller and Honeywell 25 ton Rankine chillers operating at 195 ^{o}F and 300 ^{o}F, to space condition a small commercial office building in four cities, Phoenix, Ft. Worth, Miami, and Washington, DC.

FUTURE ACTIVITIES

Additional simulation analysis is required to complete the generation of baseline cost goals for small commercial 25 ton solar cooling systems. Needed tasks include: modeling of the Carrier 230 ^{o}F 20 ton air cooled absorption chiller and simulation analysis of solar cooling systems using this chiller in four cities; modeling and analysis of the UTRC 18 ton absorption heat pump; reviewing the conventional and advanced technologies that solar cooling will be competing with in the commercial market place, including both performance improvement of conventional chillers and reduction in cooling loads as a result of energy conservation and passive cooling measures; and modeling a conventional vapor compression machine in the context of the present simulation methodology to establish that the assumed seasonal performance of the conventional competition is reasonable.

Additional analysis is also required to establish baseline cost goals for residential 3 ton solar cooling systems. This work includes detailed simulations with Honeywell Rankine chillers operating at 195 ^{o}F and at 300 ^{o}F, with the Carrier 3 ton air cooled chiller operating at 230 ^{o}F, and with the Arkla 3 ton chiller operating at 195 ^{o}F. The competing conventional technologies should also be reviewed. In addition, the new Arkla 3 ton double effect machine (currently being developed) should be modeled.

Improved regional estimates of cooling markets and market growth are required to better determine the potential for energy savings through applications of solar cooling/heating systems.

Once baseline cost/performance goals have been established, further analyses will be necessary to evaluate the effects of anticipated improvements in collectors, chillers, controls and control strategies. Baseline studies have been confined to only four cities. Available methods will be used to extend the analysis and evaluate the regional variation of energy savings without the need for a large number of detailed simulations.

CONTROLS RESEARCH

Previous research projects in controls for active solar systems have focused on understanding the control of the collector loop, determining optimal control configuration and strategy, developing new control hardware, and evaluating the impact of solar systems on utility peak and off-peak energy use.

Collaboration between researchers at Drexel University and Middlebury College has resulted in validation of a computer model that describes the dynamics of the collector loop in detail [24,25,26]. Other work at Colorado State University, Los Alamos National Laboratory, and at Lawrence Berkeley Laboratory has investigated the comparative effectiveness of different strategies for controlling active heating and cooling systems.

In earlier contracts with Honeywell, Solar Controls, and Rho Sigma, new controllers for active solar systems were developed. Also, two assessments of the need for new controllers were made [27,28]. Franklin Research Institute has examined the impact of active solar energy systems on utility loads [29]. Rho Sigma investigated variable heat pump speed control and has identified problems with continuous compressor speed control [30].

Ongoing experimental work at Colorado State University is focused on developing and evaluating complete space conditioning systems including the implementation of different control strategies. Projects at CSU include developing and evaluating: an Ambient Temperature Observer-Predictor (ATOP) controller to operate the off-peak auxiliary heat supply on Solar House I; a "third generation" Arkla chiller system in combination with an optimally controlled variable speed collector to storage pump, storage stratification enhancement, and a heat-pipe evacuated tube collector; developing and evaluating solar assisted air-to-air heat pump system including an ATOP controller for off-peak cooling of rock storage; the Carrier air-cooled 3-ton lithium bromide absorption chiller system, including controls, for Solar House III; and a solar assisted water-to-air heat pump system.

New controls research will focus on improving local loop chiller control, developing integrated control of cooling, heating, and auxiliary backup functions, and integrating the building space conditioning system with the building configuration and use pattern to achieve comfort with minimal energy use.

Control strategies for chiller operation should be examined to determine how much the chiller seasonal COP can be improved by adjusting the chiller operating point to meet the load and weather conditions [31]. Strategies that can be implemented include chilled water temperature reset, cooling tower return reset, and capacity modulation. The effect of collector array sizing on chiller performance and control cycling also needs to be investigated.

The interaction between the HVAC system and the building's thermal mass is important for the integration of passive cooling strategies such as night cooling with active solar or conventional space conditioning equipment. The dynamic response of buildings to heating and cooling is an active area of research [32].

Finally, the application of building energy controls can increase the efficient end use of energy in both new and existing buildings. Measures can vary from simple steps such as getting existing controls to work properly and adjusting thermostat set points, to comprehensive approaches such as implementation of modern energy management and control systems. The application of controls for efficient energy use is currently an active area of research, application, and discussion [33,34]. Research and development for controls for active solar space conditioning systems should be considered part of the more general analysis of energy control in buildings.

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