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A COMPARISON OF COMPUTER PROGRAMS USED FOR MODELING SOLAR HEATING AND AIR CONDITIONING SYSTEMS FOR BUILDINGS

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Robert M. Graven

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DISCLAIMER

A COMPARISON OF COMPUTER PROGRAMS USED FOR MODELING SOLAR HEATING AND AIR CONDITIONING SYSTEMS FOR BUILDINGS *

by

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ABSTRACT

A comparison of the major architectural structure of computer programs available to aid in the design of solar heating and cooling systems for buildings is presented. A brief description of each program including the size, availability, inputs required, and the flow of information through the program is outlined. The equipment required to run the programs and the costs of obtaining and running the programs is summarized. "Program Notes" summarize the pertinent details required to select a computer program for educational or commercial applications.

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* Work performed in facilities provided by the U.S. Atomic Energy Commission

CONTENTS

1. Introduction

A survey and analysis of the computer programs currently available in the United States as of June 1974 which deal with solar heating and air conditioning systems for buildings has been performed. The total time invested has been about one person for one week, hence this survey is not to be considered comprehensive or complete.

The restrictions initially placed on the program included (1) it must provide detailed engineering design information, (2) it must be readily obtainable, (3) it must be easy to use, (4) it must produce guaranteed results, and (5) total cost must be less than $500. No programs were found which satisfied these restrictions. However, several engineering consulting companies do offer a service which includes computations, interpretations, and recommendations.

The detailed engineering design information desired to make accurate predictions for using solar energy included the effects of variations in (1) flat plate collector designs (angle of tilt, number and type of cover plates, efficiencies, flow rates), (2) storage capacity and form (water, salts, solids, paraffins), (3) load patterns (meterological effects, use patterns, internal heat sources, temperature zones), (4) building variables (orientation, window area, construction details, architectural features, shading, infiltration, heating and cooling distribution system options, etc.), and (5) an economic analysis

(sensitivity to first cost, comparisons of life cycle costs as functions of intrest rates and fuel prices, variations between types of fuel, distributions with respect to location, etc.). In order to study the effects of each variable and select a successful path through the labyrinth of options, one must have an extremely versatile computational tool. No single source was found which could provide the desired documentation and versatility.

A literature search revealed a number of computer programs dealing with various relationships broadly outlined above. Unfortunately, even the most detailed papers do not list all the assumptions and input data used to arrive at the output curves. Indeed, in order to properly describe the limitations and assumptions involved in the calculations requires a book to be written for each computer program. Only the computer program authors can provide answers to a reader's questions as one attempts to understand and properly use the computational work of others. References to other work do not provide a deeper understanding of the current program being studied.

A telephone survey revealed that prices for copies of various programs ranged from $50.00 to "unavailable at any price, proprietary information." Copies of printed output and the results calculated by existing programs in response to given specifications are available from a variety of sources. Several companies offer computational and consulting services to the building industry. Prices ranged from "free" (charged to advertizing costs) to "beyond consideration, except

as a percentage of a specific proposed large office building." A few utility companies have heating load, cooling load, and cost analysis programs available for their service area.

The American Society of Heating, Refrigeration, and Air Conditioning Engineers (ASHRAE) has performed work in the area of computer programs for prediction of building performance. However, no programs currently exist which satisfy all the above criteria. A brief outline of several programs, each of which satisfies some portion of the desired result, follows.

2. Computer Programs

A. Post Office Program

The post office department funded a detailed computer study of the energy utilization in postal facilities. The initial work is described in four volumes (Ref. 1). Their investment has spawned a selection of variations and improvements on the original program.

ASHRAE has certified that the calculations provide reasonable estimates of the heating and cooling loads as well as costs of operating the building. It calculates the heating and cooling requirements as functions of building construction details and can study variations in duct design and comfort conditioning control. It is a very complex procedure which uses a U.S. Weather bureau tape and building construction and orientation details as inputs. Figure 1 illustrates the overall flow of information and outlines the structure of the program itself. Modified and expanded versions of this program are available at GATX, Niles, Illinois; Hittman Associates, Columbia, Md; and at Consultants Computation Bureau, San Francisco. The department of Housing and Urban Development (HUD, Washington, D.C., 20410) is funding the use of this program for some of its studies.

The program does not treat the design of solar collectors and heat storage apparatus. It is primarily a building load study program. However, the effects on the heating and cooling load of adding collectors on the roof or walls can be calculated. Also, the use of recessed windows, and other architectural features can be studied in detail. Infiltration heating and cooling loads are treated in the main text of the program.

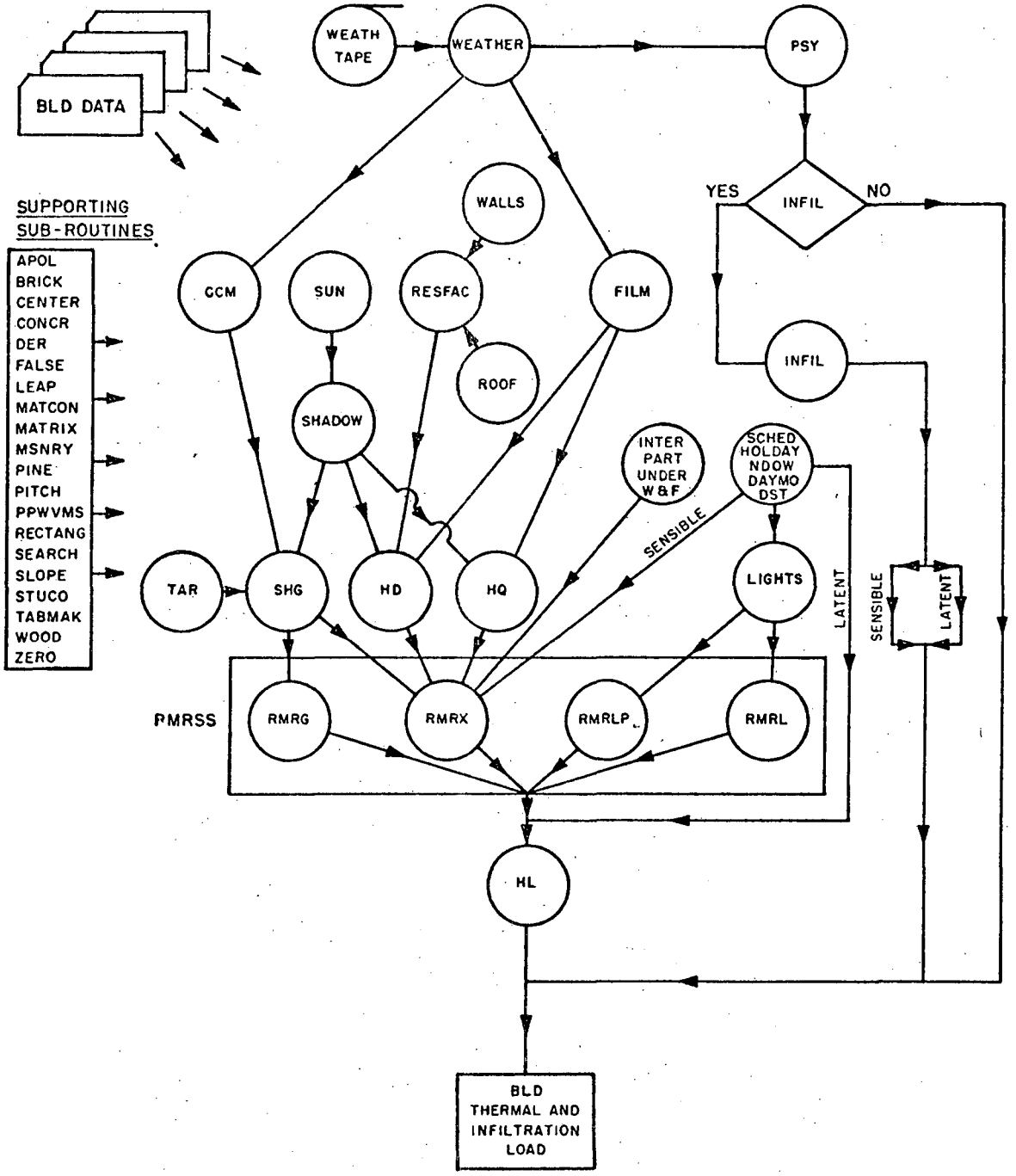


Figure 1: Interrelationship of Load Calculation Sub-program Subroutines

Copies are available on magnetic tape and cost about $700 including documentation. CAUTION: Never overestimate the usefullness of obsolete documentation for any computer program.

B. Universities

The University of Wisconsin received a National Science Foundation (NSF) grant titled "Modeling of Solar Heating and Air Conditioning" beginning in the summer of 1972 (Ref. 2). One result of that contract is a computer program called TRNSYS. The organization of the program is similar to a file handling system, having an executive and a list of subroutines. The input and output call sequencing is controlled by the executive, which allows various combinations of subroutines to produce the desired result. For example, models for a collector, pump, and control strategy can be studied as a combination. The program is presently about 800 cards long plus a sample data deck, about 200 cards long and represents the result of NSF's premier funding for research in solar energy for heating and cooling of buildings.

A DRAFT version of a card deck and manual was released in June 1974. It was written for, and runs on a U. of Wisconsin modified Univac 1110 computer. Copies are available on cards and cost $50. Presently the program is rather machine dependent. It was written by about five graduate students in mechanical and chemical engineering under the supervision of Professor Beckman.

Researchers at Colorado State University (CSU) have several computer programs and subroutines available for their own use. The funds were partially supplied by NSF and Eastman Kodak. The organization of the program is similar to a file handling system, having an executive and a list of subroutines. The program is analogous to the design of an electrical network. It operates from a "control" viewpoint, i.e.,

a control strategy is selected and the response of the system is studied. The program is about 8,000 cards long, runs on a CDC 6400, uses extended FORTRAN, and requires about five minutes of central processor time to calculate 15 minute intervals for a 24 hour period. Copies are available on request; however, detailed documentation is not available, and improvements are continually being added (Ref. 3).

Building loads are derived from a National Research Council (NRC) of Canada program, an ASHRAE program, and routines written at CSU. U.S. Weather Bureau tape are used for meterological input data. Output is available on X-Y plotters, CRT's printers, or microfiche. The program is presently being used to study the dynamics of a proposed 417,000 ft^2 office building. About two man years of development have been invested by CSU researchers. Tybout and Löf's article summarized a large amount of previous computational work dealing with solar house heating (Ref. 4).

The Jet Propulsion Laboratory (JPL) of the California Institute of Technology has a computer program for simulating hot water heating using solar energy. The Southern California Gas Company and NSF/RANN funded a small effort to explore possible effects of gas demand if solar water heaters were to be used extensively in the Los Angeles basin. The calculations performed apply to a ten unit apartment building. The program is called SAGE and is breifly discussed in reference 5. However, no detailed formal documentation on how to use the program

exists, hence a flow chart can not be presented here. The collector model used included transient analysis of heat demands and variations in storage volume. Questions of costs and limitations on the successful introduction of solar water heating in the Los Angeles area are discussed.

There are several other computer programs available at various universities across the nation. Almost all are the result of a master's thesis or similar project. A few are decendants of the post office program, although some of them exibit very little resemblance to their ancestors. Ohio State, Minnesota, and Massachusetts Institute of Technology have computer programs in various stages of development which deal with heating and cooling of buildings using solar energy.

One purpose of this survey is to emphasize that we need a large diffuse supply of educated engineers and architects to serve the large diffuse housing industry. It is hoped that many more universities will offer courses which allow an opportunity to study the effects of solar energy on building design in detail, presumably by using established and generally accepted computer programs as one of many tools.

C. National Laboratories

Los Alamos Scientific Laboratory (LASL) and the Sandia Corporation in New Mexico developed computer models to study solar communities. Subdivisions or groups of housing having utility services derived from solar energy are examined. Studies of energy collection at either individual houses or a central park are being performed. Programs for modeling collectors, heat storage apparatus, and fluid transmission lines are available. Cost sensitivity analyses and comparisons with the cost of gas, coal and electrical energy have been performed. Documentation describing the detailed use, operation, and availability of the programs is unavailable. Results of these calculations have been summarized in a few reports available from LASL and Sandia.

Argonne National Laboratory in Illinois has recently developed a light concentrating solar collector to bridge the gap between focussing and flat plate collectors (Ref. 6). Computer modeling of their collector will be performed during fiscal 1975. Predictions of the performance of their collector and its operation in a building heating/cooling system will also be calculated. No documentation is presently available.

Lawrence Berkeley Laboratory in California has a modified version of the Post Office program running on a CDC 7600. To calculate the response of a building for a 24 hour period using 15 minute integration periods requires about four seconds of central processor time and costs about $5. Separate programs are operating which calculate the performance of various solar collectors and the use of earth for heat storage. Digital programs

which simulate analog computer models of a solar heating system have also been run. Programs for studying the stratification effects in liquid heat storage systems will be written. The performance of a residential solar heating and cooling system presently being designed under an NSF/RANN contract will also be modeled, as funds permit, to simulate its performance in various California climates (e.g., deserts, mountains, coastal, and valley). No documentation exists describing the operation of the various programs.

Lawrence Livermore Laboratory in California is studying solar ponds. A minimal amount of computation has been performed to develop proposals. No documentation or public programs are available.

NASA Lewis in Cleveland, Ohio is developing computer models to study the performance of flat plate solar collectors, particularly the effects of selective surfaces. A system simulation computer program is also being developed for their use. No documentation or public programs are presently available.

NASA, Marshall sponsored a computer study of solar heating and cooling of buildings. The work was performed at Lockheed, Huntsville and has been reported in reference 7. This document describes the results of the calculations, not the details of how the program was written. No further work appears to be planned, and several attempts at tracing the author of this work failed. Hence no remarks can be made describing the details of this program or how to obtain copies in order to study it.

D. Private Sector

A variety of consulting firms provide calculational services of heating and cooling systems for buildings. Most of these follow the ASHRAE, Post Office or the NRC programs. One primary objective of these programs is to determine the minimum cost comfort conditioning system. Also to study the effects of window area, overhangs, roof insulation, and other architectural and construction variables. Solar collectors and heat storage tanks and other not generally widely and immediately available components have not been included in most consultants programs. Until an unimpeachable source exists to substantiate the performance of "commercially available" solar collectors, independent consultants should not repeat the claims of manufacturers.

A number of private corporations in the business of supplying heating and cooling apparatus are developing mathematical models of their products. Essentially all of this work is proprietary to the individual companies in support of their in-house engineering, research and development. Some results may appear in sales literature; however, assumptions, documentation, and copies of the programs will probably never be available to the general public (and presumably their competitors).

3. Program Notes

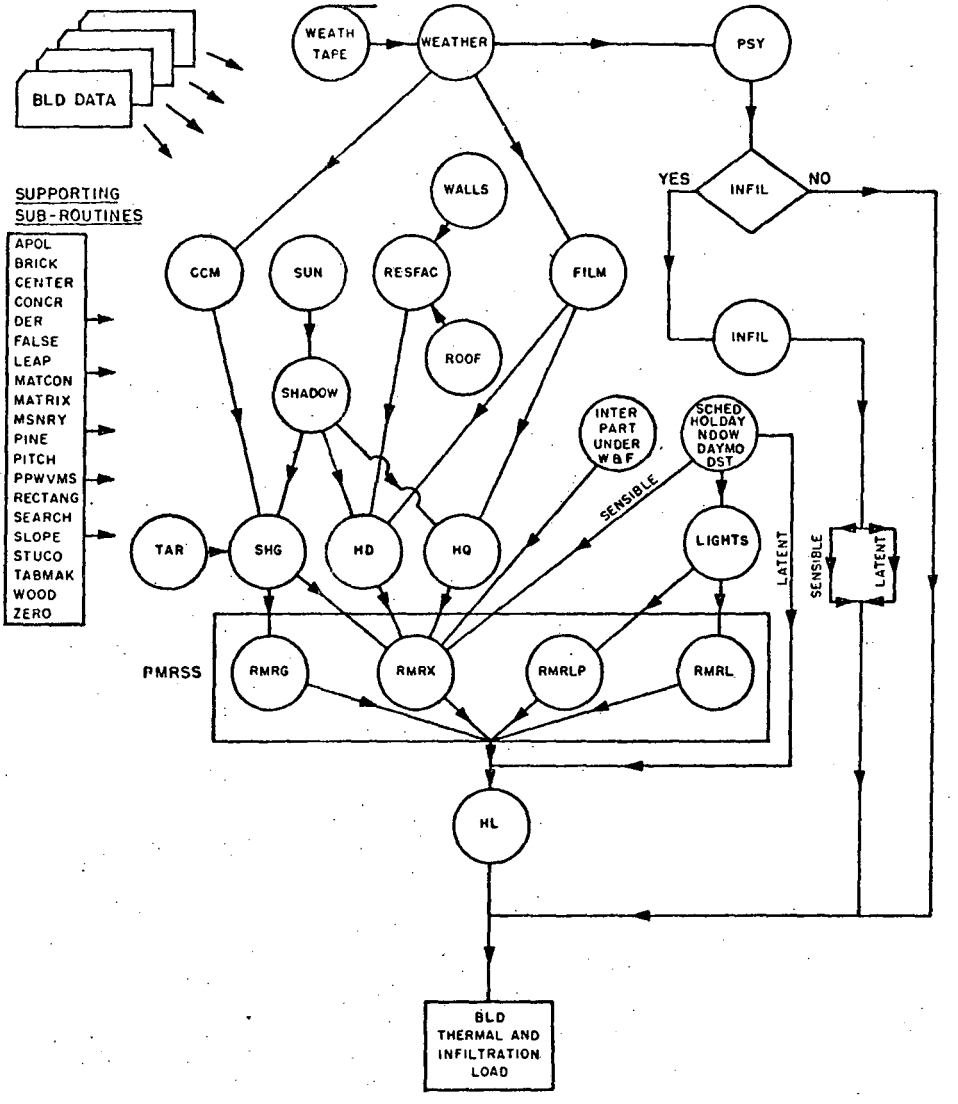
Typical "program notes" are included to illustrate a technique for comparing various programs to calculate solar heating and cooling of buildings. The concept should be considered as a generally useful method of creating a catalog of in-house research computer programs and commercially available computational services.

PROGRAMS FOR SOLAR
HEATING AND COOLING
OF BUILDINGS

SYSTEM
Post Office
June 1974

U.S. Postal Service

Flow Chart



Abstract

A detailed analysis of multi-zone temperature control, building construction details, air-conditioning equipment, and operating costs for industrial and commercial buildings. ASHRAE approved.

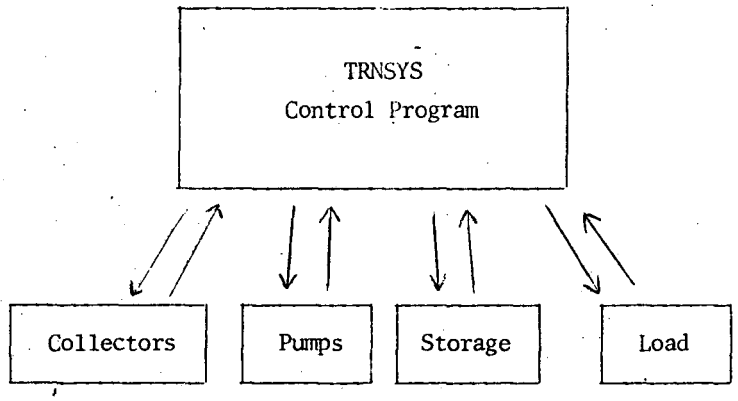
Programmable Variables

Collectors	Inputs: None Outputs: None
Storage	Inputs: None Outputs: None
Heating	Inputs: U.S. Weather Bureau magnetic tape records of climate. Detailed building construction data including wall cross sections giving thicknesses, material used, area of glasing, type of glass, drapes. Performance specifications of commercial equipment (fans, furnaces, ducts) are primary input variables. Outputs: Tables and/or graphs of heat load per hour. Variations in ducting circuits, fan sizes, zone temperatures, and use (occupation) patterns are easily studied.
Air Conditioning	Inputs: See heating inputs above Outputs: See heating outputs above
Cost Calculations	Inputs: Interest rate (scaler), equipment prices, fuel costs (scaler) Outputs: Expected operating costs and capital equipment depreciation during the lifetime of the building
Program	Language: Fortran IV Machine: CDC 7600, 6600, IBM 360/ , 370/ , Univac Time/run: For 15 minute integration periods. 24 hours requires minutes of CP time Cost/run: From about $ and up Documentation:
References	
Availability	U.S. Post Office does not provide copies. Various consultants and corporations presently have complete up-dated, and usually modified versions in operation including: Consultants Computation Bureau 594 Howard Street San Francisco, CA 94105 (415) 982-1293 Attn: Zulfikar Cumali General American Transportation Corp. 7449 N. Natchez Niles, IL 60648 (312) 647-9000 Attn: Mustafa Akalin Hitman Associates Columbia, MD (301) 730-7800 Attn: Metin Lokmanhekim

PROGRAM FOR SOLAR
HEATING AND COOLING
OF BUILDINGS

SYSTEM
U. Wisconsin
June 1974

University of Wisconsin



Abstract

A program for simulating the transient behavior of solar heating and cooling systems. It is based on a "building block" approach in which individual components (collectors, storage systems, controls) are modeled and the component models are assembled into a system model. Applies to single family residential buildings.

Programmable Variables

Collectors	Hottel-Whillier-Bliss Model, liquid collectors, edge losses neglected Inputs: Number of glass cover plates, tube spacing, tube diameter, angle of tilt, rear insulation, k factors, collector area Outputs: Efficiencies, heat outputs, temperature rise, mass flow rates
Storage	Liquid storage tank, three temperature stratification studied Inputs: Tank construction, wall thickness Outputs: Heat loss by conduction, convection and radiation
Heating	Applies to a small single family house having a flat roof, concrete slab floor, south facing wall having 15% glass area, stucco construction, no infiltration estimates. Inputs: U.S. Weather Bureau magnetic tape records of climate Outputs: Tables of heat loss per hour, demands for service hot water
Air Conditioning	Inputs: Outputs:
Cost Calculations	Total yearly costs can be compared for various collector costs ($\$/ft^2$) and for various fuel costs ($\$/10^6$ BTU). Mixtures of supplemental energy and solar energy can be studied to determine system design trade offs and cost minimums. Inputs: Outputs:
Program	Language: Fortran IV Machine: Univac 1110, Modified Time/run: For 15 minute integration periods, 24 hours requires minutes Cost/run: From about $ and up Documentation: TRNSYS manual, June 1974
References	
Availability:	DRAFT copies of the card deck and TRNSYS manual can be obtained for $50 from: TRNSYS Coordinator Engineering Research Building University of Wisconsin 1500 Johnson Drive Madison, Wisconsin 53706

4. Summary

No generally accepted programs are available to the public which can provide the desired detailed design information or meet the initial restrictions. Very few have adequate documentation to describe the operation, construction, and assumptions built into the program itself. In order to encourage the development of solar energy for heating and cooling of buildings, a widely dispersed group of engineers skilled in the use of generally accepted programs is needed. The design of small and medium office buildings, factories, and shopping centers is usually performed by local architect/engineering consulting firms. Computational services could be provided for these firms through their local universities, time-sharing networks, and regional national laboratories.

5. References

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2. "Modeling of Solar Heating and Air Conditioning", NSF Progress Reports, January 1973 and 1974, Engineering Experiment Station, 1500 Johnson Dr., U. of Wisconsin, Madison, WS 53706, 608-263-1586.

3. Personal communication, Gearold Johnson, Colorado State University, University Computation Center, Fort Collins, CO 80521, 303-491-6558.

4. R.A. Tybout and G.O.G. Löf, "Solar House Heating", Natural Resources Journal, Vol. 10, p. 268-326, April 1970.

5. Edgar S. Davis, "Project SAGE Phase I Report", June 1973, Environmental Quality Laboratory Memoranda No. 11, California Institute of Technology, JPL, 4800 Oak Grove Ave., Pasadena, CA 91103, 213-354-4321, and personal communication, Ab Davis.

6. Personal communication, Ari Rabl, Argonne National Laboratory, 9700 S. Cass Ave., Argonne, IL 60439, 312-739-7711.

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8. M.K. Selcuk and G.T. Ward, "Optimization of Solar Terrestrial Power Production Using Heat Engines", ASME, 345 East 47th Street, New York, NY 10017, Paper 69-WA/Sol 9, Journal of Engineering for Power.

9. R.C. Jordan (Ed.), "Low Temperature Engineering Application of Solar Energy", ASHRAE, 345 East 47th Street, New York, NY 10017.

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