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AEROSPACE TECHNOLOGY REVIEW FOR LBL WINDOW/PASSIVE SOLAR PROGRAM FINAL REPORT

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AEROSPACE TECHNOLOGY REVIEW FOR LBL WINDOW/PASSIVE SOLAR PROGRAM
FINAL REPORT

R. Viswanathan

June 1979

Prepared for the U. S. Department of Energy
under Contract W-7405-ENG-48

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Final Report

AEROSPACE TECHNOLOGY REVIEW FOR LBL WINDOW/PASSIVE SOLAR PROGRAMS

LBL Purchase Order 4811102

June 30, 1979

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FOREWORD

This final report was prepared by Hughes Aircraft Company, Technology Support Division under a Lawrence Berkeley Laboratory Purchase Order 4811102. It is submitted in complete fulfillment of the contract on the "Aerospace Technology Review for LBL Window/Passive Solar Programs". Acknowledgement is given to the scientists and engineers throughout Hughes Aircraft Company who contributed their knowledge and time to various parts of this project. Their names and topics of contribution are as follows:

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INTRODUCTION

This is the final report of a review by Hughes Aircraft Company of aerospace literature to uncover material pertinent to the Window and Passive Solar Programs of Lawrence Berkeley Laboratory. The aerospace industry had developed over the past twenty years new materials, concepts and measurement techniques, some of which, it was believed, can be used by the Department of Energy in their programs for efficient use of solar energy.

The project was of an exploratory type covering several diverse areas such as Optical Shutters, Soils, Thermal Storage and Transfer, Optical Properties of Materials and Clouds, Human Engineering, High Efficiency Light Sources and Solid State Electronics, Thermal and Optical Properties of Landscape and Building Materials and Measurement and Diagnostic Techniques. Due to the nature of the program, frequent contacts with monitors were maintained and the emphasis and direction were suitably altered as the program continued. The project consisted of two phases. In the first phase the pertinent literature references were selected and ordered, and in the second phase technology reviews in certain selected topics were conducted. This report covers the total contract period of September 8, 1978 to June 8, 1979.

The first step in the literature search was to generate the computer key words for each topic given in the Statement of Work. These key words varied; those appropriate for a DOE search could not be used for a DOD (TAB) search and still others were required for a NASA (STAR) search. Further, at the beginning of the program, difficulties were experienced with requests for computer runs. As it was imperative that publications be obtained as quickly as possible for the program, STAR and TAB, the abstracting journals, were physically searched by Hughes directly month by month from 1970 to 1978. The fields in which the searches were conducted are indicated in Appendices A and B. At a later point in the contract special computer searches were performed for specific topics. The topics of these searches are indicated in Appendix C.

This report is arranged into several sections, each section referring to one or more topics of the Statement of Work for clarity and to avoid duplication. Each section consists of a technical overview and the applicable references. All other references that were found in the NASA and DOD searches are listed in Appendix D, under appropriate section titles. Some open literature references are also included in Appendix D. It is to be noted that many of these references are not easily available in the open literature and that no attempt was made to make this list exhaustive. At times during the program it was felt that more specific topics with definite focus would have been more beneficial. Nevertheless, within the constraints of time and the exploratory nature of the program, suggestions for future work are given as a summary at the beginning of this report.

At the start of the program several articles were individually reviewed but this was partially discontinued during the second phase due to lack of time. All the individual reviews performed for this program are included in Appendix E. These are also indicated with asterisk marks in the lists of references under each section and in Appendix D. The thermal analysis program of Hughes Aircraft Company, which was used to analyse window arrangements, is given in Appendix F.

SUMMARY

The aerospace industry has developed over the past twenty years new materials, concepts and measurement techniques, some of which, it was believed, would be useful for efficient use of solar energy. With this in mind, the aerospace literature was searched by Hughes Aircraft Company to uncover material pertinent to solar energy programs of Lawrence Berkeley Laboratory. The project was of an exploratory character and it covered a wide spectrum of topics. These topics were relevant to the Windows/Lighting and Passive Solar programs of the Department of Energy.

Windows are essential parts of most of the residential and commercial buildings. They are visually prominent and functionally important elements of the buildings. They provide light and view and among other things, affect the psychology and aesthetics of the occupants of the buildings. For energy-efficient buildings, special care must be taken in the design of windows, due to their comparatively high thermal conductivity.

The effect of window frames on the thermal performance of a window has always been a matter of speculation. In this project, the thermal analysis program, TAP-3, of Hughes Aircraft Company was used to analyze a few simple window arrangements (Section 4). Such a program must be applied to well-defined window arrangements – with single, double, and triple glazings and with/without gases in between. With computer graphics, the isotherm diagrams can then be constructed. These results should be compared with experimental data to understand the thermal transfer problems associated with windows.

In this connection, it is valuable to demonstrate the feasibility of an integrated heat pipe (Section 4) thermal control system. Such a system would provide thermal transport and control in a completely passive manner by

utilizing the properties of the heat pipe switch, thermal diode and the variable conductance heat pipe. The performance characteristics of individual components of such a system are well-known, but the total system performance is yet to be demonstrated.

If the transmission characteristics of windows could be changed automatically according to the available daylight, it would be quite valuable for energy conservation. For such a purpose, the use of liquid crystals, photochromic, thermochromic and electrochromic materials (Section 1) as optical shutters for window applications is very attractive. However, further detailed studies are needed to evaluate the technical capabilities of these materials. The operating lifetime, sensitivity to UV, and operating temperature range are a few of these problems. The cost of fabrication of most of these high technology materials is often prohibitive. However, the requirements of light transmissions through the window for the building community are not very stringent. Once the technical limitations are reasonably understood by further research, an attempt could be made to cut the cost of fabrication for the nonstringent window applications.

As an alternate approach, the idea of heat pipes (Section 4) should be actively pursued for passive solar applications such as variable transmittance windows. Conceptually, a flat glass envelope can be rendered opaque, like frosted glass, or a good reflector, like a mirror, by the presence or absence of a fluid within an envelope. The movement of the fluid to a desired location can be accomplished by means of slight temperature differences. A demonstration program to prove this principle of thermal switch and its applicability as an optical shutter is quite straight-forward and would be worthwhile.

The optical properties of windows could be altered by applying suitable coatings to them. It appears that with regard to coating materials (Section 5) for window applications, the best efforts would be to develop methods of producing larger dimensioned windows from non-toxic halides. Concurrently, cheap durable IR and visible reflective coatings such as the halides and oxides should be pursued as well as cheap methods to apply them to larger surfaces. The cost of coating windows with a dielectric is normally high, whereas the polymer coatings can be applied relatively cheaply to existing windows as a coating, as a filler in glazed windows or in curtain-like sheets.

Future work in polymer chemistry should be directed toward improving the UV cutoff and the 8-12 μm transmission. Currently, work is being done at Hughes Research Laboratory on polymerization of organic materials for use as thin protective coatings on IR optics. Films which have good transmission in the 8-12 μm and 3-5 μm regions have been developed. Effects of surface finish of the substrate on the durability are being investigated.

In addition, future research should be directed toward the development of thermosetting, oxidation resistant polymers having no hydrolyzable functional groups within their molecular structure. Examples of such materials are the phenylene-X polymers such as polyphenylene oxide and polyphenylene alkalene. Isomer configuration is of course crutial to the achievement of the property objectives. Such materials have potential use in window sealants and glazing protective coatings, geothermal well gasket and sealant materials, etc.

Another area of research is in IR opaque materials. Such materials can be blends of compatible polymers having significantly different IR absorption spectra. Blends with up to five different polymers could likely be developed which exhibit an essentially continuous absorption spectrum above 3 μ. Another approach to the development is to synthesize a single polymer with a large number of different types of functional groups. With the current technology, individual polymers can be used, but thick films (~ 40 mils or more) are required to provide complete opacity.

A third potential area of research involves the development of an IR transparent polymer, such as the one which has no C-H, C=0, C-0 -C≡N, C-Cl, C-F, Si-O, etc. A possible candidate is a completely brominated hydrocarbon polymer. Other candidates would likely have to be inorganic polymers although it is not known with certainty that IR transparency is feasible.

The long-term durability of the coatings is very important for cost-effective window designs. With regard to environmental testing of coatings (Section 5), a number of military specifications are available for military hardware. However, no set of standard environmental tests now exists for solar conversion coatings. This makes it difficult to provide a coating-to-coating comparison for an overall evaluation of the state-of-the-art on durability. A standard set of durability specifications for solar coatings needs to be generated and round-robin tests must be performed. The testing facility must have the capabilities not only to subject the coatings to proper tests, but also to measure their optical properties before and after the exposure.

The optically and thermally efficient windows, discussed in earlier paragraphs, are only as valuable as the amount of daylight available in a given location. The daylighting is very much dependent on the optical properties of atmosphere and clouds. An understanding of the properties of atmosphere and clouds and how they affect the terrestrial illumination and whether they can be properly modeled to predict the available daylight are a few of the topics which require careful further study (Section 5). The effect of moisture, gases, etc., on the optical characteristics of atmosphere must be studied using the clear atmosphere models with appropriate profiles to represent the temperature and concentration gradients. Further work on the aerosols' contribution to decreasing the total solar radiation received at the surface is necessary. This could be done by correlating the satellite measurements, pollution monitoring measurements and hourly values of solar radiation. The available atmospheric models do not relate the percentage cloud cover to the total solar radiation over averaging times less than a month. An attempt must be made to establish satisfactory functional relationships between percentage cloud cover, thickness, cloud type and distribution with respect to sun angle, using satellite and ground-based measurements of solar radiation.

Another source of potential energy conversion is in the lighting of buildings in the residential, commercial, industrial and public sectors. Energy used in artificial lighting can be substantially reduced while maintaining or improving high quality illumination. Fluorescent gas discharge lamps satisfy, at present, two-thirds of all lighting needs in the United States. Fluorescent lighting technology has advanced greatly in the past forty years. However, further advancements are quite possible (Section 7). Production costs of integrated or hybrid circuits capable of handling appreciable power levels are continuously decreasing to the extent where the replacement of the ballast and associated passive components by an active integrated circuit may become feasible. Based on this fact, the following attempt must be made. A computer model of a typical fluorescent lamp including such parameters as high starting voltage, negative slope current-voltage, aging and other electrical characteristics should be developed. Using the principles of circuit synthesis with the computer, the response requirements of a four terminal network or "black box" interposed between the lamp and the power system should be developed subject to the nominal constraints such as power input 0-100 watts, voltage input 110-270V, frequency 50 Hz-10 kHz, reduced EMI coupling back into the power system, minimum power dissipation and high initial peak starting voltage. This would establish the response function of the network. Then it can be determined if it is physically realizable. If so, a set of design parameters can be developed for fabrication and testing.

The design of passive solar systems must consider the properties of the buildings/landscape materials quite seriously. The two most important properties of interest for this program were the optical and thermal characterisitcs of these materials (Section 8). Although thermal properties of building materials can be found in engineering handbooks, those for landscape materials are not easily available. It may be worthwhile to develop a program for measuring thermal and radiative properties of landscape materials. As regards optical properties, the available information for many materials in the range of 0.2 to 15 μm are very much incomplete. It appears no information is available on reflection or emissions for building materials. To obtain this information, a measurement program is necessary. To evaluate a building material from an energy standpoint and to study the quantitative effects of the environment on the material optical properties, both field and laboratory measurements must be performed. If portable instruments are used for field measurements, they should be thoroughly checked and correlated with absolute laboratory measurements quite systematically.

Next only in importance to the efficient use of the available solar energy by careful considerations of window design, window coatings and optical shutters is the topic of thermal energy storage. This problem is quite well treated in open literature. The focus in our program was only on the phase change materials usable in the ambient temperature range of 40^{o} to $90^{o}F$. There are large numbers of paraffins and salt hydrates whose properties are well documented in literature for this purpose (Section 3). Metal hydrides also offer interesting possibilities for thermal storage.

Encapsulation techniques for these materials and their stability after many thermal cyclings need careful study.

In this connection, properties of soils are of importance. Not only can soil be used for thermal energy storage, but also it is valuable for passive solar designs of buried or bermed structures. The thermal transport properties of soils (Section 2) are severely influenced by the moisture content. However, this point is often forgotten or neglected. Carefully designed experiments on soil properties as a function of moisture content and an appropriate mathematical modeling will be quite useful for passive solar designs of buildings.

Measurements/diagnostic techniques for various parameters representing thermal and other properties related to buildings need special attention to make the window/passive solar programs successful. In this project, special attention was given to the photoacoustic, infrared and flow techniques (Section 9). The value of photoacoustic techniques for measurement of radiation distribution in a room is doubtful. However, this technique is suitable for evaluation of window and coating materials and measurement of optical absorption properties of materials such as paint and plant matter. As regards infrared technology, recent advances made for military and space applications are too expensive due to their high accuracy and resolution. No commercial spinoffs of this latest technology are anticipated in the near future. An attempt is being made at Hughes Aircraft Company to solve the problem of emissivity/true temperature measurement. This developmental program is intended to put a new product in the market. Techniques are available on the commercial market for pressure, temperature and humidity measurements. However, for liquid and other flow measurements, new technologies are being developed. The ultrasonic doppler technique is one such technique which would require further study.

Consideration of underground buildings and other structures with limited amount of glazing for energy efficient passive solar designs is not uncommon. In such cases, the topic of human engineering (Section 6) becomes quite important. Living in underground buildings and other structures with limited amount of glazing can affect the performance and behavior of the occupants. There are very few experimental data in the literature concerned with the effects of working in a 65° to $85^\circ F$ environment. Particular effort must be made to study the long-term effects of exposure to radiant heat, which is known to cause fatigue. Long-term studies of miners and the psychological effects (if any) of their occupation would give a clue to the performance changes due to isolation and confinement. In addition, very little data were found on asymmetric radiation and on the combined effects of heat stress and confinement. It would be worthwhile to do specific literature searches on some of these topics as applied to solar energy systems before embarking on laboratory or field experimentation, which would be quite expensive.

SECTION 1
OPTICAL SHUTTERS

SECTION 1. OPTICAL SHUTTERS

INTRODUCTION

A literature study for electro-optical shutter material was made with emphasis on references pertinent to the Window/Passive Solar Program. Materials and systems were identified whose optical properties change with light, heat or applied voltage and could therefore be used for windows with a variable transmittance. Systems considered for such optical shutters include liquid crystals, suspended crystals, electrophoretic displays and electrochromic displays. Basic properties of the above systems were reviewed with regard to their application to windows.

A. LIQUID CRYSTALS

Liquid crystals (LC) have been widely used in displays such as watches, calculators, flat panel television and devices like page composers, electronic reticles, waveguide switches, etc. LC advantages include low operational voltage, low power consumption, rapid response and good resolution capability. Basic liquid crystal properties, their surface alignment and a review of their electro-optical applications are summarized in reference 1.

1. TWISTED NEMATIC FIELD EFFECT LC

In field effect devices, the electric field rather than the electric current determines the orientation of the liquid crystal. The effect that is commercially most significant is the rotation of polarized light by the twisted nematic alignment and the disappearance of this effect when a field is applied. For window application both polarizers should have high light transmission, above 50 percent, such as Polaroid HN55[2]. To achieve maximum transmission through a system of polarizer/LC/analyzer, the light transmission through the polarizer must be parallel to the director at the point where the light enters the liquid crystal, and the analyzer must be positioned to transmit the rotated plane at the exit.

Application of a twisted nematic field effect LC as an optical shutter for windows is demonstrated in Figure 1. The "optical shutter" is assembled from 2 indium-tin-oxide (ITO) coated glass electrodes separated by 1/2 mil Mylar spacer and filled with biphenyl liquid crystal mixture, BDH E7. Liquid crystal alignment is parallel to both glass electrode surfaces, which are rotated 90° to each other. An HN55 polarizer and an analyzer are placed on the two sides of the cell with a polarization direction matching the LC alignment. Transmission through the above optical shutter is between 37 to 41 percent in most of the visible region. Applying a low ac signal, less than 5 volts at 100 Hz, to the LC cell decreased the transmission to less than 10 percent in the 550 to 700 nm wavelength region. Transmission characteristics can be altered by variation of the polarizer film, its lamination onto the glass and by changing the reflection of the conductive electrodes. Limitation of twisted nematic LC for optical shutters requires further detailed studies, such as

a. Viewing angle effect,[3]
b. Uniform alignment without reverse twist,[4]
c. Operating temperature range,[5]
d. Long term stability of polarizer,
e. Liquid crystal lifetime.[6]

2. LIQUID CRYSTAL COLOR DISPLAYS

Of the many liquid crystal color displays[7,8], the guest-host effect is the best applicable to an optical shutter. The principle of operation is similar to the twisted nematic LC, except one of the polarizers is replaced by a pleochroic dye dissolved in the liquid crystal. Using a guest-host system for an optical shutter enables color selections according to the dye

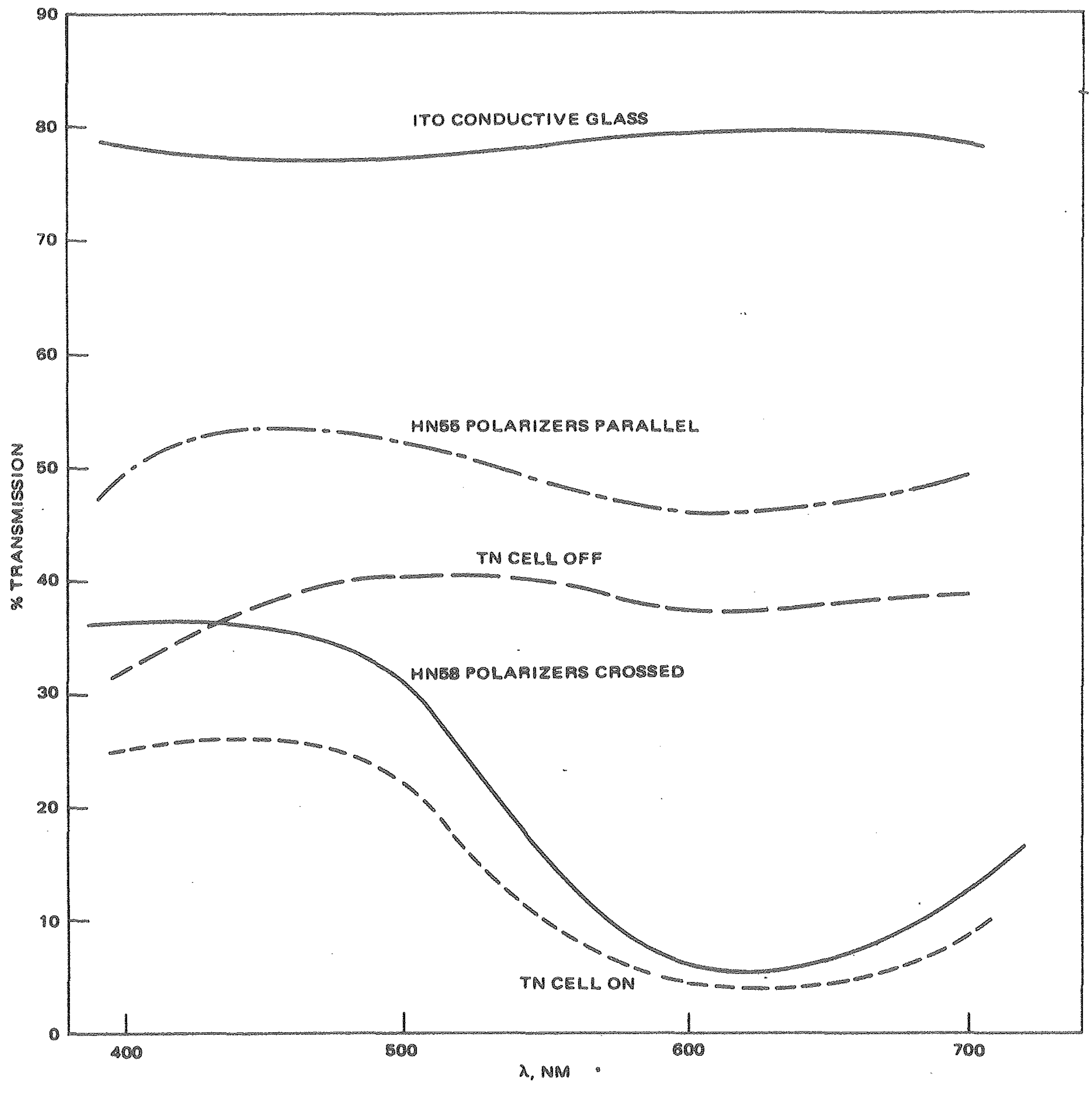

Figure 1. Transmission characteristics of a typical twisted nematic liquid crystal cell with signal off and on. Twisted nematic cell includes two HN55 polarizers on the two ITO conductive glass electrodes with 1/2 mil BDH E7 liquid crystal.

used, but light transmission through this device is often lower than in the twisted nematic system and more wavelength dependent. Transmission vs. wavelength characteristics of a typical dye-LC cell are shown in Figure 2 together with HN55 polarizer. Advantages of this system include low voltage and low power consumption coupled with no angle dependence. Limitation of this device is due to lack of photostability of the dye. Other problems of alignment, wide temperature range liquid crystal mixtures and stable polarizers should be further investigated.

3. DYNAMIC SCATTERING DISPLAYS

In a typical dynamic scattering liquid crystal device[9-12], prior to application of an electric field, the liquid crystal is aligned and appears transparent. When activated, the turbulent motion of the liquid crystal causes diffuse scattering of the light. However, about 90 percent of the light is scattered in the forward direction, which may limit applications to a window-optical shutter, unless some special designs can be made which effectively utilize this diffuse scattering effect.

4. PHOTOACTIVATED LIGHT VALVES

Photoactivated liquid crystal light valves refer to a high resolution medium for temporary image-storage used mainly for projection displays[13, 14] and real-time optical data processing systems[15, 16]. Such light valves are not recommended as optical window shutters due to their size limitation, high technology and cost of fabrication, as well as problems with temperature and thickness control in such applications.

5. LIQUID CRYSTAL FILMS

Cholesteric liquid crystals are incorporated into elastomeric films that change color with temperature variation by reflecting a certain wavelength of light[17-20]. Application of liquid crystal films are widespread as temperature sensing devices in the medical field. Patent literature[18] also refers to other applications as optical filters, color displays, surface

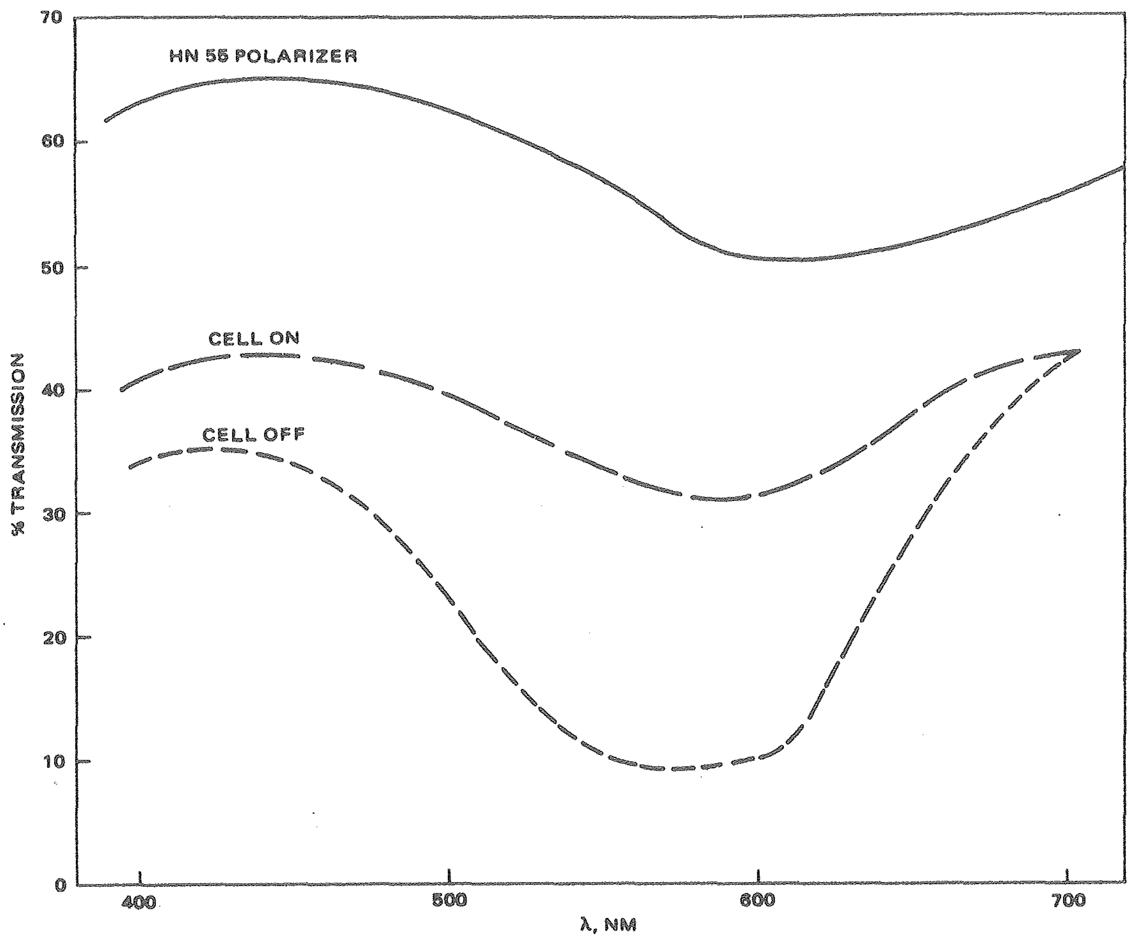

Figure 2. Transmission characteristics of a dye cell in the visible region. LC dye cell assembled from two ITO electrodes using one HN55 polarizer and 1/2 mil BDH E8 liquid crystal and DBH D-3 dye.

flaw detection systems and decorative items. For application in an optical window shutter, the cholesteric liquid crystal film has several basic problems such as:

a. The film is not highly transmitting in the off state; that is it scatters the light to give an iridescent color.

b. Cholesteric liquid crystals are circularly dichroic for some wavelength region, therefore one circularly polarized component of the incident light is transmitted whereas the other is scattered.

c. The LC film color varies greatly with temperature.

d. Light transmission is largely angle dependent.

B. SUSPENDED CRYSTALS

Colloids, mostly herapathite suspensions, which exhibit electric dichroism are used in suspended crystal systems[21-23]. Progress in this field up to 1976 showed reduction in voltage and power requirement, but problems of field stability and operational lifetime were still prevalent. Research Frontiers, Inc., privately demonstrated a good, transmission mode, suspended crystal display[22] that changes from colorless to blue with good color uniformity; however, there are no publications by this research group to this date.

C. ELECTROPHORETIC DISPLAYS (EPID)

The electrophoretic display is a light modulating display in which changes in transmission and color occur as a result of the migration of pigment particles in a dye solution under the influence of an electric field[24]. Desirable features include high contrast, wide viewing angle, wide operating temperature range, memory and low power consumption. An EPID consists of a sandwich cell between two electrodes filled with a suspension of sub-micron pigment particles in a colored liquid. The pigment forms a lyophobic suspension in which the particles are electrically charged. Application of a field causes the migration of the particles to one electrode and the EPID assumes the pigments' color. An important feature of this display is its memory, but it is limited in its lifetime, photostability and reliability of the suspension system. Elecrophoretic systems are not feasible for window optical shutters, since the pigment particles are always present on one of the two electrodes, resulting in no light transmission through the display.

D. PHOTOCHROMIC MATERIALS

Many compounds in the solid or liquid state change color when exposed to electromagnetic radiation. Photochromism is the term used to describe the phenomena of induced coloration and reversion to the original state by radiation stimulations. This phenomenon is also referred to as phototropism or thermophototropism. The "writing" light may be visual or ultraviolet light, and the "erasing" light is usually that of a longer wavelength. That is,

$$\underset{\text{(colorless)}}{\text{State 1}} \underset{h\nu_2 \text{ or heat}}{\overset{h\nu_1}{\rightleftharpoons}} \underset{\text{(colored)}}{\text{State 2}}$$

$$\nu_1 > \nu_2$$

The erasing process is sometimes called "bleaching," if the original state is colorless. The term "thermophototropic" is also used when erasing is caused by heat instead of light.

Numerous organic and inorganic materials show photochromic properties. An extensive review of these materials is available in literature[25]. Among better known materials are:

Organic: spiropyrans, anils, indanthrene dyes, polymethine dyes

Inorganic: titanates ($SrTiO_3$, $CaTiO_3$), CaF_2, $LiNbO_3$, silver halides (crystals), HgI_2, HgS (powder), hackmanite, etc.

Applications of photochromic materials which have appeared in the literature where mostly in the area of digital data storage, replacement for cathode ray tubes, optical displays, reversible and fixed large screen displays, optical recording/processing, recording of holography, special optical glass, optical filter, photoelectric shadowgraphs, passive shutters in Q switching lasers, and protective coating for goggles to prevent flash-blindness from nuclear explosions.

The photochromic materials will be very ideal as a passive optical shutter for saving energy. Photochromic materials are promising because most of them can be fabricated into polymer films or glass forms. Corning Glass Company developed variable transmission silicate glasses sensitive to sunlight which darken when exposed to sunlight and return to transparency again when no ultraviolet irradiation is present. This type of glass will give a self-adjusting optical shutter. In these glasses, color change is activated by silver halide crystals dispersed and stabilized in borosilicate glasses. In the variable transmission silicate glasses, the color change is accomplished[26] by optically pumping color centers by electron transfer from europium (II) or cerium (III). Some similarity in applications to solar windows also may be found in publications by Levin, et al., who used colored LiF, some two component, reversible color-center systems used for thermophototropic temperature coatings for the space environment[27,28]. Such a coating was capable of providing active thermal control on a spacecraft surface. It functioned as a variable absorptance coating compensating inversely for changes in solar irradiance of the surface. The ability of a thermophototropic coating to control temperature[29] and the use of phase-change coatings for variable thermal control of spacecraft[30] are well documented in early literature.

A thermophototropic VADO (Variable Density Optical Material) was developed by Marks Polarized Corporation by suspending metal halides in plastic matrix. The film was darkened by light or other energy (heat), and was restored to the original transparency by itself upon removal of external excitation. No fatigue was reported when the color switching was cycled 70 times over 6 weeks. One disadvantage of this system appeared to be a requirement for an auxiliary electrical energy input.

E. THERMOCHROMIC MATERIALS

The color change in photochromic materials is caused by light, whereas in thermochromic materials, the stimulant is heat. The material changes color when heated and reverts to its original color on cooling. This reversible dependence of color on temperature is known as thermochromism.

Most photochromic materials are also thermochromic. Thermochromic materials also embrace both organic and inorganic materials. They can be in solid, liquid, and solution forms. The materials known and widely reported are:

> Organic, spiropyrans, benzoquinones, dioxanthylenes, anils, 2,2'-bis-(benzothiazolyl) disulfide dyes, non-aqueous solutions of the stearates of Cu, Co, Ni, Cr^{III} and Fe^{III} in decalin, and cholesteric liquid crystals.
>
> Inorganic: Cu_2HgI_4, various metal chlorides such as those of Ca, Mg, Co, Ni, Cu.

Thermochromic optical shutter systems for sunlight filters can be self-adjusting without a separate sensor device. Their usefulness as energy saving devices depends on energy absorbancy (effectiveness as a light filter) or light reflectivity.

Several problems may be encountered in the attempts to use cholesteric liquid crystals in a shutter system. They degrade too easily by UV light, and color change occurs only in a narrow temperature range. Most organic systems tend to be UV sensitive (decomposition by UV light) or have fatigue problems.

Inorganic systems are more promising in this aspect. Laminated glass with variable light transmission was used to protect against severe heating up of rooms(31). The laminated glass, which contained chlorides of Ca, Mg, Co, Ni, Cu, or their mixtures, was nearly transparent at normal temperature and turbid at an elevated temperature. The turbid glass became light reflective.

The use of phase transormation of metal semiconductors such as Cu_2HgI_4 in vanadium oxides in infrared recording applications is also known. The phase transition causes change in reflectance. The phenomenon may also be useful for passive optical shutters.

F. ELECTROCHROMIC MATERIALS

Some compounds, both organic and inorganic, have different absorption spectra depending upon the oxidation state. For instance, a colorless material may become colored by electrochemical oxidation during passage of the electric current and restored to its original colorless state by reversing the direction of the current flow. This reversible redox reaction is known as electrochromism. The applications of electrochromism have been in the area of memory, storage devices, and information displays. Nothing on the application of electrochromism in optical shutters has been published. Its use as a window shade would require a separate sensing device which is connected to a power supply to power the electrochromic window.

The principle of electrochromism and its applications are reviewed widely in the literature[32]. In the usual electrochromic display design, the colored species is deposited on either the front or back electrode and, therefore, light transmission is either very limited or absent. Variation in this design is feasible with the use of one transparent electrode and a second electrode incorporated into a conductive frame.

Hughes Research Laboratory and Rockwell International have done extensive R&D on viologens as electrochromic display materials. The problems of using viologens were the oxygen sensitivity (irreversible oxidation to colored species) of the compounds and the fatigue from repeated switching. American Cyanamid Company and Optel Corporation have worked on tungsten oxide in the solid state film systems, such as SnO_2, WO_3, MgF_2, Au, MgF_2, and SnO_2, WO_3, SiO, Au, for many years. Their main objective was to use the systems for digital displays, especially for wristwatches. Judging from the fact that no practical display devices of this sort have appeared on the market, serious technical problems still exist. The problems appeared to be in fabrication technology and cost. It was said to require at least 2 million dollars to perfect the technology. The fabrication problems will be even greater for windows whose size is several orders larger. In addition, electrochromism has a few serious problems such as reversibility side reactions, and operating lifetime, and its industrial applications are limited[33].

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SECTION 2

SOILS

SECTION 2. SOILS

INTRODUCTION

Heat and mass transfer in soils are of interest in a number of engineering applications, such as underground containment of radioactive waste, thermal energy storage in unprepared earth, structural support of pavements, and underground electrical transmission lines. The field of soil science, oftentimes referred to as pedology, is very broad, and the background literature is very extensive and mainly unclassified. It was found that an understanding of soil thermal engineering requires a familiarity with soil chemistry, electrochemistry, geology, hydrology, and thermodynamics, as well as a familiarity with mathematical techniques for handling complex heat and mass transfer problems.

The scope of this technology review was directed to the two areas of: (a) soil properties data base, and (b) analytical techniques for heat and mass transfer in soils. Since both of these topics are very broad, only the major features of each area will be discussed. Many of the literature sources cited in this review contain extensive bibliographies which can be consulted for more detailed information. An additional topic, (c) measurement techniques, is also briefly discussed.

A. SOIL PROPERTIES DATA BASE

A review of the literature[1-3] indicates that such a data base may already be available at the U.S. Department of Agriculture in the form of soil survey maps. The Department of Agriculture uses the pedological classification system for soils. This system, which groups soils on the basis of climatic influence as well as textural properties, is based on the vertical soil profile, in which the soil is classified according to the different layers or strata existing at various depths. Soils of like color, texture, structure, number and arrangement of strata, and geology of parent material are said to be the same soil series, regardless of where the soil is found. A soil series is named after the geographic location where it was first recognized and described. An engineer familiar with the composition and texture of a given soil series can get a fairly good idea of the thermal resistance of the different strata from the basic information provided in the next several paragraphs.

Soil texture is related to the size of the soil particles, and the nomenclature used for classifying particle size is shown in Table I. Cobble and boulder are two other particle-size categories; the particle diameter of cobble ranges from 3 inches to 8 inches, and the particle diameter of a boulder is 8 inches or more. A coarse-grained or granular soil is one in which gravel and sand predominate. A fine-grained or cohesive soil is one in which clay and silt predominate. Quartz is the most common material found in coarse-grained soils found in humid climates. The minerals found in coarse-grained soils vary to a large degree. For instance, gypsum ($CaSO_4 . 2H_2O$) is the main component of New Mexico white sand, while calcium carbonate ($CaCO_3$) is the main constituent of coral and shell beach sands. Clays have an affinity (attraction) for water. The three basic types of clay are Kaolinite, Illite, and Montmorillonite. Clays play an important role in the movement of soil moisture.

A convenient classification of soil types is found in Table II. This table also lists a few of the physical handling characteristics of each soil type.

The main determinate of soil thermal resistivity is particle size; particle shape exerts only a secondary influence[1, 2, 4]. A compacted (i.e., dense) soil consisting of large-size particles in intimate contact with each other and small size particles filling the interstices is the most desirable type soil from the viewpoint of low thermal resistivity. Dark soils indicate the presence of decayed organic matter and a soil of relatively high thermal resistivity in comparison with a soil with little or no organic matter present. This is illustrated in Figure 3, in which the thermal resistivity of dry Russian black earth, which contains a great deal of organic matter, is

TABLE I. PARTICLE-SIZE CLASSIFICATION OF SOIL TEXTURAL TYPES

Particle-Size Classification	Diameter of Particles, Millimeters (mm)	U.S. Standard Sieve Size	
		Passing	Retained On
Gravel	Larger than 2.0		No. 10
Sand:			
Coarse	2.0-0.42	No. 10	No. 40
Fine	0.42-0.074	No. 40	No. 200
Silt,	0.074-0.005	Cannot be separated by sieving Determined by settling velocity in soil-water suspension	
Clay,	Smaller than 0.005		
Colloidal,*	Smaller than 0.001		

*Colloids are usually included in clay fraction in test reports of mechanical analysis.

compared to that of typical dry soils in the U.S. The thermal resistivities of typical soil constituents are listed in Table III. The best material for thermal backfill for buried electrical transmission lines is a mixture of quartz sand and kaolinite clay. In Table III, it is seen that the thermal resistivity of quartz is the lowest of the various soil constituents and that quartz is the natural choice from a heat dissipation point of view. The addition of kaolinite, a non-swelling clay, aids the retention of water in quartz sands and also permits a greater degree of compaction of the sand. Silts have very undesirable thermal characteristics, namely high thermal resistivity in the dry state and noncompactibility for the wet state.

The effect of moisture content on the thermal resistivity of soil is illustrated in Figure 4. There are three types of soil moisture: (1) hygroscopic water which is absorbed and tightly bound to the soil particle surface, (2) capillary water which is held in the pore or interstices between soil particles, and (3) gravitational water which is free to drain under the influence of gravity. Heat transfer in soils is strongly influenced by the movement of capillary water. Gravitational water is associated with the water table; that

TABLE II. FIELD IDENTIFICATION OF INORGANIC SOIL TEXTURAL TYPES

	General Characteristics				
Textural Type	Main Fractions*	Appearance, Dry Condition	Rubbed Between Fingers, Dry Condition	Squeezed in Palm of Hand, Moist Condition at Field Capacity	Rolled into Ribbon, Moist Condition
Sandy soil	At least 85% sand particles	Crumbly with no clods or lumps; individual soil grains visible to naked eye	Gritty; soil grains readily felt	Can form cast; crumbles with least amount of handling	Cannot form ribbon
Sandy loam soil	At least 50% sand particles; not more than 20% clay	Mainly crumbly and loose; soil grains readily seen and felt	Gritty; soil grains readily felt	Can form cast that will bear careful handling	Cannot form ribbon
Loam soil	At least 80% sand silt in about equal proportion; not more than 20% clay	Mainly crumbly; some clods or lumps	Fairly smooth but some gritty feeling; lumps easily broken	Can form cast that can be handled freely	Cannot form ribbon
Silt loam soil	At least 50% silt; not more than 20% clay	Quite cloddy but some crumbly material	Lumps easily broken and pulverized; thereafter floury texture and soft feel	Can form cast that can be handled freely; wet soil runs together and puddles	Cannot form perfect ribbon; it has broken surface, i.e., cracks appear

*Based on the textural classification of the U.S. Bureau of Public Roads.

(Continued next page)

Table II, concluded

Textural Type	General Characteristics		Rubbed Between Fingers, Dry Condition	Squeezed in Palm of Hand, Moist Condition at Field Capacity	Rolled into Ribbon, Moist Condition
	Main Fractions*	Appearance, Dry Condition			
Clay loam soil	20 to 30% clay	Fine-textured soil; quite cloddy but some crumbly material	Lumps hard; not easily broken	Can form cast that can be handled freely; soil plastic	Can form perfect rib-bon but breaks easily
Clay soil	30 to 100% clay	Fine-textured soil; breaks into very hard clods	Lumps very hard; difficult, if not impossible, to break	Can form cast that can be handled freely; soil plastic; sticky when wet	Can form ribbon that will support its own weight
Silt soil	At least 80% silt	-	-	-	-

*Based on the textural classification of the U.S. Bureau of Public Roads.

Refer to text for: shaking (dilatancy) test; shine test; dry-strength test.

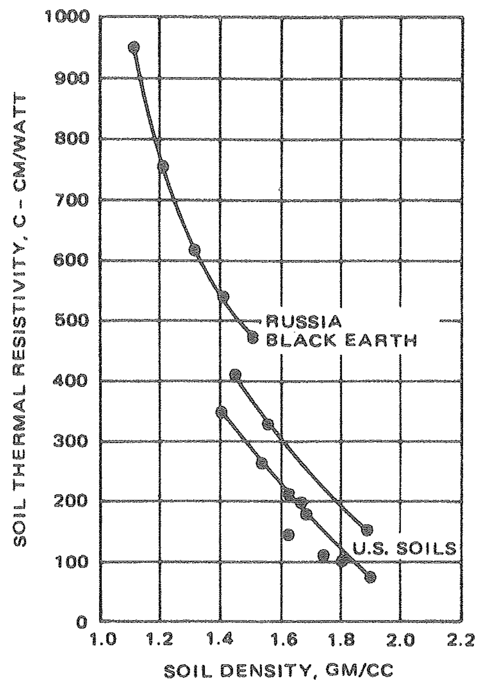

Figure 3. Comparison of thermal resistivity of Russia black earth and United States soils, zero moisture

TABLE III. THERMAL RESISTIVITY OF TYPICAL SOIL CONSTITUENTS

Material	°C-cm/watt
Quartz, average	11
Granite	25-58
Limestone	45
Sandstone	58
Mica	170
Water	165
Organic material	400, wet, to 700, dry
Air	4,000

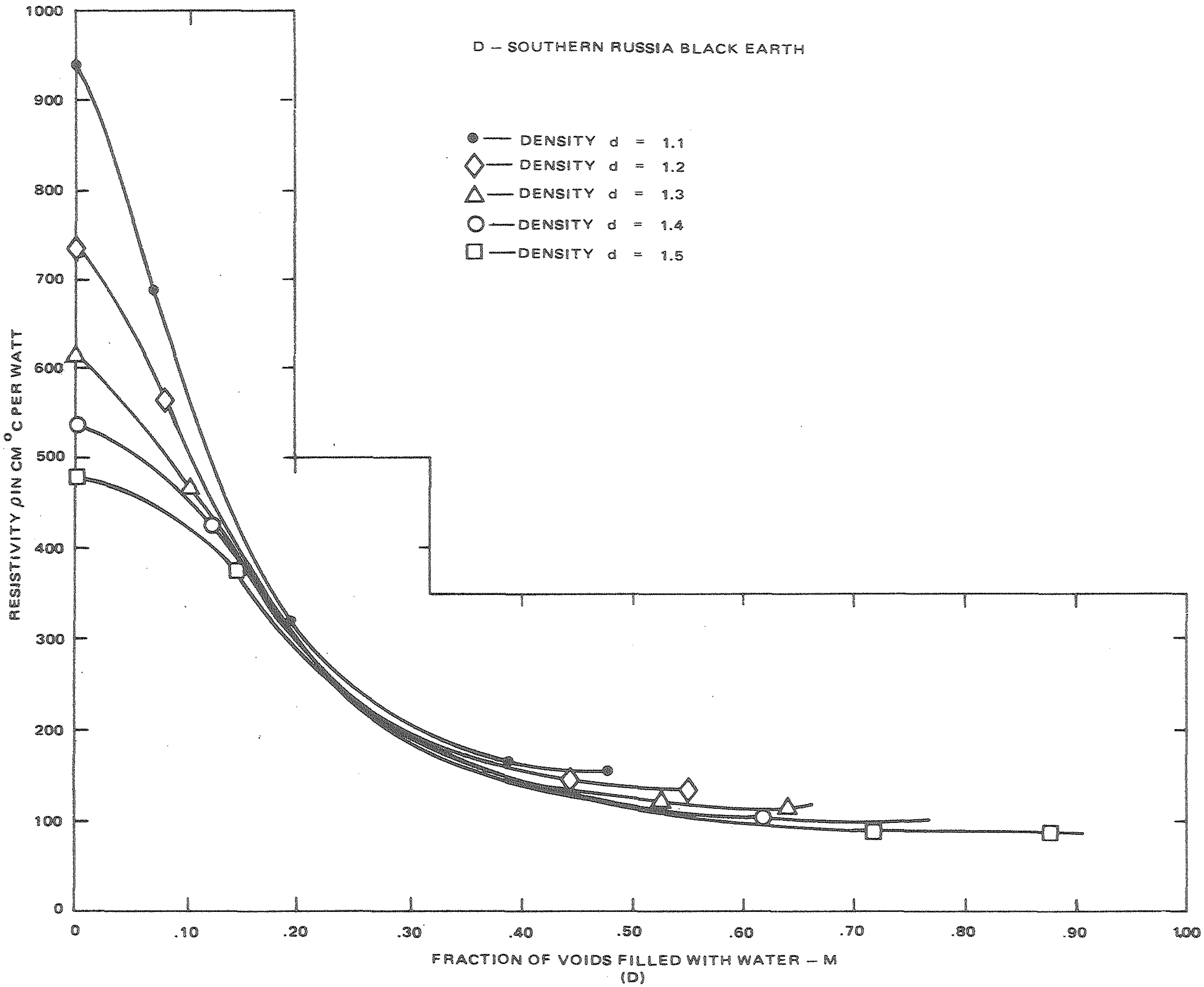

Figure 4. Soil thermal resistivity vs. moisture content

is, where the soil is completely saturated with water. The depth of the water table below the ground surface (all operating water wells must penetrate the soil to the level of the water table) is strongly affected by climatic variations, ground cover, and soil porosity.[2,5]

The design of soil mixtures is very complex. For instance, clays have electrical properties which affect the movement of capillary water.[2,6-8] The amount of moisture and thus the thermal resistivity of a soil is strongly influenced by the type of ground cover at the surface. The rate of moisture loss (transpiration) from a soil covered with trees is much higher than a soil covered with grass, which, in turn, is higher than that for bare soil.[2] This will have a heavy impact on the passive solar design of buried or bermed structures as well as on thermal storage systems using unprepared earth. For instance, a dry soil of high thermal resistivity would be favored in the winter to reduce heat losses from the building; on the other hand, a moist soil would be favored in the summer to aid cooling of the building. The choice of ground cover is not based on thermal considerations alone; aesthetic considerations, drainage, and erosion protection must be included as well.

B. ANALYTICAL TECHNIQUES

In many ways, heat and mass transfer in soils can be viewed as heat and mass transport in porous media. However, the latter is often concerned basically with two component systems, i.e., a porous solid saturated with liquid or, in some cases, a porous solid containing a second component which exists as both liquid and vapor. On the other hand, soil systems contain a porous (not necessarily uniform) matrix, air, liquid water, and water vapor. Heat conduction in the solid matrix and movement of the air, water vapor, and liquid water all contribute to the transport of heat in soils. The basic transport phenomena are[9]:

1. Fourier heat conduction in solid soil particles
2. Matrically induced water flow (Darcy's Law)
3. Thermally induced water flow
4. Vapor mass flow due to localized evaporation in the soil
5. Airflow resulting from displacement by liquid water and water vapor.

An analysis taking into account all five of these transport mechanisms is available[9] where some simplified, but still useful, techniques are also developed.

Water migration occurs when there is a temperature gradient in the soil. Here, water evaporates in the high temperature region and subsequently condenses in the cooler region. Liquid water returns to the hot region through the porous soil by means of surface tension as in a heat pipe. Thermally induced liquid water flow is a nonequilibrium thermodynamic coupling effect which is often referred to as thermo-osmosis[6-8]. It is interesting to note that thermo-osmosis (flow of liquid due to temperature gradient) is quite similar to electro-osmosis (flow of liquid due to electrical potential gradient) and the latter has been used as a means to study dry soils[6, 8]. Heat transport in arctic soil systems is further complicated[10-13] by the presence of ice as well as liquid water and water vapor. This is a topic of current interest due to the construction of oil pipelines in Alaska and Canada.

Many mathematical analyses[14-22] deal with predicting the performance of buried electrical equipment. None of these, however, take into account the presence of the water table, which exerts a strong influence on the temperature distribution of the buried equipment. The moisture content of a soil and the variation of the moisture content with depth is controlled by the depth of the water table beneath the ground surface, the soil texture, and the ground cover (i.e., pavement, grass, trees, etc.). The depth of the water table varies with season; the depth is greatest during summer and least in winter[2]. Most mathematical analyses of buried equipment[15-19, 22], as well as those dealing with buried thermal energy storage systems[23, 24] either ignore water migration or attempt to use an "equivalent" thermal resistivity in order to account for this effect. A few analyses[14, 19, 21] attempt to account for moisture migration by making various assumptions to simplify the mathematical complexity of the problem. Schmill[21], for example, reviewed the soil thermal conductivity data and assumed that the soil moisture content varied linearly with radial distance from a round cable buried near the ground surface; he also assumed that the thermal resistance varied exponentially with moisture content. Yeh also reviewed[14, 19] conductivity data and assumed that the change in soil moisture content varied linearly with the temperature gradient and that the change in soil thermal resistivity is directly proportional to the change in the moisture content. The proportionality constants in Yeh's analyses vary non-linearly with moisture content. Most analyses dealing with buried cable systems assume that the surrounding medium is of uniform thermal resistivity. However, in most cable systems, the cable is buried in a trench; the trench is then back-filled with thermal sand (a mixture of quartz sand and kaolinite) which has a lower thermal resistivity than the surrounding soil. The surrounding soil medium is then characterized by two (not one) thermal resistivities. This problem of discontinuous thermal resistivity and the resultant expression for the temperature distribution is very complex(20). This analysis did not take the water migration into account. The problem of heat and mass transport at the soil/air interface(25,26) becomes apparent when one wishes to determine the temperature distribution around a cable buried not too far beneath the soil surface. The method of images commonly used for such analyses(17,18,20-22) assumes a pure conduction mechanism and hence its validity becomes questionable when there is moisture migration and evaporation of water through the ground surface into the atmosphere.

Theoretical predictions of the temperature distribution in soils is complicated by the seasonal changes of the thermal environment. Only one reference(22) in this review attempted to address this problem. This reference used one of the standard equations for calculating the temperature field around a buried cable and then adding the ambient (i.e., the seasonally-varying temperature in the absence of the cable) temperature to arrive at the actual temperature distribution around the pipe. The authors then compared their results with test data and concluded that the heat flow from the buried pipe went mostly to the ground surface in the winter time and mostly into the earth in the summer (i.e., the earth acts as a sink in the summer). Although it is not altogether clear how the authors came to this conclusion, it appears that this finding will have a significant influence in the design of earth thermal energy storage systems.

Transient temperature data are available(16,27) from field tests performed with buried, horizontal, and cylindrical heat sources. The effects of ground cover[26] (i.e., black top or plain earth) and long-term transients due to seasonal weather changes[15] have been demonstrated quite well in these field tests. These data indicate that thermal time constraints of buried cable systems can be several weeks long. These data also illustrate quite effectively the effects of ground cover. For instance, an extensive series of tests in the Phoenix area showed that, during the summer, the temperatures underneath a blacktop surface were consistently higher (about 6°C) than temperatures measured at the same depth under a bare soil surface. These results indicate that the radiant energy exchange properties of the ground surface also play a major role in the seasonal variation of ground temperatures. A pavement heating study[28] indicates that while solar heat may be collected by pavement and stored in the soil during the summer months, heat losses in the soil during the fall made this storage system ineffective for winter use in a de-icing capacity.

It is to be noted[5] that the computer program HEAT[29] is successful to analyze thermal performance of buried cable systems.

C. MEASUREMENT TECHNIQUES

Discussions of different methods for measuring soil thermal resistivity are available in literature[1-3, 5, 30]. The thermal needle is the most commonly used instrument for measuring thermal resistivity in the field. This device consists of a slender metal cylinder containing a heater element and thermocouples along the length of the cylinder. Operation of the thermal needle is based on a comparison between the measured temperatures and the theoretical temperature response to a step change in heater power from a line heat-source in a semi-infinite-medium. Detailed drawings and an operating procedure for use of a thermal needle[2] and other types of laboratory equipment for measuring thermal resistivity of soils[2, 5, 30] are available in literature.

A Shelby tube, which is a 2-inch OD thin-walled tube, is used to obtain undisturbed soil samples from the field for density measurements. The procedure is to auger a 4-inch diameter hole down to the desired depth. The tube is then fastened to the end steel drive rod and then hammered about 18 inches into the soil. The central portion of the soil sample is cut to a convenient length and then weighed. The sample is then dried and weighed again. The density for both moist and dry soil as well as the moisture content can be calculated from these data. Neutron moderation[2] and dielectric constant measurement techniques[31] are also used to determine soil moisture content.

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SECTION 3
THERMAL STORAGE

SECTION 3. THERMAL STORAGE

INTRODUCTION

The major emphasis in this topic was thermal storage at temperatures in the normal ambient environmental range (approximately 40^{o} - $90^{o}F$). Current passive systems utilizing sensible heat storage in, for example, water or rock beds are well understood and they are not discussed here. The primary effort was devoted to phase change materials (PCM) so as to provide information on materials rather than applications. In addition, chemical, photochemical and metal hydride systems are also briefly mentioned as they are related to the thermal storage topic.

A. PHASE CHANGE MATERIALS (PCM)

PCM thermal storage systems are very attractive since they allow a relatively large amount of thermal energy to be stored isothermally. Thermal systems are easier to design when heat input and rejection are known to be at constant temperature over a wide range of operating conditions.

There are a number of types of phase change which have been examined for applicability to solar energy storage[1]:

1. Solid to solid phase changes are of considerable interest since they involve relatively high energies and are accompanied by negligible volume changes. One significant problem is that such materials break down after a large number of cycles (e.g., MgO-$Mg(OH)_2$ ([2]).
2. Solid to liquid phase changes are by far the most popular. Generally, they have the highest energy density of any phase change type. Volume changes are quite small.
3. Solid to gas and liquid to gas PCM's are not generally useful for low-cost solar systems. These require complicated and expensive equipment and volume changes are large.

4. Liquid to liquid phase changes usually have volume change, but usually not much energy is involved in the phase change.

Most of the literature deals with the various aspects of solid to liquid PCMs. These PCMs have melting temperatures which cover an extremely wide range. Thus, different materials are applicable to a number of specific functions, depending on their melting temperatures; e.g., 70° - $80^{\circ}F$ range is good for space heating, 100° - $150^{\circ}F$ is good for hot water heating, etc. High melting temperature substances are generally considered only for large-scale solar power plant type applications where high solar concentration factors are common(3,4). Some low melting temperature PCMs (water, for instance) are considered for use in conjunction with heat pumps(5). The heat pump heats a living space by freezing the PCM in the winter and solar energy is used to thaw out the PCM during the summer.

Major problems which are quite important in the PCM field are:

- PCM stability (or durability) after many thermal cycles(2,4,6,7).
- Supercooling - Many PCMs tend to supercool when undergoing the liquid to solid transition(8). Simpson(9) has studied temperature stratification and crystal growth techniques to eliminate this phenomenon with sodium phosphate materials. By always maintaining a "seed crystal" at the bottom of the storage tank, supercooling can be prevented.
- Heat Transfer - With few exceptions, most PCMs currently being analyzed and tested have quite low thermal transfer properties. This means that heat exchanger design is crucial; to utilize the isothermal nature of PCMs, ways must be found to effectively increase the conductivity of the PCMs. Bailey(6) has been performing analytical and experimental research on honeycomb thermal capacitor confinement techniques. Yang(10) has developed some mathematical modelling for dynamic thermal response of both sensible and latent heat-storage systems.

One particular approach to solving the thermal transfer problem has been (for instance) to create a "slurry" of water and small capsules of paraffin. The slurry takes on the isothermal behavior of the paraffin at its melting temperature, but largely retains the heat transfer qualities of liquid water(7). The problem that arises in such systems is the durability of the capsules, hence encapsulation processes and materials are being examined by some researchers[7,8].

Economic analyses are important and have been pursued[11], and fabrication techniques for thermal storage systems have also been studied[12,13]. Prototype modular storage components have been built[13].

Many authors have combined lists of PCMs including thermal data, toxicity, flammability, cost, and availability data, covering the whole range of phase-change melting temperatures. Several references[1,7,8,11-15] discuss PCMs in the 40° to 90°F range (4.4° to 32.2°C).

As for the materials themselves, paraffins are quite popular because melting temperatures cover the entire range from 40 to 150°F and supercooling is not typically a problem[1,11,12,15]. Paraffins have been used extensively in the space program[1]. Also, salt hydrates are in widespread use, though they suffer more from supercooling problems[1,11-13]. In addition, eutectics of these substances and natural elements have been investigated as PCMs.

In Table IV, a selected group of paraffins which fall in the temperature range of interest (40 to 90°F) is presented[1]. In addition to this data, additional data on viscosity, specific heat, approximate prices, and density are available for many paraffins[1]. In Table V, several PCMs with melting temperatures in the range of interest including paraffins, other organics, salt hydrates, and metallics are tabulated[12]. Several non-paraffin organics and several other inorganic salt hydrates are listed[1] in Tables VI and VII respectively.

B. CHEMICAL, PHOTOCHEMICAL AND METAL HYDRIDE SYSTEMS

A number of reversible chemical reaction thermal storage systems have been considered[16]. These reactions typically require some catalyst for one or the other of the reaction directions. They absorb heat in one direction and release heat in the other and tend to be quite isothermic, i.e., the reactions occur at specific temperatures. Unfortunately, as far as this technology review is concerned, most of the reaction temperatures are above the range of interest (greater than 100°C).

TABLE IV. MELTING AND TRANSITION DATA FOR THE PARAFFINS (C_nH_{2n+2})

Name	Chemical Formula	Molecular Weight	Melting Temperature °C (°F)	Transition Temperature °C (°F)	Heat of Fusion kJ/kg (Btu/lb)	Heat of Transition kJ/kg (Btu/lb)
n-Tetradecane	$C_{14}H_{30}$	198.395	5.9 (42.5)	None	229.9 (98.9)	None
n-Pentadecane	$C_{15}H_{32}$	212.422	10.0 (49.8)	2.3 (27.9)	163.7 (70.4)	43.2 (18.6)
n-Hexadecane	$C_{16}H_{34}$	226.449	18.2 (64.7)	None	228.9 (98.5)	None
n-Heptadecane	$C_{17}H_{36}$	240.476	22.0 (71.5)	11.1 (51.9)	168.3 (72.4)	45.5 (19.6)
n-Octadecane	$C_{18}H_{38}$	254.504	28.2 (82.7)	None	243.5 (104.7)	None
n-Nonadecane	$C_{19}H_{40}$	268.531	31.9 (89.4)	22.8 (72.9)	170.6 (73.4)	51.4 (22.1)

TABLE V. PROPERTIES OF PHASE CHANGE MATERIALS

Category	PCM Material	Formula	Molecular Weight	Melting Point °C	Boiling Point °C	Density Kg/m^3		Thermal Conductance W/mK	Latent Heat of Fussion Kcal/Kg	Specific Heat (Solid) Kcal/KgK	Coefficient of Thermal Expression per °C	Vapor Pressure Torr	Compatibility	Hazard Characteristics	Cost $	Availability
						Solid	Liquid									
Paraffins	Tetradecane	$C_{14}H_{30}$	198.4	5.5	252.5	825 (4°C)	771 (10°C)	0.150	54	0.495	—	1 (74.6°C)	Non-corrosive to most metal structures.	Flammable, can oxidize with oxidizing material, non-toxic.	16 per 500g	OK
	Hexadecane	$C_{16}H_{32}$	220.5	16.7	287.5	835 (15°C)	776 (16.7°C)	0.150	56.7	0.505	—	1 (105.3°C)	Non corrosive to most metal structures.	Flammable can oxide with oxidizing material, non-toxic.	16 per 100g	OK
	Octadecane	$C_{18}H_{38}$	254	28	318	814 (27°C)	774 (32°C)	0.150	58	0.515	—	1 (174.9°C)	Non corrosive to most metal structures.	Flammable can oxide with oxidizing material, non-toxic.	6 per 100g	OK
Other Organics	Polyethylene Glyco 600	$H(OCH_2CH_2)_n$ OH	570 - 630	20 - 25	—	—	1100 (20°C)	0.160	35	0.54	75×10^{-4}	5×10^{-6} (100°C)	Non corrosive to most metal structures.	Flammable can oxide with oxidizing material, non-toxic.	4 per	OK
Salt Hydrates	Sodium Hydrogen Phosphate Dodecahydrate	Na_2HPO_4 $12H_2O$	138	36	—	1520 (20°C)	—	0.514 (solid) 476 (liquid)	66.8	0.404	83×10^{-4} (solid)	—	Corrosion to aluminum.	Very alkaline	4 or per 10	OK
	Lithium Nitrate Trihydrate	$LiNO_3$ $3H_2O$	123	29.9	—	1550	1430	—	70.7	—	—	—	Compatible with aluminum	—	8 or less per 10	OK
Metallics	Gallium	Ga	69.7	29.8	198.3	5903 (25°C)	6093 (12.4°C)	33.7	19.2	0.082	58×10^{-4} (solid)	1 (1349°C)	Very corrosive to metals especially, aluminum.	—	≈7.5	

TABLE VI. FUSIBLE MATERIALS WITH A HEAT OF FUSION GREATER THAN 185.96 kJ/kg (80 Btu/lb) LISTED IN ORDER OF INCREASING MELT TEMPERATURE FROM 4.4 TO 32°C (40 TO 90°F).

Material	Melting Point °C(°F)	Heat of Fusion kJ/kg (Btu/lb)
Tetradecane $C_{14}H_{30}$	5.6 (42)	227.6 (98)
Formic Acid HCOOH	7.8 (46)	246.1 (106)
Pentadecane $C_{15}H_{32}$	10 (50)	206.7 (89)
Ethyl Myristate $CH_3(CH_2)_{12}COOC_2H_5$	11 (51)	185.8 (80)
Acetic Acid CH_3CO_2H	17 (62)	185.8 (80)
Hexadecane $C_{16}H_{34}$	18 (64)	236.8 (102)
Lithium Chloride Ethanolate $LiCl \cdot 4C_2H_5OH$	21 (69)	185.8 (80)
n-Heptadecane $C_{17}H_{36}$	22 (71)	213.6 (92)
d-Lactic Acid $CH_3CHOHCOOH$	26 (79)	185.8 (80)
Octadecane $C_{18}H_{38}$	28 (82)	243.8 (105)
13-Methylpentacosane $C_{26}H_{54}$	29 (84)	195.1 (84)
Methyl Palmitate $C_{17}H_{34}O_2$	29 (84)	104.3 (88)
Nonadecane $C_{19}H_{40}$	32 (90)	220.6 (95)

TABLE VII. MELTING TEMPERATURE AND HEAT OF FUSION OF INORGANIC SALT HYDRATES (RANGE OF 40° F TO 90° F)

Compound	Melting Point °C(°F)	Heat of Fusion $\frac{kJ}{kg}\left(\frac{Btu}{lb}\right)$	Remarks
$LiClO_3 \cdot 3H_2O$	8.1 (46.5)	253.1 (108.9)	Needs cold finger to prevent supercooling. Not available commercially The least expensive lithium salt is the carbonate: 1971 carlot price \$0.52-\$0.46 per lb
$H_2SO_4 \cdot H_2O$	8.6 (47.5)	163.6 (70.4)	Safety hazard. Containerization difficult
$ZnCl_2 \cdot 3H_2O$	10.0 (50.0)		Strong tendency to form glasses
$ZnCl_2 \cdot 5/2H_2O$	13.0 (55.4)		Crystallization velocity at all temperatures very slow. Cold finger needed to prevent glass formation
$K_2HPO_4 \cdot 6H_2O$	11.1-13.3 (52-56)	108.8 (46.8)	Cold finger needed to prevent supercooling
$NaOH \cdot 7/2H_2O$	15.0 (59)	192.5 (82.9)	Safety hazard, containerization difficult
$Na_2CrO_4 \cdot 10H_2O$	18.9 (66)	164.0 (70.6)	Temperature rather high. Requires cold finger to prevent nucleation of different hydrates. 1971 carlot price \$0.17 per lb for the anhydrous salt

(continued next page)

(Table VII, concluded)

Compound	Melting Point °C (°F)	Heat of Fusion $\frac{kJ}{kg}\left(\frac{Btu}{lb}\right)$	Remarks
$CaCl_2 \cdot 6H_2O$	30.0 (86)	170.3 (73.3)	Congruent only if melted quickly. Slow melting forms metastable α-$CaCl_2 \cdot 4H_2O$ incongruently
$LiNO_3 \cdot 3H_2O$	30.0 (86)	295.8 (127.3)	See remarks on $LiClO_3 \cdot 3H_2O$

In general, photochemical reactions[17, 18] are not useful for thermal storage systems because light is absorbed for one direction of the reaction; heat is generated by the reverse reaction. Since heat input is not acceptable for the forward reaction, this cannot be directly incorporated into a thermal capacitance storage system.

Metal hydride reactions are very interesting. The basic idea is that certain metals and alloys of metals will absorb hydrogen at nearly room temperature and atmospheric pressure in concentrations comparable to the density of liquid hydrogen (which doesn't exist except at extremely low temperatures and high pressures)[19]. The energy is stored in the form of chemically active hydrogen. The interesting thing is that the hydrogen is absorbed isothermally and isobarically over a large portion of the total concentration range, and the specific temperature and pressure are functions of the absorbing medium. It has been shown that a metal hydride heat pump can be created which uses hydrogen as the working fluid[20]. Because of the isothermal absorption and release processes, Carnot efficiencies can be closely approached. Such a heat pump could be used to transfer heat to and from a phase change material which would otherwise be in an unusable temperature range.

Encapsulation techniques for paraffins and stability of the phase change materials after many thermal cycles need further research. Metal hydride applications for thermal storage, such as in heat pump design, should be pursued further.

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SECTION 4
THERMAL TRANSFER

SECTION 4. THERMAL TRANSFER

INTRODUCTION

The interest in this topic is mainly due to the need in the Passive Solar Community to understand the convective heat transfer processes under conditions appropriate to building physics situations. The amount of literature available on heat transfer problems is voluminous. Due to constraints of time and money three pertinent items were selected for review. One is concerned with a thermal analysis program which was used to study the thermal behavior of a few window arrangements; the second deals with the innovative ideas of using heat pipe technology for development of a variable transmittance window and as a thermal control system; and the third summarizes some information on insulations.

A. WINDOW ANALYSIS

The effect of the window frames on thermal performance of a window has always been a matter of speculation. Estimates have been made of heat losses through various types of frame (wood and metal with and without thermal barriers). The thermal analysis program of Hughes Aircraft Company, TAP-3, was used to analyze simple window arrangements to evaluate the thermal performances of different designs. For a brief description of this TAP-3 program, see the attached Hughes pamphlet (Appendix F).

One window arrangement chosen for an analysis was an aluminum frame without thermal break (high emissivity finish) as given in reference 1. Since the location of isotherm was not intended, it was sufficient to use only 61 nodes compared to the 394 nodes used in the analysis by Barnett(1). The material parameters were the same as those used by Barnett(1). The TAP-3 thermal analysis program was used to model a double glazed and a triple glazed window. The results are given in Figures 5 and 6. The analysis indicates that triple glazing reduces the heat loss through the glass by 20 percent compared to a double glazed window of the same materials. In the double glazed case the glass accounted for more of the heat loss than the frame. However, by using triple glazing, the loss via the glass has been reduced such that the frame and the glass contribute equally to the loss.

The thermal analysis program at Hughes does not have the graphics to construct the isotherm diagrams as shown in Barnett's paper. However, such an addition could be written if it were necessary. At present the program output is a computer print-out.

B. HEAT PIPES

Heat pipe technology is presently well-developed. The basic theory of how heat pipes operate is understood, and such information is available in the textbooks on heat pipes and their applications which have appeared recently[2, 3]. The transport capacity of a heat pipe can be predicted, and the performance of variable conductance heat pipes, switches, and thermal diodes can be specified with confidence[4-6]. For an exhaustive list of references refer to Appendix D.

At present, research is being performed in cryogenic heat pipes[7, 8], high temperature heat pipes (utilizing the alkali metals as working fluids)[9], and high performance heat pipe systems such as the osmotic heat pipe[10]. Heat pipes will not solve all heat transfer problems, but if the problem can be reduced to one of moving heat from one location to another, possibly with some form of control required, and without too many additional complications, heat pipes should be considered. Specialized heat pipes to provide the environmental control needed in typical solar applications have already been demonstrated, and need only be tailored to the specific application[2, 3]. If any specific heat transfer problems exist in the passive solar area, a demonstration heat pipe system could be built and tested quickly.

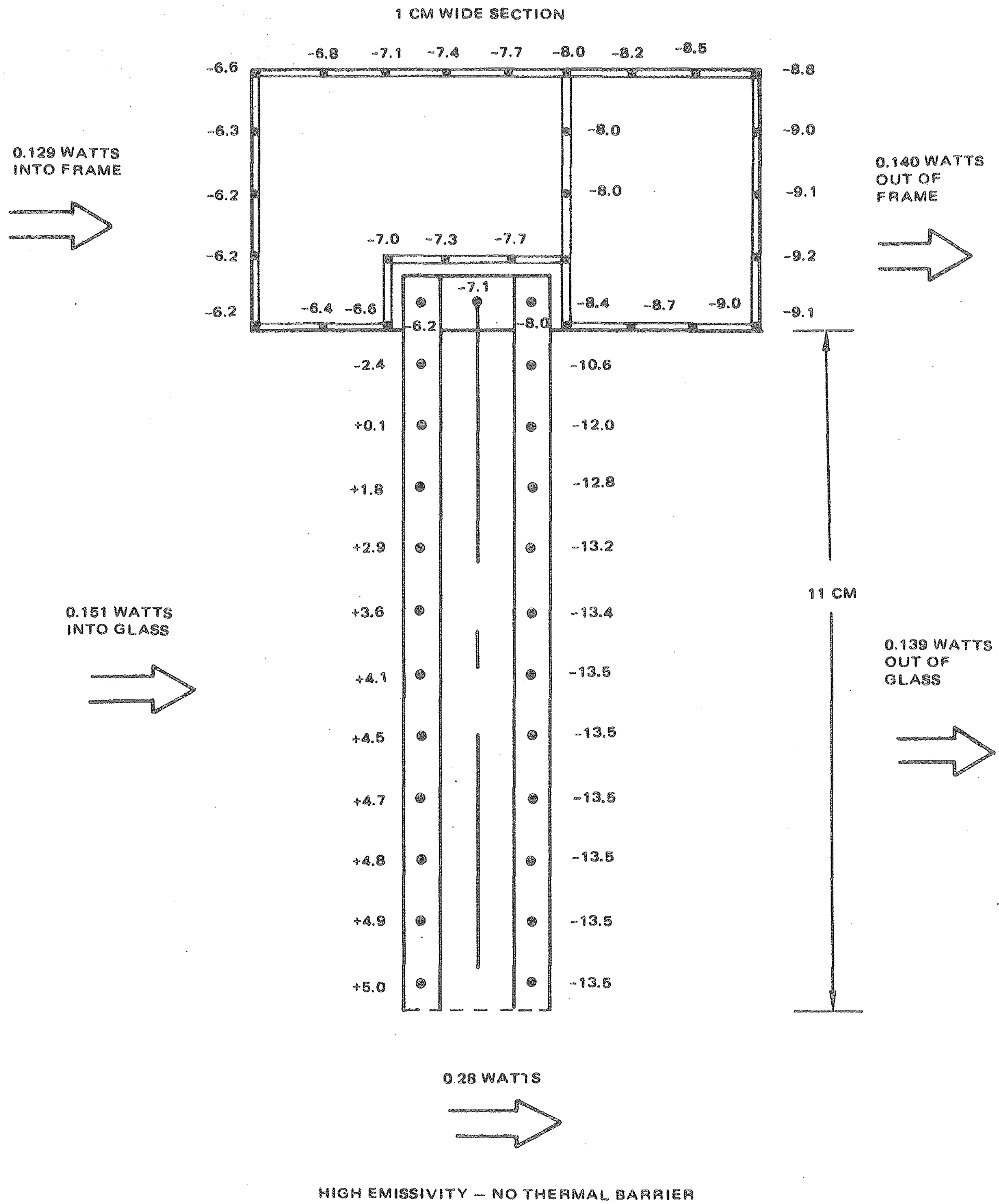

Figure 5. Double glazed window

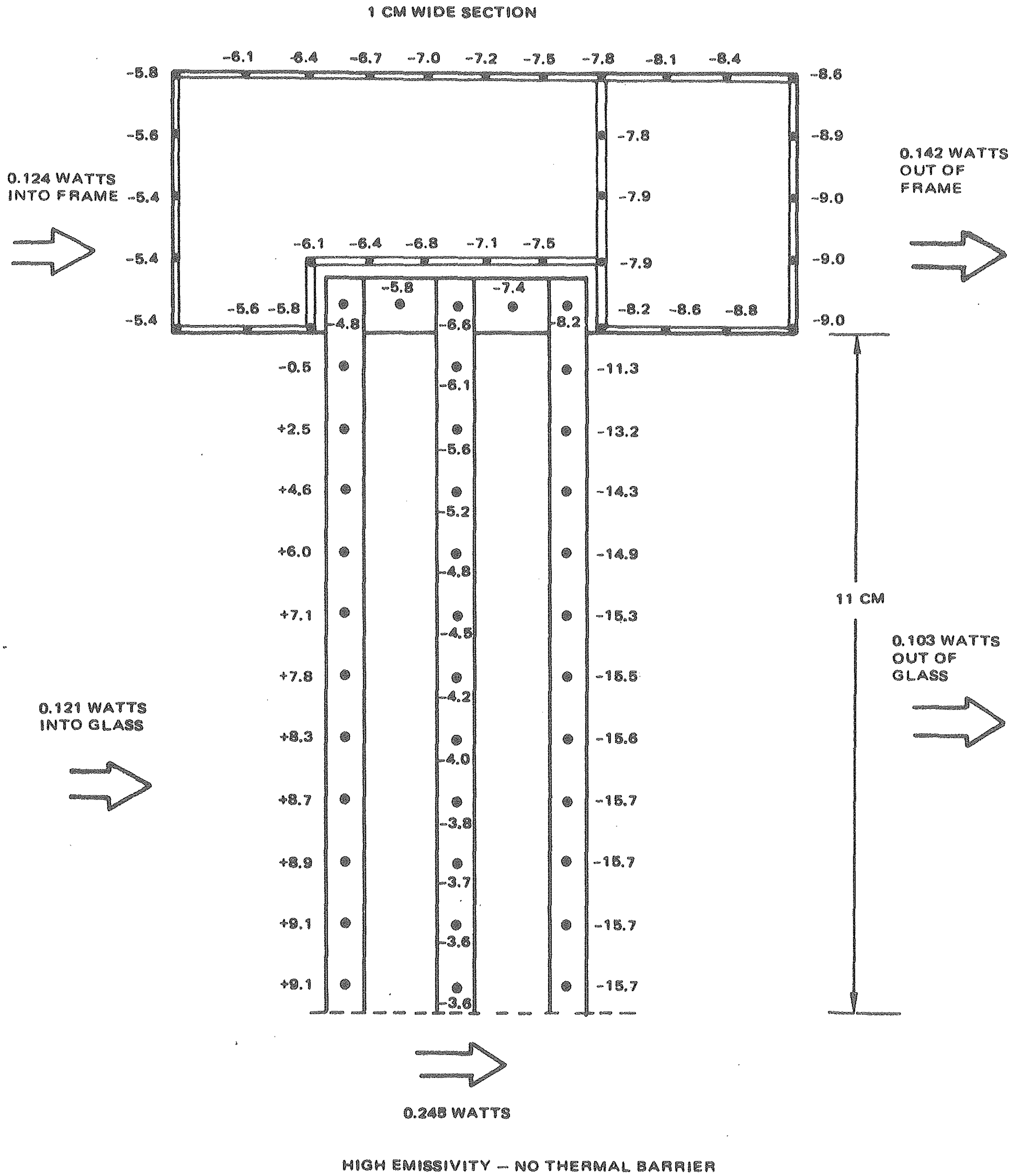

Figure 6. Triple glazed window

One potentially interesting application which has emerged from this study and which seems specifically applicable to passive solar energy systems is that of the variable transmittance window. Conceptually, a flat glass envelope can be rendered opaque, like frosted glass, or a good reflector, like a mirror, by the presence or absence of fluid within the envelope. This concept has not been demonstrated, although moving fluid to a desired location by means of slight temperature differences is what makes the thermal switch work. A demonstration program to prove out the principle and make thermal and optical measurements could be carried out relatively simply.

An integrated heat pipe thermal control system could also be built and demonstrated. Such a system would provide thermal transport and control in a completely passive manner by utilizing the properties of the heat pipe switch(5), the thermal diode(6), and the variable conductance heat pipe(4). The performance characteristics of the individual components of such a system are well known, but total system performance has never been demonstrated.

C. INSULATION

Within the last 25 years, tremendous growth has taken place in the field of thermal insulation, mostly spurred by new requirements in cryogenic storage and application and in aerospace programs (atmospheric entry and high speed flight)(11). These developments have been refinements of basic types of insulation which have been in use at least since the end of the last century(12, 13).

Performance of real insulation(14) systems is shown in Figure 7. While this chart was made up for cryogenic and ambient temperature insulations, a basic principle can be seen: an evacuated insulation is far superior to an unevacuated system. Although it must be carefully built and installed, an evacuated multiple layer system consisting of layers of aluminized mylar separated by spacers (usually a coarse plastic mesh) is the best available insulation system(15). This type of insulation has been extended to high temperature applications, although the materials must be changed to prevent metling(16-18).

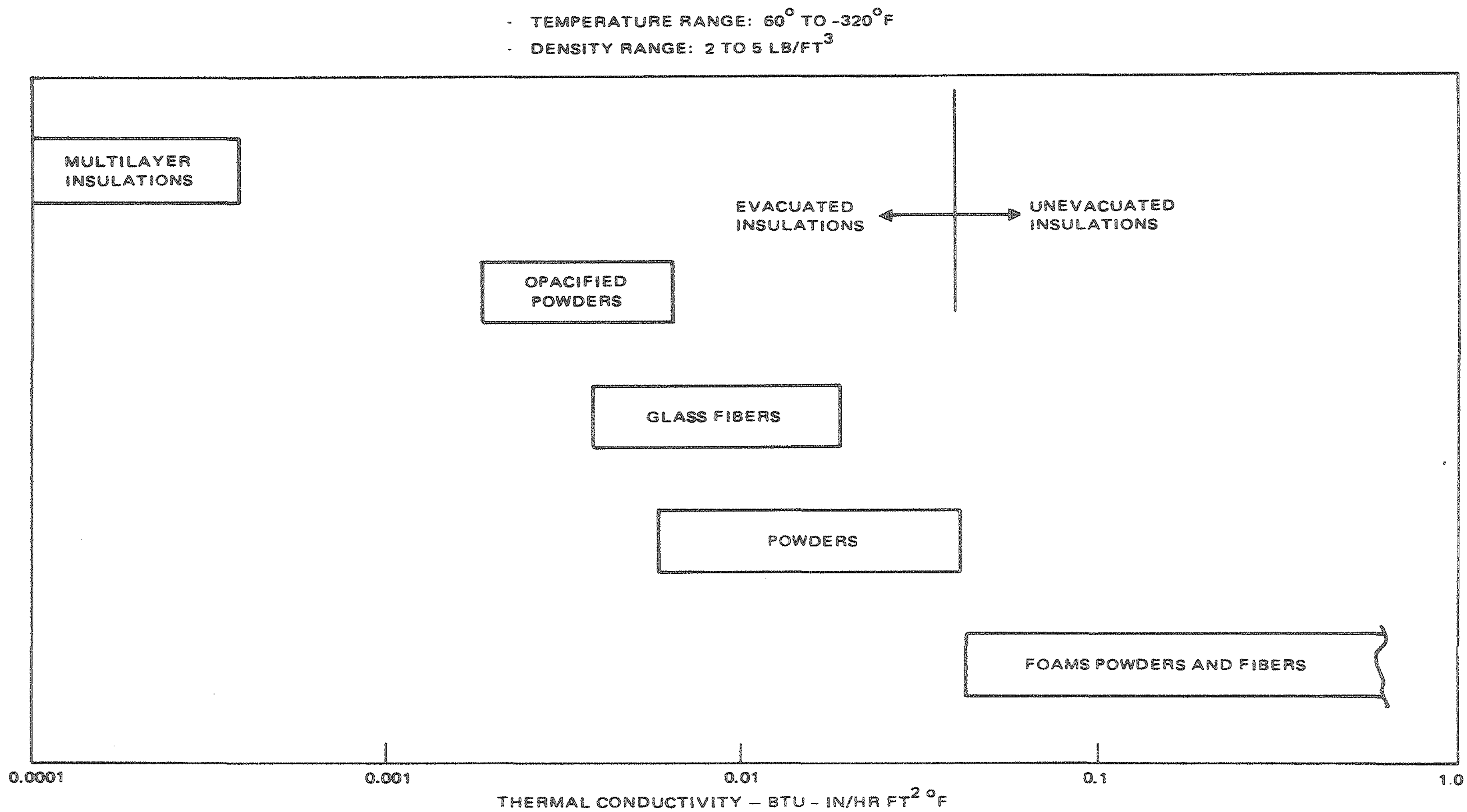

Figure 7. Thermal conductivity of thermal insulation materials

Offering significantly poorer performance (but being much less costly) are the evacuated powder and fiber insulations[19]. Any of the evacuated systems will be used only where the expected benefits of having a very low thermal conductivity outweigh the higher cost of obtaining and maintaining a vacuum in the insulation layer.

In terms of unevacuated insulation, foams, powders, and fiber-fiber-based structures are used at low temperatures, and refractory ceramic materials at high temperature[20]. High temperature materials and systems must survive in a generally harsh environment, and in general do not perform as well as systems designed for use in ambient temperature regimes.

Performance of ambient temperature, unevacuated insulations is improved by displacing the air trapped in the insulation by a dry gas of low conductivity. In polyurethane foams, for example, by creating the foam with a fluorocarbon propellant instead of CO_2, a reduced thermal conductivity can be obtained[21].

In all cases, the heat transfer mechanisms are well-understood, and design data usable with nearly any conceivable insulation system are readily available in any engineering library[22]. Areas which can be improved are the cost-effectiveness of all types of insulations and reduction of the fire hazard associated with some of the foams, notably polyurethane.

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SECTION 5
OPTICAL PROPERTIES

SECTION 5. OPTICAL PROPERTIES

INTRODUCTION

One of the most important topics for energy conservation is the day lighting applications, such as the use of diffuse skylight and sunlight to light interiors of buildings. This requires data and understanding of the properties of clouds and atmosphere and how they affect the terrestrial illumination and whether they can be properly modeled rigorously or empirically to predict the available daylight in any location. Also, the knowledge of optical characteristics of materials such as polymers are quite important for new and retrofit window applications of buildings. In addition, the durability of the coating materials, coating technology and environmental exposure testing of the coatings should be well understood for successful applications.

A. ATMOSPHERE

The atmosphere has several effects on the incident solar radiation. The clear atmosphere acts as a spectral filter due to the absorption of the constituent gases and aerosols. The cloudy atmosphere combines the absorption of the constituents mentioned above with additional absorption and scattering due to local concentration of aerosols and absorbing materials.

In the case of the clear atmosphere, models exist[1,2] which calculate the atmospheric transmission and emission from 0.25 to 28.5 μm. Since the properties of both temperature and concentration of the gases change with latitude, typical profiles for tropical, mid-latitude, and sub-arctic are included. Summer and winter profiles are included for the mid-latitude and sub-arctic latitudes. In addition to the typical profiles included in the model, it is possible to use a profile of the user's own choosing. In this way, the effects of increasing the concentration of one or more of the constituents on the spectral transmission can be determined. By integrating this spectral transmission over the solar emission curve, the effect of different concentrations on total solar radiation can be determined.

By using satellite measurements of the reflected solar energy and measurements of the total radiation at the surface of the earth, it has been determined that under cloudless conditions, the average atmospheric absorption of solar radiation is approximately 30 percent. By assuming the absorption spectra of the constituent gases and the aerosols are nearly independent and with a knowledge of the water vapor and ozone content, it was determined(3) that half of the absorption was due to aerosols and half of the absorption due to the constituent gases. From these findings, it appears that significant decreases in total solar radiation can be caused by high aerosol concentrations, whether natural or artificial. Further work on aerosol's contribution to decreasing the total solar radiation received at the surface might be considered. Correlation of satellite measurements, pollution monitoring measurements, and hourly values of solar radiation could be used to investigate these aerosol effects.

In the case of the cloudy atmosphere, work has been done to relate the diffuse component of solar radiation with the total measured solar radiation. Using a least square fit on data obtained from 1952-1956 at Blue Hill Observatory, Buyco and Namkoong(4) obtained the functional relation $y = \alpha + (1 - \alpha) (\cos \pi/2\ X)^{\beta}$ between the diffuse and total solar radiation. To obtain the least square fit, the α's and β's vary for each month and are available in the literature(4). However, the relationship between the percentage of cloud cover and the amount of diffuse illumination could not be inferred from this data. Using regression analysis, it has been found that 70 to 85 percent of the variance of total solar radiation can be explained by using percentage of possible sunshine. Thus, this parameter has been used to estimate total solar radiation. Since measurements of total solar radiation are not as widely available as sky cover measurements, attempts have been made to relate cloud cover to total solar radiation. The regression analysis using opaque sky cover could also be used(5) to explain greater than 70 percent of the variance in total solar radiation.

It has been found that the use of regression analysis is limited because coefficients may vary considerably, even between nearby locations. An empirical model is available relating total cloud amount to the percentage of possible sunshine[6], according to which $S = 1 - f_1 + f_2$ where $f_1 = ae^{-0.25\,a}$, and $a = (C + C_m + C_h)/8$, (C, C_m and C_h are the mean amounts of low, medium, and high clouds, respectively, at 0830 and 1730 hours in octas), varies from 0 to 1 as sky conditions change from clear (0 octas) to overcast (8 octas) and f_2 = latitude correction $(0.02 + 0.08 \cos 4\,\emptyset)$ up to 45° latitude and -0.06 for latitudes above 45°, $\emptyset$ being latitude in degrees.

None of the models discussed above can relate the percentage of cloud cover to the total solar radiation over averaging times less than a month. No models relating instantaneous or even hourly surface illumination with cloud cover could be found.

To evaluate solar radiation as a function of percent of cloud cover, the thickness, cloud type, and distribution with respect to the sun angle must be included. By using satellite data and ground measurements of solar radiation, it would be possible to evaluate the solar radiation as a function of these parameters. Once these functional relationships are determined, the 3 DNEPH cloud analysis program[7] or a probability cloud cover program can be used to determine the long term levels at any location.

Although satellite data are available from the National Environment Satellite Service (NESS)[8, 9], the data must be read from data tapes and then properly formatted and analyzed. In addition, ground measurements must be gathered which are concurrent with the satellite data. Some of this data is probably available from existing National Oceanic and Atmospheric Administration (NOAA) measuring stations. university measuring programs, or weather pollution monitoring stations, but some new ground based data collection, concurrent with satellite fly overs, may be necessary.

B. MATERIALS

1. GLASSES

To make an ideal "window," the materials should have one of the following characteristics. The material should either: (1) transmit the solar spectrum and reflect the infrared, or (2) reflect the solar spectrum and transmit the infrared. Windows with the first set of characteristics (Figure 8) would be useful for passive solar heating when outside temperature is low, while those with the second set of characteristics (Figure 9) would be useful for passive cooling, when outside temperature is high.

As stated, those characteristics are ideal ones, and no single material possesses all of these characteristics. Common window glass is an approximation to the solar heating characteristics. However, instead of reflecting the infrared, glass absorbs the infrared beyond about 3 μm primarily as a SiO absorption. Since absorbing materials re-emit the energy in all directions, half of the energy is lost to the outside of the window. All SiO_2-based glasses have the same general nature as discussed above, i.e., absorbing in the infrared and transmission cutoff at between 2 - 3 μm. Germanium is an approximation of the solar cooling characteristics. It has good reflectance in the visible and transmission up to 27 μm. It is commonly used as a solar rejection material. Since it does have a large index of refraction, Fresnel reflection losses are significant. To reduce this reflection, germanium should have an anti-reflection coating for the IR[10].

Since halides, other oxides and chalcogenides also form amorphous glassy states, alternate materials are possible. Many of the halides have good transmission extending from the visible to 20 μm or more. However, the halides are hygroscopic or water soluble and have low softening temperatures. Uncoated, the halides would not withstand exposure to environmental conditions[11].

The oxide glasses generally behave like common SiO_2 based glasses with cutoffs between 1 and 6 μm and restrahlen bands in the 8 - 13 μm and 16 - 26 μm regions. The restrahlen band in the 8 - 13 μm region helps cut down the energy loss (radiative) due to the re-emission, since the band corresponds to the peak of the room temperature (300°K) blackbody emission curve[11].

The chalcogenide glasses generally have good transmission in the 8 - 13 μm region with some, such as the telluride glasses, extending out to 20 μm. Except for some of the sulfide glasses, they all have short wavelength cutoffs in the near infrared, 0.8 - 1.0 μm[2].

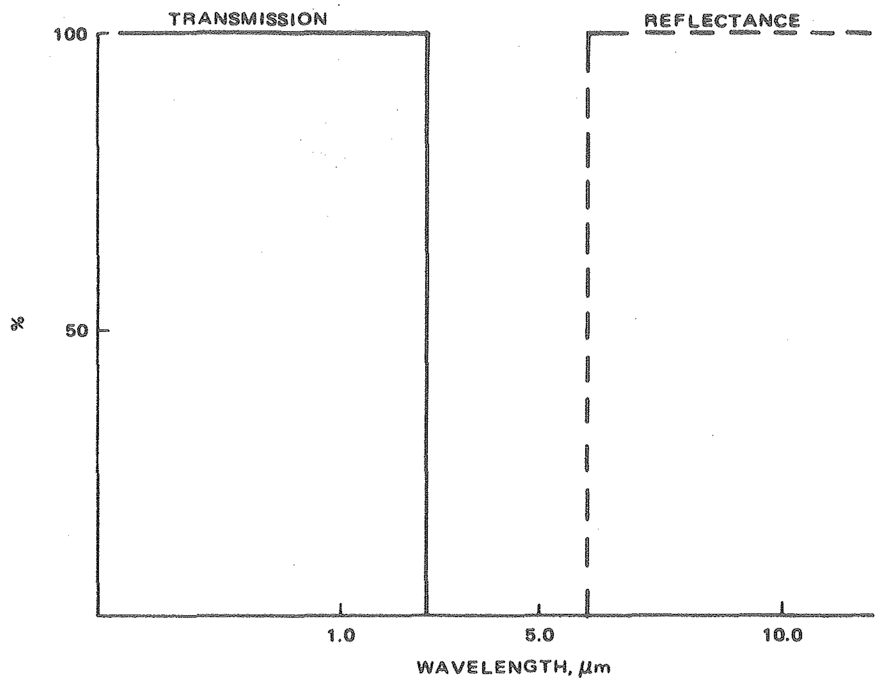

Figure 8. Ideal solar heating window

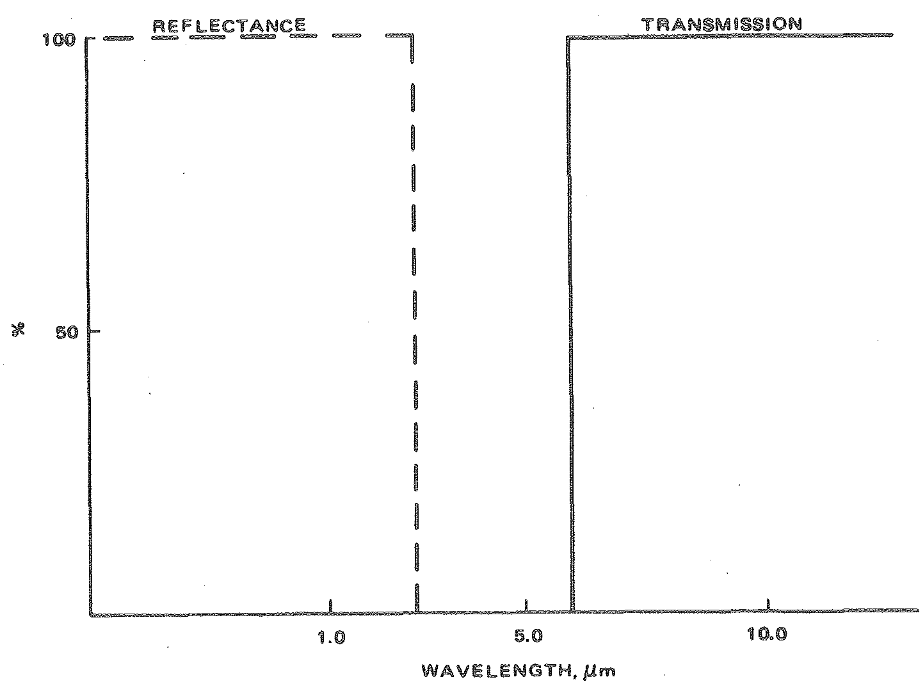

Figure 9. Ideal solar cooling window

Windows for passive solar heating could, at least in theory, be fabricated from either the halides or the oxides. By placing infrared reflective coatings on these materials, the characteristics shown in Figure 8 would be approximated. As noted above, the halides are hygroscopic and thus would require some type of protective coating. The IR reflecting coating might well be made to serve both purposes. The durability of coatings will be discussed further below.

For passive solar cooling, the windows could, in theory, be fabricated from either the halides or chalcogenides. By placing visible reflective coatings on these materials, the characteristics of Figure 9 would be approximated. The requirements of the coating for the halides are the same as noted above.

The transmission and reflection characteristics of the materials commonly used in the IR are available[12-17] including those in the categories discussed above. However, most of these materials can be termed exotic from the standpoint of supply and cost of making the material. In addition, at present, these materials are available in limited dimensions. Most are not available in pieces larger than 1 foot in diameter. An even more serious problem relating to the use of many of these materials is their high toxicity. Many cannot be handled except under strictly controlled conditions. The development of new non-toxic window materials is not likely under the current stimulus.

2. POLYMERS

Because of the cost of coating windows with a dielectric coating, interest in using polymers as a substitute has increased. Polymers have the advantage of being applied directly to existing windows as a coating, as a filler in glazed windows, or in curtain-like sheets.

Optically, most polymers are transparent in the visible, but have strong absorption bands throughout the infrared. Table VIII lists characteristic groups common to polymers[10].

TABLE VIII. CHARACTERISTIC GROUPS OF COMMON POLYMERS

Molecular Bond or Group	Wavelength of Absorption in μm
O-H	2.8 (stretch)
N-H	3.03, 6.12, 6.46
C-H	3.3-3.4 (stretch), 6.85 (deformation)
Carbonyl	5.6-6.1
Methyl	7.2-7.4 and 6.8-7.1
Ester	7.7-8.7
C-O	7.7-10
C-Cl	12.5-16 but generally 13.5-14.3

Most hydrocarbon polymers have absorption bands at 3.4, 6.81 and throughout the 8-13 μm region. In addition, all the polymers have the problem of discoloring due to the absorption of ultraviolet. This discoloration decreases the visible transmission of the polymers. Even though they are transparent to the visible, the absorption in the infrared, especially in the 8-13 μm region, reduces their effectiveness as window coatings. Because of the strong absorption, sheets thick enough to be used as curtains are essentially opaque in the infrared for most polymers. Of the polymers such as Lucite, Plexiglas, Mylar, Kapton, and polyethylene, only polythylene has good transmission in the 8-13 μm band for thicknesses of ≤1 mm[10, 18].

Work has been done with fluorocarbon polymers, fluoroalkylated polyphosphazenes and fluoroalkylated silicones in an attempt to extend the infrared cutoff to 6 μm for use as binders in highly reflective aircraft coatings[19, 20]. These materials do have good transmission out to 6 μm, but are highly absorbant and essentially dead in the 8-13 μm region. The transmission does increase to approximately 30 percent for longer wavelengths, but this depends upon sample thickness.

The polymers which have high absorption in the infrared above 6 μm can be used as filler in double glazed windows or as surface coatings to impede radiative cooling. However, these materials are not as effective as materials which are reflective in the infrared. Since the visible properties of the polymers are deteriorated by the UV incident on the polymer, the UV absorption of the glass attenuates the UV incident on the filler.

Polymer films which are completely transparent in the long wave infrared (5-30 μm) are non-existent, since all organic compounds have at least one major absorption in this region. Of the existing films, FEP Teflon, TFE Teflon and polyethylene come closest to being transparent, although polyethylene still has absorptions at 6.8, 7.2, and 13.9 μm with gradually increasing absorption above 14.3 μm. FEP Teflon has a strong doublet at 8.3 and 8.7 μm and TFE Teflon absorbs primarily at 8.4 μm. Aromatic compounds and chlorinated or brominated compounds all have strong absorptions in this region, with C-Cl bonds absorbing around 13-16 μm and C-Br absorbing above 16 μm. The minimum number of absorptions, which a compound or polymer exhibits, occurs when the compound is highly symmetrical. Thus, simple compounds such as CCl_4, CS_2, CBr_4, etc., have only one to four significant absorptions. Theoretically, it would be possible to produce a poly(tetrabromoethylene) with absorptions only about 15 μm, but such a polymer not only would be extremely difficult to produce, but also would have a low level of thermal and UV stability.

In contrast, polymers which are opaque or essentially opaque in the 5 - 30 μm region of the spectrum are numerous, and it is only in very thin layers, such as less than 0.005 inch, that it is even possible to identify individual absorption peaks. Maximum opacity is achieved with aromatic polymers such as poly(dimethylphenylene oxide), chlorinated styrenes, poly(phenylene sulfides), polysulfones, polycarbonate, Mylar, Parylene C, etc.; however, it should be noted that even FEP Teflon, although one of the most transparent polymers, is almost totally opaque (0-2 percent transmittance) in 20 mil thick films. Thickness thus is a major factor in appraising opacity, since virtually any polymer film is opaque if the thickness is

40 mils or more. Polycarbonate is another example where transmission falls to 0 - 3 percent in 30 mil thicknesses. Films such as "Parylene C" cannot be effectively produced in thicknesses greater than 2 - 3 mils, thus the potential of this relatively opaque material cannot be realized in all practicality. In a recent study conducted at Hughes for the purpose of selecting the most opaque film material for use as a radiative heat transfer barrier, FEP Teflon and Lexan polycarbonate were chosen largely on the basis of their availability in appropriate thicknesses. Polysulfone was totally opaque in 130 - 140 mil thick films, but this thickness is excessive and intermediate thicknesses (about 15 mils) were not available for evaluation.

Inorganic polymer films, such as silicon nitride, can also be considered for use as potentially opaque materials. Silicon nitride for example, absorbs strongly at 11.5 and 21 μm, and with sufficient thickness, total opacity could be achieved[21]. Technology recently developed at Hughes on low temperature SiN coating processes has demonstrated that high strength impermeable continuous films up to 3000 μm thick can be applied.

Near IR absorption (1.0 - 2.5 μm) also occurs in polymer films, but thicknesses must be sufficiently great if the absorption is to be detected. In thin films, no absorptions can be detected in this region because they are too weak; however, with a 1/4 inch thick Lexan polycarbonate sample, 5 to 6 percent of the spectrum will be absorbed. Absorption peaks are detectable at 1.13, 1.37, 1.67, 1.87, and 2.15 μm and up, with the 1.67 μm absorption being the major one. These absorptions are overtones of the aromatic C-H stretching vibrations normally found at 3.1 - 3.35 μm (note that 1.67 is exactly half of 3.35).

In research conducted at Hughes on infrared reflective paints, major efforts were concentrated on the development of cure processes for fluorocarbon polymers. This general class of materials was selected because, as noted previously, they are relatively free of absorptions up to 6 μm. The problem of utilizing them as paint binders is in their processability. High molecular weight materials of this type cannot effectively be dissolved in solvents, and those that are soluble must be cured by processes which do not deteriorate their thermal stability, add undesirable IR absorptions, or introduce significant coloration. Cure processes utilizing mixtures of benzoyl peroxide and 1,4-diazabicyclooctane, or cesium fluoride and magnesium oxide were developed for Viton type materials such as Viton AH-V and the analogous Kynar 7201[20].

Future work in polymer chemistry should be directed toward improving the UV cutoff and the 8 - 12 μm transmission. Currently, work is being done at Hughes Research Laboratory on polymerization of organic materials for use as thin protective coatings on IR optics. Films which have good transmission in the 8 - 12 μm and 3 - 5 μm regions have been developed. Effects on the surface finish of the substrate on the durability are being investigated[22].

In addition, future research should be directed toward the development of thermosetting, oxidation resistant polymers having no hydrolyzable functional groups within their molecular structure. Examples of such materials are the phenylene-X polymers such as poly(phenylene oxide) and poly(phenylene alkylene). Isomer configuration is of course crucial to the achievement of the property objectives. Such materials have potential use in window sealants and glazing protective coatings, geothermal well gasket and sealant materials, etc.

Another area of research is in IR opaque materials. Such materials can be blends of compatible polymers having significantly different IR absorption spectra. Blends with up to 5 different polymers could likely be developed which will exhibit an essentially continuous absorption spectrum above 3 μm. Another approach to the development is to synthesize a single polymer with a large number of different typed of functional groups. With the current technology, individual polymers can be used, but thick films (40 mils or more) are required to provide complete opacity.

A third potential area of research involves the development of an IR transparent polymer, one which has no C-H, C=O, C-O-C≡N, C-Cl, C-F, Si-O, etc. A possible candidate is a completely brominated hydrocarbon polymer. Other candidates would likely have to be inorganic polymers, although it is not known with certainty that IR transparency is feasible.

3. PIGMENT

The pigments used in camouflage coatings are developed to have high reflectance in the solar IR (0.8 - 2.0 μm). Coatings are made by adding pigments with high reflectance to a polyethylene base which, as noted above, is transparent in the near IR for sufficiently small thicknesses. The spectral reflectance of many of the pigments used in the coatings are contained in references 23-25. Pigments such as lead chromate yellow, cadmium sulfate yellow, molybdate orange, and monoazo red seem to have the best reflectance over the solar spectrum. (From the data contained in the references, it appears that a white undercoat would be necessary to achieve high solar reflectance.) These pigments could be applied to buildings, particularly roofs, to decrease solar heating.

C. COATING TECHNOLOGY

1. COATING DURABILITY

Of prime importance to any coating considered for solar energy conversion systems is its durability under adverse weather conditions. Practically every coating used will have to endure exposure to rain, snow, hail, UV irradiation, etc. This report first discusses the durability of transparent coatings on glass and various polymers, then it addresses the environmental testing of coatings on various infrared transmitting materials.

Pastirik and Sparks(26) report on forming anti-reflection coatings on soda-lime glass, using various coating methods including acid etching, plasma etching, and dipping the substrate into a solution of sodium silicate. Durability tests included exposure to ultrasonic vibrations in abrasive free water, then subsequent buffing with a mild abrasive. Both the acid etch and sodium silicate films were deemed durable enough to withstand outdoor exposure. The plasma etched films were very water soluble and found to be entirely unusable for outdoor applications.

Lowery(27) reported on the optical and durability characteristics of various types of coatings and surface finishes. All of the coatings addressed were black solar absorbing coatings formed by various techniques. This study indicated that most of the electroplated coatings tested had excellent resistance to moisture, as did the chemical conversion coatings. Only the anodized coatings exhibited unacceptable degradation.

Marks[28] discussed the deposition of a superhard (Moh > 5) coating on transparent polymeric sheet substrates. The coatings were comprised of submicron sized hard particles suspended in a polymeric matrix. The coating was exposed to various types of solvents, including acetone, alcohol, water, etc., with no observable effects. Two days' humidity exposure had no effect on the coating, although five minute immersion in boiling water did soften it.

Coated panels of plexiglass were exposed[28] to ultraviolet radiation for 30, 60, and 90 minutes after being heated to 100°C for 2 hours. The coating remained clear and free from crazing. Further exposure to higher levels of ultraviolet radiation slightly increased the coating hardness.

Test samples were impacted by a 200 gram steel ball falling from 50 cm without any apparent damage to either coating or substrate. Adhesion tests using cellulose adhesive tape produced no separation of coating from substrate. All in all, this coating showed remarkable resistance to practically every environmental test used.

Many types of environmental durability tests have been performed on infrared transmitting materials and their associated anti-reflection coatings. Most of the tests address the capability of the materials and/or coatings to withstand rain erosion with impact velocities approaching Mach 1. This is intended to simulate the conditions of a window on a low flying jet fighter. Rain erosion tests of coatings are described in the literature[29, 30]. One of them[29] reports on rain erosion tests of multilayer anti-reflection coatings on chemical vapor deposited zinc sulfide, IRTRAN II, and gallium arsenide. The anti-reflection coatings used zinc selenide as the high index material and thorium fluoride, lanthanum fluoride or neodymium fluoride as the low index of refraction materials. The simulated rainfall was 1 inch/hour for 20 minutes at 470 mph. The coatings on the zinc sulfide substrates passed these tests while those on gallium arsenide did not. The surface polish of the substrates was a critical factor in determining whether a given coating would be able to withstand this environment. Obviously, this durability test is much too severe for testing coatings for solar applications. Although solar coatings may not have to endure as severe a short period test as described, it may have to endure a wider variety of environments for a considerably longer time period.

The military has published a number of military specifications that specify the types of environmental and durability tests required of coatings applied to military hardware. These include MIL-STD-810, MIL-M-13508 (aluminized mirrors), and MIL-C-675 (MgF_2 anti-reflection coating on glass) and MIL-C-48497 (interference coatings) among others. The military may require a coating to pass only part or all of the tests specified in a particular specification. A typical environmental callout for HAC-specified exterior coatings is shown in Table IX. In instances where the military specifications are not stringent enough for a given application, HAC has specified its own requirements, but always using the military specifications as a guideline to define the type of test and the test method. An example of this is the humidity test in Table IX. This coating is used on the exterior surface of aircraft mounted infrared windows. This is similar to the humidity test specified in MIL-C-48497, except the time period is extended from 1 day to 28 days. One thing is clear from this investigation: no similar set of environmental tests now exist for solar conversion coatings. Every investigator is basically defining his own set of tests to subject his coatings to. Unfortunately, this makes it difficult, if not impossible, to make a coating to coating comparison for an overall evaluation of the state of the art on durability. The environment to which solar coatings will be exposed is quite different from those covered by present military specifications. A standard set of durability specifications for solar coatings needs to be generated either by starting from scratch or by revising presently available specification. Then, samples of the various types of solar coatings should be procured and all tested to the same specifications. That way, a true calibration of the state of the solar coating art can be determined.

It is imperative that the testing facility have the capabilities for not only subjecting the coatings to the proper tests, but also being able to measure the coating optical parameters prior to and after exposure.

TABLE IX. TYPICAL ENVIRONMENTAL TEST SPECIFICATION

A. THE COATING SHALL BE SUBJECTED TO THE FOLLOWING ENVIRONMENTAL AND DURABILITY TESTS IN THE ORDER LISTED:

1. SALT SPRAY FOG PER MIL-C-675

2. SEVERE ABRASION PER MIL-C-48497.

3. ADHESION PER MIL-C-48497.

B. FOLLOWING THE TESTS OF NOTE A, THE COATING MUST BE EXPOSED TO A RELATIVE HUMIDITY BETWEEN 95% AND 100% AT A TEMPERATURE OF 120°F ±4°F FOR A PERIOD OF 672 HOURS. AFTER THIS TEST, THE COATING SHALL BE SUBJECTED TO THE MODERATE ABRASION AND ADHESION TESTS OF MIL-C-48497.

C. AT THE CONCLUSION OF THE TESTS OF NOTES A AND B, THE COATING SHALL CONFORM TO THE REQUIREMENTS OF MIL-C-48497, SECTION 3.3.1 (PHYSICAL), 3.3.3 (ENVIRONMENTAL AND SOLUBILITY BLEMISHES), 3.3.4 (SPATTER AND HOLES) AND 3.3.5 (SURFACE DEFECTS).

2. COATING DEPOSITION METHODS

A major factor in the utilization of solar energy for large scale electrical generation or even for more modest projects such as home heating and cooling is the overall production cost of converting solar energy into a more useful form. The initial cost of the solar conversion unit and the maximum size of this unit are two factors that directly relate to this cost effectiveness. The methods used to deposit the optical coating on the solar conversion unit has a major effect on the cost of producing the unit and directly determines the maximum sized unit producible. With that in mind, a review of the major coating deposition methods is presented.

(i) Electroplating[31]

This process involves the deposition of a metallic coating via the use of electrolysis. It consists of making the substrate being plated the cathode submerged in a suitable electrolyte. The anode is the metal being deposited.

The electrolyte consists of a solution of a suitable salt of the metal being plated. This process is easily adaptable to mass production, although recent problems with the Environmental Protection Agency (EPA) have altered the cost effectiveness of this coating method.

(ii) Chemical Deposited Coatings[32]

This process deposits metals by pyrolitic decomposition of metallic oxides by oxidizing organometallic compounds. The chemicals are applied by either dipping or spraying. This is the method used to mass produce architectural coatings and blue tinting of automobile windshields. The capital costs of this method are divided between deposition equipment and the annealing furnaces. The costs are quite dependent upon the coating design used, but are significantly less than either sputtering or vacuum deposition systems.

(iii) Vacuum Deposition Coatings[32, 33]

This process involves the thermal or electron-gun heating of a coating material source which, in turn, ejects atoms, some of which are deposited onto the substrate surface. Vacuum deposition must take place in a hard vacuum. This necessity results in a substantial part of the cost of this process. Although both Libbey-Owens-Ford Glass Company and OCLI have developed very large vacuum deposition systems, the high capital costs do not project a bright future for this method in solar energy coatings.

(iv) Sputtered Coatings[32, 34]

Sputtering is produced by ions bombarding the coating material source. The ions transfer their momentum to coating material atoms resulting in their being emitted towards the substrate surface. Both reactive DC sputtering and planar diode sputtering produce films of adequate quality at competitive prices. Like vacuum deposition, sputtering must occur in a vacuum and both metallic and dielectric films are produced.

Both Battelle and OCLI have developed large scale sputtering deposition systems. Since this process does not require a hard vacuum, the sophisticated pumping equipment needed for vacuum deposition techniques is not required. Thus, the capital outlay is not great, making this method quite cost effective.

(v) Spin Coating Techniques[28]

Superhard coatings for helicopter transparencies have been deposited onto polymeric sheet substrates using the spin coater method. These coatings are produced by suspending submicron sized particles in a polymeric matrix. This process involves high speed spinning of the substrate while pouring the coating onto it. Centrifugal force moves the coating towards the outer edges of the part. Coating thickness is a function of fluid viscosity, rpm, and time. There does not appear to be a limitation on the size of panel to be spincoated so long as the maximum slope of the surface relative to the horizontal does not exceed 45° .

(vi) Acid Etched Films[26]

In contrast to other techniques, the acid etch method does not deposit an anti-reflection coating on glass, but rather produces a film by chemically and optically altering a thin layer of the glass surface itself. Glass is a solution of a variety of oxide compounds, mostly SiO_2, but also certain metal oxides. The object of acid etching is to selectively leach the non-silica components, leaving a skeleton of pure, porous SiO_2. This skeletonized layer has an index of refraction between that of glass and air, and the layer of thickness, as well as its optical properties, can be varied by adjusting the temperature and duration of exposure to the acid.

The major problem with this method is in controlling the parameters of the supersaturated acid solution. Once these problems are solved, this method may prove to be a viable method of anti-reflection coating glass.

(vii) Other Coating Techniques

There are a variety of other methods for depositing coatings on substrate surfaces. These include dipping[26], spraying[32], painting[32], plasma etching[26], and gravity flow. Each has its strong points as well as its weaknesses. Spraying and painting are usable only when coating uniformly is not important, such as black paints, etc. Plasma etching is similar to acid etching discussed earlier and it is produceable on a mass production basis, but to date, the coatings have had poor durability.

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SECTION 6
HUMAN ENGINEERING

Section 6. HUMAN ENGINEERING

INTRODUCTION

Occupancy in underground buildings and other structures which have limited amounts of glazing potentially affects the occupants' performance and behaviour. The focus of this review was thermal comfort in the 'normal' temperature range (65 to 85°F) and the effects of radiant heat on human comfort. Isolation and confinement and health and safety topics were also looked into with emphasis on a quality maintenance/control in enclosed environments. The information furnished below should be sufficient for indicating the type of work being done on the above topics and the problems that need further study.

A. THERMAL COMFORT

The material uncovered in this area falls into two categories: the effects of heat stress (high heat) on physiology and performance, and the development of mathematical models to predict human heat tolerance. In the first category, Nunneley, et al,[1] found that radiant heat (117°F black globe) was more fatiguing to subjects than "normal" heat (95°F_{db}, 79°$_{wb}$), and that both conditions altered the learning curve for some parts of the Repetitive Psychometric Measures (RPM)[1]. The authors concluded that similar conditions in an aircraft would result in impaired performance. This decrease in performance due to heat stress was also observed by Durren[2]. He found a statistically significant increase in performance time necessary for subjects to complete a prelearned maintenance task in hot (110°F_{db}) vs normal (72°F_{db}) condition. In this study, subjects reported that sweat rate in the hot environment made handling of the tools (for the maintenance task) difficult, thus affecting performance time.

A different approach to the study of heat stress involves the use of mathematical models. Goldman[3] defined human heat tolerance in terms of the body's ability to eliminate heat that exceeds its storage capacity. He stated that the relationship between the body's demand for evaporative cooling (E_{req}), and its maximum cooling capability (E_{max}) results in a ratio (E_{req}/E_{max}) defining the amount of "skin that must be sweat wetted" to alleviate heat stress. This model, and others using the same parameters, have been developed to predict heat tolerance limits under varying conditions, with further study to adjust for age, sex, and physical condition. Coupled with this was a discussion of the clothing insulation unit[4]. This model was developed to determine the insulating capabilities of various types of clothing as a means of maintaining comfort in the 65° F to 85° F temperature range.

The findings reported in these articles are of value to our review in two ways. First the heat stress studies indicate that the effect of radiant heat may result in increased fatigue and that at least a portion of the performance decrement in a maintenance task is due to increased sweat rate. Secondly, the modeling approach to heat stress provides the means of establishing individual heat tolerance levels for various conditions based on biological functions and clothing. From this, it is is possible to know not only what problems to expect under certain conditions, but also how to deals with them.

The literature reviewed in the area of thermal comfort deal primarily with high heat stress on human physiology and performance. Although subjective responses to high heat include increased fatigue and difficulty in handling maintenance tools due to increased sweat rate, these responses cannot necessarily be generalized to the more "normal" heat conditions of concern to our program. There were few experimental data in the literature concerned with the effects of working in a 65° F or 85° F environment, and none that deal with large but gradual temperature changes. The apparent lack of interest in this area might stem from the difficulty in assessing the significance of small or gradual temperature changes, particularly in the normal comfort range. If the problems are going to exist in solar energy systems, then special research in this area would be appropriate, with particular attention paid to the long-term effects of exposure to radiant heat and working in the upper and lower limits of the comfort range.

B. HEALTH AND SAFETY

The major concern for our review in the area of health and safety is air quality maintenance. Passive solar energy systems might call for underground buildings or buildings with limited fresh air ventilation and/or reduced air flow, thereby increasing the amount of CO_2 in the air. The literature reviewed in this area was limited to CO_2 removal systems designed for special purposes -- namely, for use in submarines and manned space missions.

In addition, each study investigated the use of new and different materials and methods for CO_2 removal. Lithium hydroxide was referred to by Rudy(5) as a previously used material for CO_2 sorption, yet neither Fuest and Brice(6) nor Patel and Baker(7) mentioned any current or previously used materials as a comparison. Hence, it is unknown what materials or systems have been or are now being used, and no background information on CO_2 removal systems was supplied in any reference. From these technical documents it is evident that various methods and systems of CO_2 removal are currently under investigation by the Navy and NASA.

Two articles reviewed were concerned with the human factors of health and safety. Newberry, et al(8), reported the results of a study on the effect of increased CO_2 consumption on performance. This work stemmed from previous investigations indicating that increased CO_2 in an oxygen-poor breathing mixture prevented alkalemia in pilots at high altitudes and decreased the negative effects of G-forces on animals. The Newberry, et al, study on vigilance concluded that a 4.5 percent concentration of CO_2 in three oxygen/nitrogen mixtures did not significantly affect operator performance on a vigilance task. These results could provide a baseline level of tolerable CO_2 consumption with respect to office workers in enclosed environments.

Of special interest to our review would be the report by Young(9) on the solar energy research at Sandia Laboratories. His discussion of the associated health and safety concerns was limited to possible eye damage resulting from exposure to the reflecting dishes used in the collection of solar energy. The selection (as it were) of chorio-retinal damage as the main health concern was due to the reflection and reradiation of solar energy in the immediate area. Because the eye is the most sensitive organ to this condition, its protection assures the safety of other tissues (such as hair and skin).

Air quality maintenance (particularly CO_2 removal) systems are undergoing continuous development for submarine and manned space missions, and the sponsoring agencies could provide additional information, as needed. The health concerns of Sandia may apply only to solar energy collection systems rather than to office/residential building design. Further research into this area would be appropriate.

C. ISOLATION AND CONFINEMENT

Interest in this area stems from construction and design criteria necessary for solar energy system utilization. Underground buildings (residential or office) represent one area resulting in possible isolation and confinement due to limited visual contact with the outside and perhaps limited living/work space. Akins(10) addressed these problems in relation to space colonization. In his discussion of the sensory/perceptual, temporal, and social types of isolation expected, he stressed the need for variety in visual stimulus and activity to offset the strains of limited environments. Confinement was also discussed, and Akins suggested that plant life and creative room structure and interior design be used to decrease the feeling of confinement. This would be of particular importance in the application of findings by Johansson and Lundberg(11), who reported, subject's perceived degree of crowdedness on a train was a square function of the actual number of passengers.

Laboratory experiments on both perceptual and social isolation and on confinement indicate that confinement produces more stress than isolation. Zukerman, et al(12), found that "confinement without social or sensory isolation reduced generalized psychological and endocrine arousal". His findings were supported by Zubek, et al(13), who noted that while the decrease in occipital alpha frequency after isolation was significant, no significant difference existed between groups, suggesting that the decrease was produced by confinement alone.

Reports of extreme isolation and confinement add additional support. Studies on group structure of weather stations in Antarctica undertaken by Gunderson[14] indicate two major stress producing factors associated with confinement: 1) after the onset of winter there was no possibility of evacuating the station or obtaining outside help, and 2) there was no possibility of leaving the group, even temporarily. Mende and Ploezer's report[15] on miners trapped in a cave-in would be applicable here, except that the stress conditions of confinement were enhanced by total darkness and the continuous threat of death by subsequent cave-ins.

The topic of isolation and confinement yielded some interesting information, yet the applicability of this information to our program is questionable. The Antarctica studies were concerned with various problems associated with total isolation and confinement in an extreme environment. Laboratory studies on perceptual isolation and limited sensory variation were conducted in small cubicles, subjects were confined to beds (except for meals and going to the toilet) throughout the experiment, and the methods of telling time (clocks and watches) were nonexistent. These conditions were usually the same for the isolation and confinement groups. In both the laboratory and Antarctica studies, the conditions were more extreme than would be encountered in the solar energy system. It is doubtful that any proposed solar energy system would require personnel to live and work underground for weeks or months at a time with no opportunity for escape, as is the case in Antarctica. The concerns in this area for our program seem to be short term (several hours) exposure to an enclosed environment and the effects on a worker's performance.

The ability of the usual office worker to do his job in a sensory limited environment could be dependent on such factors as job interest, task requirements, and his individual preference or tolerance of certain environmental conditions. The problem posed by underground buildings might best be likened to the conditions experienced by mineworkers, who spend their workdays underground with little contact with the outside. Any literature on this subject might be useful, especially any long-term studies of miners and the psychological effects (if any) of their occupation.

It appears that isolation and confinement are primarily associated with extreme environments (Antarctica and space missions) or conditions (mining disasters). Even the laboratory conditions were more prison-like than would hopefully be encountered in a solar energy designed building. More general information on less "specialized" conditions would be appropriate; a good reference unavailable for review would be Rasmussen[16].

Little data on asymmetric radiation was found in this literature review. The combined effect of heat stress and confinement was not covered in our search. Its application to solar energy systems would make it an interesting topic for experimentation. Further review of the literature is necessary to focus the problems of human engineering as applied to passive solar environments.

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SECTION 7

HIGH POWER SOLID STATE ELECTRONICS AND HIGH EFFICIENCY LIGHT SOURCES

Section 7. HIGH POWER SOLID STATE ELECTRONICS AND HIGH EFFICIENCY LIGHT SOURCES

Fluorescent gas discharge lamps satisfy, at present, two-thirds of all lighting needs in the United States. Fluorescent lighting technology has advanced greatly in the past 40 years since its introduction[1], but suppliers of the fluorescent lighting equipment display some reluctance to consider innovative concepts that differ significantly from the usual[2].

Fluorescent discharge lamps offer a fairly efficient conversion of electrical energy into light energy. Typical efficiencies are 60-80 lumens/watt into light energy[3]. Fluorescent discharge lamps have a negative current/voltage characteristic and require a current limiting or ballast device, which is normally provided as a saturating reactance. Besides the current limiting function, the ballast circuity provides the means of starting the discharge lamp and stabilizing the operation under warm-up and steady-state conditions.

The fluorescent discharge lamp and ballast circuitry are highly interdependent and should be considered together.

Several developments have taken place in the last few years which offer a significant improvement in the combined efficiency of the fluorescent discharge lamp and the associated ballast circuitry. Considerable effort was devoted to optimize fluorescent discharge lamp performance in respect to luminous efficiency, color rendering, physical operating conditions and operating life. Operating at high frequencies (100 kHz), using proper gas mixtures and pressure as well as optimized fluorescent tube dimensions, will result in an approximately 80 percent conversion efficiency of electrical into UV light energy, which then causes the fluoresence[4].

Further significant improvements in fluorescent discharge lamps are not likely. However, improvements in the ballast circuitry can lead to a significant improvement in overall efficiency. Solid-state electronic ballast circuits have been demonstrated which cut the percentage of power loss from 20 percent for the saturated reactance ballast to less than 5 percent for the solid-state electronics ballast circuitry[5].

Solid-state electronic ballasts convert the 60 Hz line power first to dc and then to 20-50 kHz ac[6]. The higher operating frequencies are desirable, as mentioned before, not only for achieving higher efficiency in the electric power to light conversion, but also for using smaller magnetic cores and capacitors. A ferrite core of comparable volume to a 40W saturated reactance ballast operating at 60 Hz can handle 600-800W at 50 kHz.

A significant performance improvement in semiconductor power devices[7,8] contributed to the success of the solid-state electronics ballast. In general, improvements in solid-state power devices were made in the following areas:

- Power handling capability
- Voltage and current rating
- Upper operating frequency
- Reliability
- Transient survival
- Cost

Specifically the following devices are current state-of-the-art:

<u>Asymmetrical Silicon Controlled Rectifiers (ASCR)</u>[9,10]

- 40 kHz operating frequency
- 4 kW power

<u>Gate Turn-Off SCR (GTO SCR)</u>

- Requires substantially reduced power for gate turnoff

<u>Power V-MOS</u>[7]

- 400V/2A rating
- 100W power
- 5 ns switching time

Schottky Power Diodes[11]

- Low forward voltage loss
- 0.7V at 50A
- 150V reverse voltage
- 50 ns switching time

Advances in capacitors have also been made to reduce the size of solid state electronic ballasts significantly. Electrolytic capacitors suitable for higher frequency operation are now available with Equivalent Series Resistance (ESR) of < 1 mΩ and Equivalent Series Inductance (ESC) of < 1 nH[10].

These advances in component technology created the basis for the solid-state electronic ballast circuitry. Further increases in operating frequencies can be expected and these will allow matching of optimum operating frequency of the fluorescent discharge lamp.

The current design techniques for solid-state electronic ballasts are in general compatible with integrated circuit technologies. This will have a significant cost impact on the future market for solid-state electronic ballasts, considering the annual shipment of about 60 million reactance ballasts in the U.S. Circuit techniques for the solid-state electronic ballasts have been known for many years. The ringing choke converter, the push-pull inverter and the switching regulator, which is the most efficient converter circuitry, have been used[12,13].

Solid-state electronic ballasts have to provide the capabilities of:

- Starting the fluorescent discharge lamp
- Warm-up stabilization of the fluorescent discharge lamp
- Steady state operation of the fluorescent discharge lamp

Improvements in the area of solid-state electronics ballasts are required for:

- Increasing reliability
- Reducing cost
- Minimizing RF interference

Ballasts employing improved magnetic materials, new winding techniques, and operation at higher frequencies have already been investigated for cost effectiveness and energy conservation, with some success; but, barring any massive breakthroughs in technologies or magnetic materials, the law of diminishing returns applies. An approach is proposed below for investigation of fluorescent lamp ballast replacement utilizing space age technology. Inductance/transformer ballasts, with integral power factor correction capacitor and starter circuits (standard since 1940 for conventional fluorescent lamps) need to be analyzed for possible material and energy savings from application of space technology.

Production costs of integrated or hybrid circuits capable of handling appreciable power levels are continually decreasing to the extent where the replacement of ballast and associated passive components by an active IC circuit may become feasible. Based on this fact, a computer model of a typical fluorecent lamp including such parameters as high starting voltage, negative slope current-voltage, aging and other electrical characteristics could be developed. Using the principles of circuit synthesis with the computer, the response requirements of a four terminal network or "black box" interposed between the fluorescent lamp and the power system could also be developed, subject to the following nominal constraints.

- Power input: 0 to 100 watts
- Voltage input: 110V to 270V
- Frequency: 50 Hz to 10 kHz
- Reduce EMI coupling back into power system
- Minimize power dissipation
- High initial peak voltage for starting

After establishing the response function of the network, then it would be determined if it is physically realizable. If so, the required parameters for actual fabrication and testing of a prototype hybrid can be specified.

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SECTION 8
LANDSCAPE/BUILDING MATERIALS

Section 8. LANDSCAPE/BUILDING MATERIALS

INTRODUCTION

The design of passive solar systems must consider the properties of the building and landscape materials quite seriously. The two most important properties of interest for this review were the thermal and optical characteristics of these materials.

A. THERMAL PROPERTIES

The primary thermal property of interest is the thermal insulation capability of building materials. It is expressed as a conductance or overall transmittance or overall heat transfer coefficient or U-value. For a slab of thickness W in the heat flow direction, $U = k/W$, where k is the thermal conductivity. It is also expressed as an R-value, $R = 1/U$. Common usage expresses U in Btu/(hr-ft^2-°F) and R in (hr-ft^2-°F)/Btu. For example, R-19 refers to a slab of material having a unit thermal resistance of 19°F/((Btu/hr)/ft^2). For certain materials (e.g., plastics), the following thermal properties also are of interest. Coefficient of thermal expansion, deflection temperature at various pressures, continuous, no-load service temperature, flammability characteristics, and resistance to thermal cycling. For glass, the softening temperature is of interest.

The thermal properties of standard or generic building materials are listed in the open literature[1,2,3]. Some of these materials have found new uses in modern buildings. For example, formed galvanized steel sheets have been used as the main skin (roofing and siding) for a house, at the same time serving as a collector for solar heating of the house[4]. Materials as familiar as water, paint, masonry, and fiberglass are used as dual construction materials and solar absorbers/storage in modern passive-solar buildings[5]. Plastics have been found to have advantages for replacing or augmenting glass in windows[6].

The present review was restricted to two areas — thermal properties of new building materials, and unusual thermal properties of standard materials. It is to be noted that very little information was found on thermal properties of landscape materials.

1. THERMAL PROPERTIES OF NEW BUILDING MATERIALS

One type of new building material which has been developed extensively in recent years consists of insulating window and coating materials and window shades and blinds. Some of this development work has been reported in the government literature[7] and the bulk of the recent and ongoing work is well documented[8].

Another type of new building material which has been developed extensively in recent years consists of materials used for walls and roofs. The objective of these developmental efforts is to devise new materials or novel combinations of generic materials that increase the R-value (i.e., decrease the U-value) of walls and roofs. Houses typically are constructed with R-values ranging from R-3 to R-5 for walls and from R-2 to R-5 for ceilings[9]. Recommended R-values for an optimum trade-off between energy savings and insulation installation cost for ceiling insulation based on 1978 prices are R-19 for warm regions such as Southern California, and R-30 to R-38 for colder regions. ASHRAE 90-75 mandates maximum U-values of 0.20 to 0.38 (minimum R-values of R-5 to R-3) for walls and 0.06 to 0.10 (R-17 to R-10) for roofs[10], and maximum U-values as low as 0.05 (R-20) are being specified for roofs[11].

Pre-insulated panels usually are better insulators than required by ASHRAE and decrease energy usage more than a third compared with insulated masonry construction. They are commercially available and consist of a ready-to-install sandwich of steel exterior and interior walls with insulation in between. The interior surface is galvanized sheet steel from 0.028 to 0.040 inch thick, finish-painted on the exposed surface. The insulation core, normally 2 inches, 2-1/2 inches, or 3 inches thick, consists primarily of polyurethane or isocyanate foam, although fiberglass, gypsum, perlite, asbestos board, and polystyrene have also been used. The outer ply is usually painted on the exposed surface. Optional for exteriors is weathering steel, stainless steel, porcelain enamel, and an aggregate stone comprised of chips permanently bonded to steel. For use as roofing-insulation units, the exterior or top surface has the option of employing aluminum-coated or aluminum/zinc coated steels, which reflect about 85 percent of the solar heat. Foam cores now in use meet accepted fire test standards, especially the recently-developed isocyanate-base foams. They have passed the Underwriters' Laboratories Tunnel Test BLBT with a Flame Spread rating of 25, and Fuel Contributed value (with steel skins in place) of 0. Recent UL E-84 Steiner Tunnel Tests have resulted in Smoke Developed Ratings of 75 and 40. Thermal insulation properties of pre-insulated panels and competitive materials are compared in Table X[1].

TABLE X. THERMAL INSULATION PROPERTIES OF VARIOUS BUILDING MATERIALS

Material	U	R
Pre-insulated panels	0.048 - 0.062	21 - 16
Four inch face brick plus 4-inch common brick	0.48	2
Four inch face brick plus 8-inch concrete block (cinder)	0.33	3
Twelve inch concrete block (gravel aggregate)	0.47	2
Six inch poured concrete	0.31	3
Two vertical glass sheets with 1/2-inch air space	0.55	2
ASHRAE 90-75 standard (walls)	0.20 - 0.38	5 - 3
ASHRAE 90-75 standard (roofs)	0.06 - 0.10	17 - 10

In addition, DOD has several active programs for development of new materials and construction methods for military buildings. They include projects to improve roof materials and concepts[11], insulation techniques for ceilings, walls, and joints around door and window frames in houses[12], various structural envelopes such as space frames, tensile structures, air inflatables, and geodesic domes for enclosing building groups in cold regions[13], and general design and construction techniques for buildings[14, 15]. One of these programs involves the retrofit of spray-on cellulosic wood fiber insulation with an R-value of 30 in existing Navy houses for comparison with similar unretrofitted houses. Cellulose, however, has the unfavorable thermal property of being probably the most flammable of the currently available insulation materials[9]. Although cellulose can be treated with fire-retardant chemicals such as boric acid and sulfates[9], Southern California Gas Company recommends only fiberglass and mineral wool as candidate materials for retrofit in ceilings of houses[16].

2. UNUSUAL THERMAL PROPERTIES OF STANDARD MATERIALS

In recent years, tests have been performed to evaluate the ability to withstand thermal cycling of materials used for piping of water in building plumbing systems and solar absorbers. The National Bureau of Standards tested the long-term effects of cyclic hot water flow (thermal cycling) on polyvinyl chloride (PVC) drainage stock assemblies and chlorinated PVC (CPVC) pressure piping assemblies, and it tested the long-term effects of water hammer (shock pressure) on the CPVC assemblies[17]. For CPVC, the tests indicated a use life of at least 50 years at the highest test temperature of 180°F (82°C) with pressures of 150 psia (1034 kPa). With intermittent hot water flow, the performance of all test assemblies was satisfactory at the completion of the tests (approximately 1500 cycles on the CPVC pressure pipe and 750 cycles on the PVC drainage pipe). Polyset, Inc., of Manchester, Massachusetts, tested the ability to withstand thermal cycling of carbon-black-reinforced crosslinked polyethylene for solar water heater absorbers[18]. Five tube specimens containing water at pressures as high as 80 psi survived 100 freeze-thaw cycles.

Reliable, complete thermal properties data are not available in a useful form even for conventional, commercially available building materials; thermal properties are either missing or of unknown accuracy[19]. In recognition of this situation, non-DOE government agencies such as NBS[20] and DOD[14, 19] have initiated several projects to collect, catalog, and evaluate these data. In particular, the Naval Civil Engineering Laboratory issued a contract (Contract No. N68305-79-C-0008) to Dynatech of Cambridge, Massachusetts, to compile, compare, and evaluate existing thermal data on envelope insulation materials and to recommend future measurements[19].

B. OPTICAL PROPERTIES

Since building materials as well as barren terrain and vegetation provide the background for many objects of interest to optical sensors, spectral measurements have been made on a variety of materials. The interest for this review, however, has been in the availability of optical properties for various materials rather than in the variations for a given material.

The Michigan reports[21] contain reflectance measurements of many materials, both building materials and vegetation. The measurements are of hemispherical reflectance and were taken in the laboratory in the 0.2 to 15 μm region. However, no single material was measured over the whole spectral range.

It has been found[22] that the emissions from building materials all approximate a greybody in the near IR. Measurements made at night show a greybody type spectrum from 0.3 to 3.0 μm, while measurements taken in daylight show a modified solar spectrum reflected in the visible portion of the spectrum and a greybody spectrum in the near IR. Concrete is an example with this characteristic and is illustrated in Figure 10.

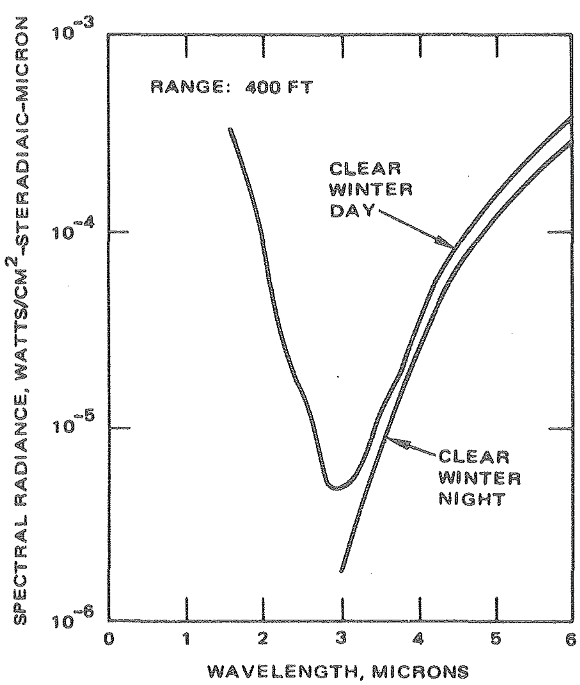

Figure 10. Spectral radiance of concrete wall during day and night.

No information on variations in reflection or emissions for building materials has been found. It appears that to obtain this information a measurement program is necessary. To evaluate a building material from an energy standpoint and to study the quantitative effects of the environment on the optical properties of materials, both field and laboratory measurements are necessary. By using both sets of measurements it can be determined what effects surface changes (either due to chemical changes of the surface or due to surface structure) have on the emission spectrum of the material.

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SECTION 9
MEASUREMENT/DIAGNOSTIC TECHNIQUES

Section 9. MEASUREMENT/DIAGNOSTIC TECHNIQUES

INTRODUCTION

For windows and lighting and passive solar projects, measurement and diagnostic tools are quite valuable. For several applications the recently developed photoacoustic technique may prove useful. Infrared (IR) technology presents itself as a versatile non-contact and sometimes long-range temperature indicating tool. IR can thus help locate heat losses and assist in thermal analysis and design of buildings. The pressure, temperature and flow measurement techniques provide the valuable fundamental data to understand the materials and energy transfer processes. These topics are reviewed below.

A. PHOTOACOUSTIC TECHNIQUE

Photoacoustic (or optoacoustic) techniques consist of detecting light by converting the light energy into sound and then into an electrical signal. In the early 1970's, the use of lasers as excitation sources enabled attainment of higher sensitivities than could be obtained by other techniques[1]. As a result, photoacoustic techniques were investigated for applications such as the detection of trace amounts of gas contaminants in concentrations smaller than 0.1 ppm[1,2] and the measurement of absorption coefficients[1-9,14] in gases smaller than 10^{-7} cm^{-1}. Photoacoustic spectroscopy (PAS) also has proven to be useful for measuring the absorption spectra of solids and liquids, especially in the case of highly reflective, light-scattering, or absorptive materials that are difficult to investigate with other measurement techniques[1,10]. Some of the PAS researchers in this country are listed in Table XI. Several review articles[1,10-12] on PAS have been published in the open literature in the late 1970's. References 1 and 10 are two of the most valuable publications on this topic. Photoacoustic spectrometers have been

TABLE XI. SOME PHOTOACOUSTIC SPECTROSCOPY (PAS) RESEARCHERS IN THIS COUNTRY

Person	Organization/Location	Telephone Number	Involvement in PAS
• Nabil Amer	Lawrence Berkeley Laboratory/Berkeley, California	(415) 486-5601	Uses PAS in laser power meter
• Jon A. Noonan	EG&G PARC/Princeton, New Jersey	(609) 452-2111	Manufactures commercial photoacoustic spectrometer
• Dr. David A. Depatie	Air Force Weapons Laboratory/Kirtland Air Force Base, New Mexico	(505) 264-0721 (Office) 264-0419 (Laboratory)	Applies PAS to measurement of absorption coefficients of gaseous species at IR laser wavelengths
• Dr. Howard Schlassberg	Air Foce Office of Scientific Research/ Washington, D. C. (formerly at Air Force Cambridge Research Laboratory/ Bedford, Massachusetts)	(202) 767-4908	Developed PAS system for evaluation of candidate window materials for high-energy lasers while at AFCRL

commercially available for several years. The principal suppliers are Gilford Instrument Laboratories of Oberlin, Ohio, and EG&G PARC of Princeton, New Jersey[7,10].

In this review, the usefulness of PAS as a method of measuring the radiation distribution in a room and a few other applications of possible relevance to the windows and lighting and passive solar programs are discussed.

1. MEASUREMENT OF RADIATION DISTRIBUTION IN A ROOM

Although PAS may appear to be a novel method for measurement of the radiation distribution in a room, it may not be sensitive enough to measure stray visible or IR light in a room. Milliwatts of power (e.g., from a laser source) is needed. In addition to sensitivity, other potential problems include calibration; i.e., can one obtain an absolute, rather than a relative, measurement? Some development work might be required to resolve these issues. It is not obvious, however, that PAS promises to be sufficiently advantageous for this application.

2. EVALUATION OF WINDOW AND COATING MATERIALS

Since PAS can be used on virtually any solid or semisolid material[1,10], it is well suited for evaluation of window and coating materials. A product has been developed at the Air Force Cambridge Research Laboratory for measuring bulk and surface properties of materials in the UV through millimeter wavelength range by means of PAS; the system has been used extensively for evaluation of candidate window materials for high-energy lasers[13].

For highly transparent materials, conventional transmission spectroscopy can be less expensive than PAS. PAS has an advantage for highly reflective, light-scattering, or absorptive materials that are difficult to evaluate by other measurement techniques.

3. MEASUREMENT OF OPTICAL PROPERTIES OF MATERIALS SUCH AS PAINTS AND PLANT MATTER (E.G., INTACT LEAVES)

PAS is well suited for these applications. In fact, EG&G PARC and Gilford mentions them in their commercial brochures. For specific results, see the review articles 1 and 10.

4. INVESTIGATION OF INTERMOLECULAR INTERACTIONS IN LIQUID CRYSTALS

PAS is applicable to the measurement of optical data on the solid, smectic, and nematic states of liquid crystals, which are highly light-scattering. Rosencwaig has investigated[10] liquid crystals by means of PAS. However, there are doubts that reflectivity methods might be more sensitive and better suited to theoretical interpretation.

B. INFRARED TECHNOLOGY

Measurement and diagnostic techniques using infrared (IR) technology are based on the fundamental physical fact that all objects with temperatures higher than absolute zero radiate thermal energy. The intensity and wavelength of this radiation are functions of the temperature and emissive properties of the radiating object. For objects in the temperature range of, say $0^{\circ}F$ to $150^{\circ}F$, the maximum amount of energy is emitted at around 10 micrometers, that is the middle-IR region of the spectrum. The attractive feature in using IR for temperature measurement is that the intensity of radiation from an object can be sensed and converted into a corresponding temperature value, without coming in contact with the object. Long range measurements with IR are particularly suited to aerial scanning. Using an IR measuring device from an airplane, major heat leaks from buildings can be determined, in that warm surfaces lose more heat than cool surfaces, both by convection (the major portion of the loss) and by radiation (insignificant as far as heat loss but allowing one to measure the temperature with the IR device)[15, 16]. It is possible to sense underground heat leaks from the air also, e.g., broken steam lines[17]. Attempts have been made to determine the ground-moisture content by the variation in apparent temperature as measured from the air[18].

Medium-range measurements made from the ground with hand-held IR "thermometers" can determine the location of heat leaks in more detail than is possible with aerial scanning. From such measurements, wall insulation values, losses through windows, cracks, etc., can be determined[19]. Short range measurements are those made either from immediately outside a given building or from inside the building. Successful tests have been made from inside a building to determine where and how severe heat leaks were occurring, e.g., by infiltration around windows and convection from windows[20]. Also measurements of wall temperature and insulation values can be made from indoors.

Related to the heat-loss problem is the heat storage capability of various natural structures (hills, trees, rocks) as well as manmade structures. IR measurement of temperature after sundown will indicate objects that have stored excessive amounts of solar energy during the day which, in warm climates, could result in unnecessary cooling loads. In cool climates, it might show possibilities of reducing heating loads at night[21].

Non-temperature measurements for which IR might be useful depend on the transmission and absorption characteristics of particles in the air. For instance, humidity might be determined by measuring the percent of IR transmission at 1.08μm, and CO_2 content of the air by transmission at 4.25μm.

For this review only two specific areas of interest were covered. They are IR technology Spin-offs towards commercial products from military IR work and techniques for determining target emissivity "in the field".

1. COMMERCIAL SPIN-OFFS FROM MILITARY TECHNOLOGY

A large number of Hughes departments which deal with military, space and commercial IR technology were contacted and requested to describe any recent or upcoming advances in IR technology which might be applicable to the Windows and Lighting project[22-28]. The general consensus is that there have been no dramatic breakthroughs in the technology or even in applications of IR to new problems. The advances which have been made are more along the lines of improved detector sensitivity or detector array layout[24, 26, 27]. Manufacturing techniques may have seen some improvement in the last few years, which may have been reflected in slightly lower costs for IR systems[23, 27]. However, for instance, the monolithic-focal-plane arrays which are being developed at Hughes now cost in the millions of dollars for each system; cost reduction will have to be more than slight before this technology will be "mature" enough to lead to any commercial products[27].

By and large, any Hughes IR technology which ever makes its way to the commercial market will do so through the Probeye® program at Hughes' Carlsbad facility. Probeye® has been on the market for several years now and has found a wide variety of applications from heat-loss identification in buildings to electrical insulation inspection and routine machinery maintenance inspections. Current Probeye® equipment displays qualitative analog information which is quite sufficient for most such efforts; anticipated extensions of current capability include thermal image processing for video displays, color coding and isotherm mapping[(23)]. Most of these techniques, however, are also being pursued by a number of other companies.

2. TARGET EMISSIVITY

The emissivity problem seems to be one whose solution is considered unnecessary for many current IR applications[(17)]. Few people have been found who either know or care about target emissivity for the kind of qualitative information in general demand. It is enough to know that emissivity differences exist between different substances; that is, in fact, what makes thermal imaging as universally possible as it is. For certain electronics scanning projects, the unknown emissivity problem has received more attention[(29-31)]; but, apparently, satisfactory solutions are elusive, and if they have been found they are not freely available. The first practical solution is likely to find a large market for application and sales.

Another area where attention has been given to emissivity is in aerial IR photography, notable for geophysical surveys (mining, petroleum and geothermal industries[(32-34)]; even so, some of these approaches have yet to be developed into working systems.

A U.S. patent discloses a technique whereby IR scanning is simultaneously performed at two separate wavelength bands[(34)]. It was originally thought that this would shed new light on the problem of emissivity measurement, but it turns out that the inventor had another purpose in mind. With prior knowledge of a material at two different wavelengths, that material can be positively identified from aerial IR photos taken at those wavelengths. Since this technique requires knowledge of emissivity, rather than assisting in determining an unknown emissivity, it does not address the issue of primary interest to this survey.

Another U.S. patent discloses a technique by which optical reflectance data can be extracted from aerial photographs[32]. This patent seems to be concerned with the visible portion of the spectrum only, but because emissivity and reflectivity are complementary quantities (in the IR spectrum) it may be possible to utilize the same basic concept in determining emissivity. The two fundamental prerequisites seem to be (i) that the target be illuminated by a source of (in this case, IR) radiation, and (ii) that a portion of the target in question should be in shadow (relative to the source of radiation). The utility of this technique in daytime aerial (visible light) photography should be obvious; the interesting question is its possible applicability to aerial (or ground based) IR thermography.

C. OTHER TECHNIQUES

The techniques and devices for accurate measurement of pressure, humidity and temperature are fairly well established. They are discussed only briefly. In contrast, the techniques for flow measurements have been more recently developed. Hence the focus during this review was on flow measurements. Of particular interest were methods which utilize new techniques (e.g., ultrasonics). and techniques which can be used to measure very low speeds or low flow rates (i.e., room air currents or fluid flow in a thermosiphoning solar energy system). Non-intrusive measurement techniques, which do not disturb the flow and ideally would not have to disturb existing pipes, were also sought.

1. PRESSURE, HUMIDITY AND TEMPERATURE MEASUREMENTS

Pressure measurements fall into two categories: absolute pressure measurement and pressure-drop measurement. For the windows-and-lighting project, pressure-drop measurements are probably the only ones of great interest. At the low range Δp measurements, inclined manometers (accurate to perhaps ±0.01 in. H_2O to as low as 0.1 in. H_2O total Δp) and Hook manometers (which measure ±0.0003 in. H_2O down to as low as 0.003 in. H_2O total Δp.) are used. For time-varying pressure measurements which must be tracked, capacitance manometers may provide a means of measurement. They measure absolute pressure but can be hooked up to get Δp's; their advantage is very short response time.

Humidity can be measured in various ways, but one of the most foolproof methods is to measure the dew point temperature. From the dew point temperature, relative humidity can be determined easily and accurately.

Temperature measurements can be made most accurately with resistance-temperature-devices (RTD's). These are good perhaps to $\pm 0.1^{\circ}C$. For temperature measurements of more quickly varying nature, thermocouples are superior because they can be made very small (to have small time constant), though they are inherently less accurate than RTD's ($\pm 0.5^{\circ}C$). IR measurements cannot be nearly this accurate because of inherent problems with the technique.

2. AIR FLOW SPEED MEASUREMENT - ANEMOMETRY

The obvious difficulty in measuring air movements within a room is in the small velocity involved, probably on the order of a few centimeters per second[36]. The standard techniques[35] which depend on measuring pressure drop are not useful. Since at such low velocities, pressure drops are virtually zero, and they are usually only applicable for confined flows (clearly a relative term; it means that, based on the scale of the fluid motion, most of the fluid is very far from any boundaries).

There are also a large number of varieties of anemometers which are able to measure wind velocity in an unconfined environment[37]. Older methods are represented by propellers on vanes, two-axis propellers, etc. Newer, higher technology anemometers are sonic, vortex shedding, laser doppler and laser scintillation anemometers, etc. The problem with most of these, however, is that they are typically not accurate to within better than ±1 meter/second. Further, some (the laser systems in particular) require very large working spaces (several hundred meters). These limitations are severe when room air measurements are being considered[36, 38].

The anemometers which can measure flows in the several centimeter/second range are of the "hot-wire" variety, i.e., they depend on heat transfer from a hot object to the moving air; the faster the air flow, the more heat is removed. These have long been in use for wind tunnel measurements, but up until a few years ago their accuracy was not much better than the meter/sec range quoted for the other types of anemometers mentioned[37].

Flow direction can also be critical with some anemometers; generally the anemometer only gives accurate velocity measurement when oriented in a specific direction relative to the airflow. Consequently, anemometers for outdoor use often have vanes or some other means by which the speed sensor is automatically oriented properly in the airflow. For indoor use, where velocities are very small and any obstruction (however slight) can change the flow direction, this creates problems, and the speed sensing anemometer essentially must be direction independent; flow direction can be determined by some other means, such as by fine filaments of hair or soap bubbles.

In 1974, at the Royal Institute of Technology in Stockholm, Sweden, a heated thermistor anemometer was developed which had roughly ±10 percent accuracy down to 10 cm/s speeds. Careful choice of geometry eliminated any significant directional dependence and free convection error was minimal (free convection from a heated thermistor can cause severe errors in a slow vertical airflow)[38]. In 1975, the Electricity Council Research Center (Great Britain) sponsored the development of a heated thermistor anemometer. This meter was able to measure speeds down to 2 cm/s and up to 1 m/s with small directional and temperature dependence.

In 1976, the Air Force Geophysical Laboratory sponsored work to determine the capabilities of and calibrate a corona-discharge anemometer. This works in a slightly different way than the hotwire type discussed above. The anemometer ionizes the ambient air flowing through it and then senses the ion deflection caused by the air motion. Test data indicates that this anemometer might be able to measure speeds as low as 10 cm/s with ±10 percent accuracy.

The major drawback of this anemometer is that it senses velocity in one plane only — the out-of-plane velocity component is not measured; but it can introduce slight errors to the in-plane components when the flow direction is more than 30° out of plane. One major advantage of this device is its very fast response[39].

3. FLUID FLOW RATE MEASUREMENT

The major interest in fluid flow measurement for the Windows-and-Lighting project is in low flow rate, specifically the kind that would be found in typical thermosiphon solar energy systems. Typical thermosiphon flow rates are on the order of 1 gal/hr for each square foot of solar collector area. Thus, if water were the collector fluid and a 10 sq. ft. collector were used, mass flows of greater than 1 lb/min would be reasonable[40].

A major consideration for application to existing buildings is that the flow measurement not interfere with the flow. Thus non-intrusive techniques are desirable; for testing purposes of already existing systems, the techniques would ideally not have to disturb existing plumbing.

i) MASS-FLOW METERS

There are a number of mass-flow meters currently on the market. Mass-flow meters are advantageous over volume-flow meters or flow velocity meters because fluid properties are irrelevant and pipe dimensions need not be known. Micro-Motion sells mass-flow meters which measure quite accurately down into the tenths or even hundredths of pounds/minute flow range[41].

Since the Micro-Motion sensors are simple U-shaped tubes, the flow is relatively unobstructed, and if the sensor is mounted such that the U lies in a vertical plane with one port vertically above the other, the thermosiphoning effect will be undisturbed or even encouraged[42]. Disadvantages are that this would require an intrusion into pre-existing plumbing. These sensors are quite expensive. Flo-tron, Inc., also sells a mass-flow meter which is a fluid-mechanical analog of a Wheatstone bridge. Flow rates much lower than a hundredth of a pound per minute can be measured with these devices, but they also must be inserted into the fluid flow path[43]. Orion Research Inc., has developed a non-obstructive (though it also must be in series with the flow-path) heated thermistor flow meter sensitive down to the 0.5 ml/min range (0.001 lb/min if water)[44].

ii) ULTRASONIC FLOWMETERS

There are a number of ultrasonic flowmeters currently commercially available[45]. The three types are dependent on the vortex frequency counts, the transit-time difference and Doppler shift.

Vortex frequency counting meters[46] require a flow obstruction which is specifically designed to shed vortices into the flow. An ultrasonic wave is amplitude modulated by the vortices, hence it is possible to sense the vortex shedding frequency. This frequency is related to the flow velocity. Since this technique disturbs the flow, it may not be desirable.

Transit-time differencing ultrasonic flowmeters are based on the "rowboat in a stream" principle, i.e., a sound wave propagates more slowly against the flow than with the flow[47]. Controlotron, Inc., of Hauppaug, N.Y., manufactures a family of clamp-on ultrasonic flowmeters[48]. These can be fitted onto pipes as small as 1/2" in diameter and are accurate to ± 1 to 4% for flows faster than 1 fps. As such, they may not be accurate enough for thermosiphoning velocities (more like 1cm/sec)[49]. One important consideration is that the fluid must be homogeneous (not aerated or containing particulate matter).

Doppler shift measuring flowmeters are based on the fact that a sound wave bouncing off a moving target will return with a slightly shifted frequency relative to the emitted beam. This technique of velocity measurement is very popular in the medical arena for non-intrusive blood flow measurements[50-53]. Flow velocities as low as 1 cm/sec are typically measured in the bloodstream. Since the ultrasound beam scattering and reflection come from the moving fluid, it would seem that pipe size should be irrelevant. It also appears that this technique might be applicable to inhomogeneous flows, i.e., with bubbles or small particulate matter. Commercial Doppler flowmeters are on the market, but perhaps not specifically for the low flow rates found in blood vessels or thermosiphoning systems.

Nevertheless, the technology is available to measure low flow rates if it is desired. There is no reason to think that a Doppler ultrasonic flowmeter could not be made in the clamp-on style of the transit-time variety.

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LIST OF REFERENCES

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(Section 4)

A. PASSIVE SOLAR DESIGN

B. HEAT PIPES

C. INSULATION

D. MISCELLANEOUS

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(Section 5)

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B. MATERIALS

C. COATINGS

D. MISCELLANEOUS

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APPENDIX E
LITERATURE REVIEW FORMS

APPENDIX E. LITERATURE REVIEW FORMS

LITERATURE REVIEW FORMS FOR SOILS

(Section 2)

LBL LITERATURE REVIEW FORM

TITLE: Transient Heat and Mass Transfer in Soils

DATE: February 1978

SOURCE: ASME Paper 78-HT-31

AUTHORS: J. Y. Baladi, et al.

ABSTRACT:

Transient heat and mass transfer in soil surrounding a buried heat source are considered. One-dimensional (spherical) models are developed to predict the coupled heat and moisture migration phenomena. Numerical solutions of the exact formulation are given. In addition, two types of closed-form solutions are derived employing approximate models. Experimental measurements are presented for two disparate soil types--a well-graded loam (slow hydraulic response) and sand (more rapid hydraulic response). Predicted and measured temperature variations at the heat source surface are compared. In all cases, the numerical solution of the exact formulation agrees with the experimental data reasonably well. The closed-form solutions deviate somewhat from the measurements, but are shown to be useful for obtaining approximate predictions in a simple manner.

REVIEW:

This paper contains a long list of relevant references on heat transfer in soils. The effects of water table, gravity (i.e., natural convection in the soil), and surface weather conditions are neglected. Thermodynamic coupling between heat flow and water flow is included.

Looks useful in that the author presents a simplified math model that seems to predict temperature distributions in soils rather well.

LBL LITERATURE REVIEW FORM

TITLE: A study of the Superposition of Heat Fields and the Kennelly Formula as Applied to Underground Cable Systems

DATE: 1958

SOURCE: Trans. AIEE, Vol. V, 1330 (1958)

AUTHORS: Conrad A. Bauer, et. al.

ABSTRACT: None given

REVIEW: This paper discusses the applicability of one of the many mathematical expressions used to calculate the steady-state temperature of a buried electric power cable. The authors review some of their test data and conclude that the Kennelly Formula predicts the direction of heat flows correctly for the winter months; for the summer months, the direction of the heat flow is into the earth, not towards the surface as predicted by the Kennally Formula. This paper deserves a very close review.

LBL LITERATURE REVIEW FORM

TITLE: Soil Temperature Under a Paved Runway

DATE: 1972

SOURCE: AD No. 904053

AUTHORS: H. T. Beare

ABSTRACT: Specially designed temperature probes using copper-constantan wire were installed in 3 vertical holes on and near a paved runway at Defence Research Establishment Suffield (DRES) in south-eastern Alberta. Earth temperatures were monitored during the winter of 1970-71. The data obtained showed that, for that particular winter, the maximum depth of below-freezing temperatures was 64 inches. This occurred under the edge of the runway on the 9th of March 1971. In addition, they showed that surface temperatures were well below freezing for several weeks before the soil temperatures dropped below freezing at a depth of one foot; the freezing front under the runway advanced downward at a slower rate than it did at the edge of the runway and the thawing fronts advanced from above and below to meet at a depth of approximately 3 feet below both the runway and the prairie.

REVIEW:

This reference is concerned mainly with freezing and thawing phenomena in soils, which are not a high-priority interest in this program. However, the data indicates that edge effects around the runway, and therefore the ground cover, do exert an influence on the transfer of heat in soils.

LBL LITERATURE REVIEW FORM

TITLE: Heat Transfer in Soils with Freezing and Melting of Moisture

DATE: 1976

SOURCE: ASME 76-WA/HT-22

AUTHORS: J. P. Collinan, et al.

ABSTRACT:

Finite-difference techniques are employed to determine transient temperature fields in typical soils under conditions such that soil moisture undergoes freezing and melting. The techniques are applied to the specific case of the soil beneath an ice hockey rink located in north central USA. One- and two-dimensional numerical solutions of the finite difference equations are compared with good experimental data. The anaytical results agreed in general with the experimental results. However, the model predicted a more rapid penetration of the freezing isotherm into the ground than was indicated by the experimental data. It was found that the temperature profiles along the rink centerline predicted by the one-dimensional model agreed well with those predicted by the two-dimensional model. Two different boundary conditions were examined along the system lower boundary. Both produced very similar results.

The analytical tool may be used to design buildings in cold regions in the world. The freezing isotherms generated by the computer program can be used to estimate the heat losses to the ground. Temperature profiles predicted by an one-dimensional model agree well with those predicted by a two dimensional model. The 1-D model requires an order of magnitude less computer time.

LBL LITERATURE REVIEW FORM

TITLE: Heat-Flux-Temperature Relationships for Closely Spaced Underground Power Transmission Conductors

DATE: 1971

SOURCE: IEEE Transactions, PAS-90, 1256 (1971)

AUTHORS: J. E. Cronin, et. al.

ABSTRACT: The paper examines the relationship between heat flux and sheath temperature for closely spaced underground power transmission systems using both a numerical and an experimental analog approach. The closely spaced condition tends to occur with the recently developed high voltage gas insulated conductors and it is shown that the traditional method of calculation yields sheath temperatures which can be too high by up to 25%.

REVIEW: This paper uses the method of images to determine the temperature distribution around a buried 3-phase transmission line. These results are then compared with results from an electrical analog experiment where 3 copper cylinders are immersed in an electrolyte (i.e., the authors tried to simulate the thermal problem with an electrical analog). The authors conclude that the Kennelly equation is reasonably accurate for the prediction of cable temperatures when the burial depth and cable spacing exceed two cable diameters.

LBL LITERATURE REVIEW FORM

TITLE: Ampacity of Direct-Buried EHV Cables Insulated with SF_6 Gas

DATE: 1970

SOURCE: IEEE Transactions, PAS-89, March, 1970

AUTHORS: Setsuo Fukuda

ABSTRACT: Three models of 275-kV pipe-type cables insulated with SF_6 gas have been experimentally manufactured, and various tests on them were made by the author and his associates from 1965 to 1967. Some problems for the realization of such gas-insulated cables remain unsolved, and among these it may be fairly important to assess thermal characteristics of the cables when they are buried underground.

In checking the heat transfer behavior of SF_6-insulated cable installed beneath the surface of the ground, the third cable model used for short-circuit current testing was buried underground, and some heat transfer characteristics of the model were investigated in the case of steady current flow of up to 3500 amperes.

To keep the maximum temperature of the inner conductors at less than 100°C, current flow of up to 3000 amperes might be allowed, given soil of fairly good condition with a specific thermal resistivity g remaining within 65°C·cm/W. Meanwhile, when values of g are 80 and 100°C·cm/W, 2800- and 2500-ampere currents, respectively, are able to flow to maintain the conductor temperature of 90°C.

From the results of the above experimental data, thermal characteristics of gas-insulated cables can be deduced by calculation, and it may be possible to design EHV SF_6 cables so that their heat transfer characteristics are mostly feasibly accounted for.

REVIEW: This paper contains interesting information on the measurement of temperatures in the vicinity of buried power transmission cables. The experimental data indicates long time constants (on the order of a month or more), which is a result found by other authors. Temperature distributions are measured near a buried 3Ø transmission line, and it would be interesting to compare these results with analytical predictions presented by other authors.

LBL LITERATURE REVIEW FORM

TITLE: The Simulation of Thermal Behavior of Permafrost Soil

DATE: 1976

SOURCE: ASME 76-WA/HT-57

AUTHORS: C. F. Holt, et al.

ABSTRACT:

An engineering approach toward predictions of the thermal behavior of permafrost soils is described. The method employs the local weather and ground surface conditions in producing a transient heat flux boundary condition driving a finite difference soil conduction model. Ambient temperature, solar radiation, wind, and snow are the climatic variables. The nature of the cover, evaportranspiration, albedo, and emissivity are part of the surface characterization. Using available weather data (30-year means), climatic zones were established encompassing a proposed Canadian Arctic pipeline route. Soil data was obtained from borehole samples. At several sites within each zone, predictions of soil temperature were compared to measured values obtained over a three-year period. The success of these comparisons indicates that, in general, regional weather and limited soil data are sufficient for reasonably good predictions of the soil thermal behavior. The importance of soil moisture in obtaining accurate predictions is illustrated.

REVIEW:

The analytical method to predict the ground thermal behavior may be extended to include a building with various window designs to predict the interaction between the ground and the building. The analytical model would be useful in analyzing thermal characteristics of the soil and building even in very cold regions.

LBL LITERATURE REVIEW FORM

TITLE: Heat and Mass Transfer in Cold Region Soils

DATE: 1975

SOURCE: Univ. of Alaska Institute of Water Resources Report #IWR No. 65 (NTIS PB-248457)

AUTHORS: D. L. Kane, et. al.

ABSTRACT: Many parts of interior Alaska have a fire-dominated environment. It has been recognized that there are many beneficial effects of fire; consequently, the past fire control philosophy has been altered. Prescribed and controlled burning are being considered under the new approach. The more intense burns occur in the black spruce (Picea-Mariana) forests which are characterized by a thick organic layer and a shallow mineral soil underlay by permafrost. From field data, it is clear that both the thermal and moisture regimes undergo considerable alteration due to fire. The degree to which these systems are influenced depends upon many factors, primarily that of the intensity of the burn. Soil temperatures in the burned area are much higher than those in the unburned areas in both summer and winter. The impact on the soil moisture regime is not as evident as that on the thermal regime. The total moisture content in a soil column of a burned site shows a slight increase over similar unburned site, apparently reflecting the decrease in plant transpiration. A conceptual model of the long-term thermal effects is presented. In addition, a two-dimensional flow model is applied to saturated flow conditions in the organic layer. This organic layer acts as a buffer to both heat and moisture flow, and therefore, the destruction of this layer is responsible for changes to the physical system.

REVIEW: This reference is concerned with permafrost soils, which is of little interest in the present study. There is a lengthy discussion of ground water flow, which may find application in heat transfer studies of soil environments characterized by a high water table. Very little thermal modelling is found in this report, and most discussions of thermal matters are concerned with the effects of ground cover.

LBL LITERATURE REVIEW FORM

TITLE: Backfill Materials for Underground Power Cables, Phase I

DATE: June, 1977

SOURCE: Electric Power Research Institute (EPRI) Report # EPRI EL-506

AUTHORS: James K. Mitchell, et. al.

ABSTRACT: See attached

REVIEW: This report covers some on-going research at UC-Berkeley. Different methods for the measurement of soil thermal resistivity are discussed. The authors prefer the thermal needle method of measurement and present a design that they feel is adequate for experiments they are doing. The authors discuss various factors which influence the thermal resistivity of soils and present test data for several backfill materials used for buried cables. Additives to increase thermal conductivity as well as the influence of soil preparation are also discussed.

ABSTRACT: Because the allowable current loading of buried electrical transmission cables is frequently limited by the maximum permissible temperature of the cable or of the surrounding ground, there is need for cable backfill materials that can maintain a low thermal resistivity (less than 50°C-cm/watt) even while subjected to high temperatures for prolonged periods. This report describes the results of studies aimed at development of improved methods for placing backfill around underground power cable systems and special treatments to reduce the thermal resistivity and increase the thermal stability of the backfill materials.

The thermal needle method has been selected as the simplest, fastest, and most reliable method for measurement of the thermal resistivity of backfill materials in the laboratory. A special thermal needle design has been developed for this project.

Unlike most mechanical properties of sands and gravels, the thermal conductivity of backfill materials is not affected by the method of compaction used, provided comparisons are made at a given value of density. On the other hand, samples compacted wet and then dried have a lower thermal resistivity than do samples compacted dry.

Additives which can either (1) prevent water migration in the soil due to temperature gradients, or (2) substitute for water in bridging the gaps between particles have potential usefulness for backfill treatment. Three water absorbing polymers were tested and found to retard, but not prevent water migration. Once dried, samples treated with these materials had poorer thermal properties than did the untreated soil.

No additivies have been found that can produce a material with a thermal resistivity significantly less than that of the untreated wet compacted material, i.e., 30-60°C-cm/watt, depending on the soil type, density, etc. On the other hand, portland cement, C-7 (a cement-based additive), inexpensive waxes, and asphalt treatment can maintain a low thermal resistivity, even after complete drying of the material. Hence, they act as suitable water substitutes, are not susceptible to migration, and appear to be durable, although testing is not yet complete to confirm all aspects of durability.

A finite element computer program HEAT has been used to study transient and stead-state heat flows and temperature distributions for typical buried cable systems. This program allows for detailed modeling of geometrical conditions, native soil and backfill properties, surface cover, and weather conditions. The dominating influence of the thermal resistivity of the trench backfill on the temperature distributions and allowable thermal loading is readily apparent from the analyses.

Theories for moisture migration under thermal gradients have been studied, and the Philip and deVries theory has been selected for

analysis of trench and backfill systems. Thermal and moisture diffusion properties of three sands characteristic of those to be encountered in actual buried cable systems have been measured. Analyses of moisture flows to be expected for different cable operating temperatures are planned.

The next phase of this investigation will include field tests to evaluate both the performance of the most promising backfill treatments and the accuracy of the developed heat and moisture flow predictive methods.

LBL LITERATURE REVIEW FORM

TITLE: Development of a Compressed-Gas-Insulated Transmission Line

DATE: 1971

SOURCE: IEEE Paper 71 TP 193-PWR (1971)

AUTHORS: B. O. Pederson, et. al.

ABSTRACT: Development of Compressed-Gas-Insulated transmission lines for voltages of 138 to 500 kV is described. Design, manufacture and installation are presented. Dielectric and mechanical tests data are given. A 230 kV single-phase outdoor test line of 230 ft. length has been installed and voltage and current tests have been initiated. Thermal data for currents up to 3000A are reported.

REVIEW: This paper contains some measured sheath temperatures on buried power transmission calbes, and these measurements may be of interest when compared with analytical predictions made by other authors.

LBL LITERATURE REVIEW FORM

TITLE: Mathematical Solution to the Problem of the Control of the Thermal Environment of Buried Cables

DATE: 1960

SOURCE: Trans. AIEE, Vol. 76, 175 (1960)

AUTHORS: J. V. Schmill

ABSTRACT: None given

REVIEW: This paper deals with the mathematical solution of non-uniform thermal conductivity in cable trenches filled with specially prepared backfill materials. It does not address the problem of water migration, but it may be of use in those applications where water migration is small. The mathematics is typical Carslaw and Jaeger and is extremely complex algebraically.

LBL LITERATURE REVIEW FORM

TITLE: Variable Soil Thermal Resistivity - Steady State Analysis

DATE: 1970

SOURCE: IEEE Transactions, PAS-86

AUTHORS: J. V. Schmill

ABSTRACT: The detrimental effects of moisture migration in soils on the ampacity of buried cable systems is an old fact recognized by cable engineers. Yet, no direct method to take this phenomenon into consideration has been available in the past to determine the proper ratings of power cables. The effects of soil moisture content on the variation of the thermal resistivity of the soil are discussed and equations established to determine the effective thermal resistivity when moisture migration has occurred and a final steady state has been reached.

REVIEW: The author uses a simple exponential equation to characterize the effect of moisture content on the thermal conductivity of soil. He then assumes that the moisture content varies linearly with radial distance from a buried cylindrical pipe. Analytical results are presented for a cylinder buried deep in the ground and for a cylinder located near the ground surface.

LBL LITERATURE REVIEW FORM

TITLE: Underground Distribution Thermal Tests in the Phoenix Area

DATE: September 1967

SOURCE: IEEE Trans., PAS-86

AUTHORS: N. R. Schultz, et al.

ABSTRACT: This paper summarizes the results of an 18-month thermal test program conducted jointly by the Arizona Public Service Company and the General Electric Company to investigage thermal characteristics of soil and performance of underground equipment in the Phoenix area. The results presented include earth ambient temperatures at various depths over an annual cycle, earth thermal resistivity measurements by steady-state and transient methods, performance of direct burial and vault installation of capacitors, performance of a directly buried, 25-kVA, pole -type distribution transformer, and temperature rise of simulated cables.

REVIEW: Contains some interesting results. Soil temperatures measured under an asphalt blacktop surface were consistently higher than soil temperatures measured under a bare soil surface. Measurement of soil thermal resistivity proved to be difficult; the authors were most successful in obtaining good data with moist soil. Steady-state temperatures of simulated underground cables did not vary significantly with either depth of burial or type of second cover (i.e., bare soil or black-top surface).

LBL LITERATURE REVIEW FORM

TITLE: Soil Thermal Resistivity Measured Simply and Accurately

DATE: February 1970

SOURCE: Trans. IEEE, PAS-89

AUTHORS: John Stolpe

ABSTRACT: There is a growing need for each utility to gain a thorough knowledge of the soil thermal resistivity throughout its system. The volume of heavily loaded multiduct runs of power cables promises to increase rapidly in the years ahead. We can no longer afford to plan for cable loadings based purely on an assumed soil thermal resistivity. Rather, we must compile information that accurately describes the thermal resistivity of soils commonly found within specific geographic areas; then very realistic values of soil thermal resistivity can be used in the planning of new underground systems in these areas.

This paper describes the design and utiliziation of apparatus that has demonstrated convenience and reliability in the analysis of thermal properties of soils and soil-like materials. The scope of established test procedures is related. Test results and various correlations that have been found from preliminary testing are reviewed and illustrated.

REVIEW: A description of a laboratory apparatus for measurement of the thermal resistivity of soils as a function of moisture content and degree of compaction. This device is not a thermal needle, which has been used by other authors. In the apparatus described here, the soil sample is placed between two concentric cylinders; the inner cylinder is loaded and thermocouples are used to measure temperatures in the soil. The thermal resistivity is calculated by means of the Fourier heat conduction law.

LBL LITERATURE REVIEW FORM

TITLE: Dielectric Constants of Soils at Microwave Frequencies - II

DATE: 1978

SOURCE: NASA Report TP-1238

AUTHORS: J. Wang, et al.

ABSTRACT: The dielectric constants of several soil samples were measured at frequencies of 5 and 19 GHz using the infinite transmission line methods. The results of these measurements are presented and discussed with respect to soil types and texture structures. A comparison is made with other measurements at 1.4 GHz. At all three frequencies, the dependence of dielectric constant on soil moisture can be approximated by two straight lines. At low moisture, the slope is less than at high moisture level. The intersection of the two lines is believed to be a function of soil texture.

REVIEW: The main interest in this report is in that it appears to offer a way of making measurements of soil moisture content without actually having to dry out the soil sample.

LBL LITERATURE REVIEW FORM

TITLE: Soil Thermal Characteristics in Relation to Underground Power Cables, AIEE Committee Report

DATE: December, 1960

SOURCE: Trans. AIEE, PAS 79, 792 (1960)

AUTHORS: R. J. Wiseman, et al.

ABSTRACT: None given.

REVIEW: An extremely thorough report which is divided into the five following areas of concern: (1) soil types, identification, and physical properties, (2) soil moisture characteristics, (3) soil thermal resistivity, typical field valves, and calculating formulas, (4) practical application, french design and construction and (5) measurement techniques.

LBL LITERATURE REVIEW FORM

TITLE: Pavement Heating - Executive Summary

DATE: 1977

SOURCE: Federal Highway Administration Report FHWA-NJ-77-003A

AUTHORS: F. Winters, et al.

ABSTRACT: In order to evaluate a roadway heating system which utilized the energy stored in the earth for snow melting, a 3200 square foot experimental heated pavement was constructed in Trenton, New Jersey. Heat was extracted from the earth by means of a grid of pipes buried 3 to 13 ft. below ground and transferred via an ethylene glycol-water solution to pipes embedded in a test pavement. For purposes of comparison, a section of pavement heated by electrical resistance wires was also included as part of the installation.

Results of operation have indicated that the best snow melting has taken place on sections of portland cement concrete containing 3/4" and 1-1/4" wrought iron pipe spaced on 6" centers and embedded at a depth of 2 inches. These sections produced an average heat dissipation rate of approximately 100 BTU's per square foot of surface area per hour when 2 linear feet of pipe buried in the earth were coupled to 1 linear foot of pipe embedded in the test pavement. Snow melting rates were usually between 1/4 inch and 1/2 inch per hour.

During the summers of 1970 and 1971 the system was operated for the purpose of transferring heat from the warm pavement to the earth where it could be stored for use during the winters. Heat was successfully transferred; however, due to the loss of heat to the surrounding earth and the atmosphere during the fall, no significant storage of heat was achieved by the start of the snow season. The thermal insulation used with the pipes buried 3 to 13 feet in the earth was not effective in reducing heat loss during the fall.

REVIEW: Though this installation was shown to be more economical to operate than an electrically heated pavement, the total cost was higher when construction cost was considered.

This publication is of relevence to thermal storage in soils. There is little of interest that is relevant to understanding the mechanisms of heat transport in soils.

LBL LITERATURE REVIEW FORM

TITLE: The Thermal Analysis of a Direct-Buried Distribution Transformer Under Cyclic Loads

DATE: 1974

SOURCE: Underground Transmission and Distribution Conf.

AUTHORS: P. S. Yeh

ABSTRACT: The thermal performance of a direct-buried distribution transformer under cyclic loads is investigated from the simplified approach of equivalent-sphere assumption, in which, by replacing the cylindrical transformer tank with a sphere of equal surface area, the steady state and the transient state temperature rise equations are derived. These equations should be interpreted as representing the top oil rise. It is shown that for a direct-buried transformer, the exponential power of temperature rise versus loss is equal to one; the time constant is much larger than that of an overhead type, it is in the order of a few days; and the fluctuations in top oil rise are usually very small.

REVIEW: This is a conduction analysis of a buried cylindrical tank. The author assumes that the tank can be replaced by a sphere of equal surface area; the centroids of the cylindrical tank and sphere are buried to the same depth. Moisture migration is neglected, and the method of images is used to determine the temperature distribution in the soil. The transient thermal analysis is straight out of Carslow and Jaeger. This paper doesn't present test data or have a lot to say about mechanisms of heat transfer in soils.

LBL LITERATURE REVIEW FORM

TITLE: Effect of Moisture Migration on the Temperature of a Direct-Buried Cylindrical Heat Source

DATE: December 1976

SOURCE: ASME Paper 76-WA/HT-50

AUTHORS: P. S. Yeh

ABSTRACT:

For a direct-buried cylindrical heat source, such as a residential distribution transformer, the effect of moisture migration in the surrounding soil on the temperature rise of the heat source is investigated analytically. The solution for the temperature rise consists of a linear part and a nonlinear part. The linear part is a function of geometry only, while the nonlinear part is a function of geometry, heat generation, moisture migration factor, and soil thermal conductivity. The correction in temperature rise, i.e., the nonlinear part, increases as the diameter or the length of the cylinder decreases, and it increases as the moisture migration factor or the heat generation increases. This correction can be as much as 10 percent of the linear part. Present analytical results compare favorably with test results.

REVIEW:

Contains references to pertinent previous work, especially experimental tests on heat transfer in soils. Uses method of images and empirical relations for effect of moisture on value of soil thermal conductivity. Effects of gravity and water table are not included.

Include bibliography on heat transfer in soils.

LBL LITERATURE REVIEW FORM

TITLE: Heat Transfer in Solar Energy Storage

DATE: 1977

SOURCE: ASME Paper 77-HT-38

AUTHORS: S. W. Yuan, et al.

ABSTRACT:

The purpose of this investigation is to analyze the heat transfer characteristics of a solar energy storage concept that uses unprepared earth as a storage medium. Two methods of heating and extraction are considered. The first method uses a water pipe heat exchanger for both the heating and extraction phases. The second method uses a heat pipe during the heating phase and a water pipe during the extraction phase. The heat input to the earth storage is obtained by the operation of solar collectors. The solar collection process is activated during the day and is deactivated during the night. Solar energy is collected by this procedure throughout the entire year and stored in the eart reservoir. For space heating applications, house load data are appled to the earth storage during the winter months. It is demonstrated that year round solar collection and approximately 400,000 ft^3 of earch storage is adequate to provide space heating for twelve average size houses in most areas of the United States. Furthermore, the use of a heat pipe on the heating phase may reduce the initial preparation time for the earth storage.

REVIEW:

Uses transient conduction analysis in which effects of moisture on soil thermal properties and the effects of moisture migration on heat transport are not taken into account. Initial conditions and boundary conditions seem to yield soil temperatures of 180^{o}F - 200^{o}F which may not be acceptable from the environmental view point. Thermal losses from the storage system were not taken into account in the analysis, and the authors' experiments indicated that these losses could be significant.

Results might be good for first round of calculations, but not for detailed design calculations.

LITERATURE REVIEW FORM FOR THERMAL STORAGE

(Section 3)

LBL LITERATURE REVIEW FORM

TITLE: Hydrogen-in-Metals Conference

DATE: September 1977

SOURCE: Office of Naval Research

AUTHORS: W. N. Cathey

ABSTRACT: The Second International Congress on Hydrogen in Metals was held in Paris, 6-10 June 1977. This report presents a review of a few important papers. Most of the papers were related to applied problems. In particular, problems of H-related damage to engineering alloys were treated extensively. In addition to work on H in pure metals such as Pd, Nb, and other transition metals, some work was also reported on H in alloys such as Nb-Ti, Pd-Ag, and various steels. Storage of H in intermetallic compounds such as $FeTiH_x$ or $LaNi_5H_x$ was of importance.

REVIEW: This paper deals with hydrogen in metal as an energy converter on an atomic scale, a solid state physics research topic. The information has limited use to our study.

LBL LITERATURE REVIEW FORM

TITLE: Summary of the Metal-Air Fuel Cell Research Programs

DATE: September 8, 1977

SOURCE: Lawrence Livermore Lab.

AUTHORS: John F. Cooper

ABSTRACT: The objective of this research program is to determine whether a full-performance, economical electric vehicle can be developed using a mechanically-rechargeable, metal-air fuel cell as a power source.

REVIEW: The metal-air fuel cell could potentially be used for energy storage. It is important to find an inexpensive metal to make the fuel cell economically feasible.

LBL LITERATURE REVIEW FORM

TITLE: Hydration-Dehydration Cycling of MgO-$Mg(OH)_2$ for Application to Solar Heat Storage Systems

DATE: September 30, 1976

SOURCE: N77-26654, AI-ERDA-13178.

AUTHORS: G. Ervin

ABSTRACT:

A method of storing heat energy by utilizing reversible chemical reactions of inorganic oxides with water is investigated.

REVIEW:

Using chemical reaction for heat storage may not be a practical idea. It has too many problems.

LBL LITERATURE REVIEW FORM

TITLE: Thermal Energy Storage Heat Exchanger

DATE: October 1977

SOURCE: N78 14633, NASA CR135245

AUTHORS: Angelo Ferarra, et al.

ABSTRACT:

This report presents sizing procedures for latent heat thermal energy storage systems that can be used for electric utility off-peak energy storage, solar power plants and other preliminary design applications. The methods were developed in a one year study of electric utility energy storage which is documented in CR 135244 "Thermal Energy Storage Heat Exchanger."

REVIEW:

Storing excess thermal energy in the latent heat of salts during off-peak hours of electric utility plants to provide energy to meet peak requirement is an important technology. This should be investigated further.

LBL LITERATURE REVIEW FORM

TITLE: Performance Potential of the Energy Separator without Mechanical Energy Recovery

DATE: April 1977

SOURCE: N78-10601

AUTHORS: Joseph V. Foa

ABSTRACT:

An evaluation is made of the performance potential of the "basic" energy separator heating or cooling system, i.e., of the ES system that does not include any machine component for the recovery of available mechanical energy on the "hot" side.

REVIEW:

The paper points out the potential of the energy separator being used for solar energy storage and for simultaneously heating and cooling separate spaces. It is definitely worthwhile to examine the energy separator further.

LBL LITERATURE REVIEW FORM

TITLE: Solar Total Energy Test Facility Project Fast Results-High-Temperature Thermocline Storage System

DATE: April 1978

SOURCE: SAND77-1528

AUTHORS: Thomas D. Harrison, et al.

ABSTRACT:

This report contains summaries and analyses of the results of tests conducted on the High-Temperature Thermocline Storage Subsystem between August 1976 and June 1977 to determine the effectiveness of the insulation and the stability of the thermocline. The High-Temperature Thermocline Storage Subsystem is part of the Department of Energy's Solar Total Energy Test Facility at Sandia Laboratories, Albuquerque, New Mexico. The data, analyses and conclusions are complemented with those from the thermocline storage system associated with the DOE/New Mexico Solar Irrigation Project.

REVIEW:

The paper describes a thermal storage subsystem in a solar total energy test facility. Some of the features may be used for thermal storage in buildings.

LBL LITERATURE REVIEW FORM

TITLE: Development of a Practical Photo Chemical Energy Storage System (Annual Report)

DATE: June 15, 1976 - June 14, 1977 and March 15, 1977

SOURCE: ERDA SRO-893-8,-9, -10

AUTHORS: R. R. Hautala, et al.

ABSTRACT:

Significant progress toward the development of a solar energy storage system based on the norbornadiene-quadricyclene interconversion has been achieved during the past year. New sensitizers and catalysts have been discovered and conditions found where single cycles of the photosensitization step and the catalytic reversion step appear to be quantitative. Both sensitizers and catalysts have been successfully incorporated onto insoluble polymeric supports. The long term stability of these components is currently being tested using a recently constructed prototype device designed for multiple recycling experiments. Investigations are also underway on design modifications which will allow incorporation of the norbornadiene-quadricyclene system into currently available state-of-the-art solar collectors.

REVIEW:

This should be pursued for our final report. The SRO-893-10 report seems to have useful numerical data for conversion rates, etc. The others seem to be largely discussions of the chemistry.

LBL LITERATURE REVIEW FORM

TITLE: Thermal Energy Storage for Building Heating and Cooling Applications - Quarterly Progress Reprot

DATE: 1976

SOURCE: N77-22617, ORNL TM 5700.

AUTHORS: H. W. Hoffman, et al.

ABSTRACT:

Work consists of the development of a time-dependent analytical model of a thermal energy storage (TES) system, the physical chemistry of TES materials.

REVIEW:

The analytical model may be coupled to existing overall performance models of solar collectors and applications to make realistic appraisal of the entire Solar/TES/Application systems.

LBL LITERATURE REVIEW FORM

TITLE: A Design Handbook for Phase Change Thermal Control and Energy Storage Devices

DATE: November 1977

SOURCE: N78-15434, NASA TP-1074

AUTHORS: W. R. Humphries, et al.

ABSTRACT:

This document gives a comprehensive survey of the thermal aspects of phase change material devices. Fundamental mechanisms of heat transfer within the phase change device are discussed. Performance in zero-g and one-g fields are examined as it relates to such a device. Computer models for phase change materials, with metal fillers, undergoing conductive and convective processes are detailed. Using these models, extensive parametric data are presented for a hypothetical configuration with a rectangular phase change housing, using straight fins as the filler, and paraffin as the phase change material. These data are generated over a range of realistic sizes, material properties, and thermal boundary conditions. A number of illustrative examples are given to demonstrate use of the parametric data. Also a complete listing of phase change material property data are reproduced herein as an aid to the reader.

REVIEW:

This survey gives a quite comprehensive discussion of various types of phase change material for thermal storage purpose. It is a good source of information.

LBL LITERATURE REVIEW FORM

TITLE: Application of Heat Pipes to Ground Storage of Solar Energy

DATE: June 1977

SOURCE: AIAA Paper 77-729 (Presented at 12th Thermophysics Conference)

AUTHORS: E. J. Kroliczek, et al.

ABSTRACT:

A heat pipe concept design for application to residential solar energy storage has been developed. The basic feasibility of the concept has been demonstrated in prototype testing at George Washington University. The design incorporates the simplicity and high efficiency of the heat pipe together with current heat pipe thermal control techniques and an external pump assist for liqudi return against gravity. As configured the heat pipe system provides the capability of transferring heat from solar collectors to an energy storage area and points of utilization within a single heat transfer element. All control functions are inherent in the heat pipe construction including automatic shutdown of the solar collector zone when positive net energy flow is not achieved. Pumping power requirements are minimal and needed only during solar input perids. Future designs could utilize solar energy to drive the pump. Finally, the heat pipe system can be interfaced with any one or combination of household heat transfer mediums including air, hot water or working fluids from air conditioners or heat pumps. This paper describes the concept, the details of a prototype design and the results obtained with a simulated ground storage test system.

REVIEW:

This paper contains a discussion of a heat pipe capable of transporting heat from a solar collector to a storage medium at a lower elevation. Liquid return from condenser to evaporator is provided by a small pump. The same job could be accomplished <u>without a pump</u> with an osmotic heat pipe. However, this is a very interesting paper.

Of limited value for present study.

LBL LITERATURE REVIEW FORM

TITLE: Latent Heat and Sensible Heat Storage for Solar Heating Systems.

DATE: May 1974

SOURCE: N75-17005

AUTHORS: Harold G. Lorsch

ABSTRACT:

Thermal Energy Storage (TES) suitable for solar heating and off-peak air conditioning was investigated in devices using either sensible heat or latent heat. Parametric designs for two latent heat materials (sodium thiosulfate pentahydrate and a paraffin wax) and for a sensible heat material (a 1:1 mixture of water and ethylene glycol) were compared as to cost, performance, and space requirements. The conditions of equal cost for latent heat and sensible heat storage systems were determined as functions of material properties and the temperature swing allowed in the sensible heat storage tank. The comparative designs include the cost of the heat exchanger required for latent heat storage and the operating penalty due to temperature swings occurring for sensible heat storage.

REVIEW:

This paper compares the latent heat storage and sensible heat storage concepts. The information will be useful in determining what type of storage to use under various building conditions.

LBL LITERATURE REVIEW FORM

TITLE: Thermal Energy Storage for Heating and Air Conditioning

DATE: 1976

SOURCE: Future Energy Production Systems, Heat and Mass Transfer Processes, Volume 1

AUTHORS: H. G. Lorsch, et al.

ABSTRACT:

Latent heat thermal energy storage materials suitable for solar heating and air conditioning are investigated and evaluated in terms of criteria developed to judge their usefulness. Sodium sulfate decahydrate and its mixtures are shown to have undesirable melting properties, causing a reduction in storage capacity upon repeated cycling. Materials more suitable at present are paraffin waxes for solar heating, and paraffin waxes and tetrahydrofuran hydrate for air conditioning. Sensibel heat storage has the economic advantage of not requiring heat transfer surfaces between storage and collection and between storage and delivery. Latent heat storage provides operational advantages of smaller temperature swings, lower required solar collector temperature, and smaller size and lower weight per unit of storage capacity. The optimization of the thermal energy storage subsystem is dependent on the collection and delivery characteristics of the system. Parametric designs for two latent heat materials (sodium thiosulfate pentahydrate and a paraffin wax) and for a sensible heat material (1:1 mixture of water and ethylene glycol) are compared as to cost, performance, and space requirements. The conditions of equal cost for latent heat and sensible heat storage systems were determined as functions of latent heat capacity, thermal conductivity, and the temperature swign allowed in the sensible heat storage tank. The comparative designs include the cost of the heat exchanger required for latent heat storage and the operating penalty due to storage temperature swings inherent in sensible heat storage.

REVIEW:

This paper presents a good comparison of thermal storage systems, sensible heat versus latent heat. The paper goes into great details of design features of each system and discusses the pros and cons. It appears to be a good source of information.

LBL LITERATURE REVIEW FORM

TITLE: Two Component Thermal Energy Storage Material

DATE: November 1975

SOURCE: N77-10675, PB 252 592

AUTHORS: E. M. Mehalick, et al.

ABSTRACT:

Effective storage of thermal energy requires a stable storage medium which has a high heat capacity, high rates of heat transfer, and a reasonable system size and cost. A thermal energy storage medium consisting of a slurry of spherically shaped capsules of encapsulated paraffin in a water carrier combines the advantages of the heat capacity of a phase change material and the high heat transfer rate of a slurry to meet these requirements. The feasibility of this concept was evaluated by subjecting samples of such slurries to simulated solar system environmental conditions which included thermal cycling, system temperature levels, and slurry flow agitation due to stirring and pumping. The results of the evaluation program showed that paraffin can be encapsulated with a wall durable enough to withstand the temperature, thermal cycling and moderate agitation without damage. The slurry storage capacity was also shown to be a factor of two higher than a water system on a per unit volume basis, assuming a 20^{O}F temperature change and a 40 percent solids slurry. The potential exists for even higher storage capacities at higher solids concentration levels. These results, in addition to the capability of several encapsulation manufacturers to improve capsule properties with additional research, show that the encapsulated paraffin slurry is a potential high capacity thermal energy storage medium. This report summarizes the results of the evaluation program and discusses the potential for application of this thermal storage concept.

REVIEW:

Paraffins are compatible with current encapsulation techniques, low in cost and readily available. Paraffins appear to be a good phase change materials to use for thermal storage.

LBL LITERATURE REVIEW FORM

TITLE: Temperature Distribution of a Hot Water Storage Tank in a Simulated Solar Heating and Cooling System

DATE: November 1976

SOURCE: N77-12 521

AUTHORS: D. Namkoong

ABSTRACT:

A 2300-liter hot water storage tank has been studied under conditions simulating a solar heating and cooling system. The initial condition of the tank, ranging from 37°C at the bottom to 94°C at the top, represented a condition midway through the start-up period of the system. During the 5-day test period, the water in the tank gradually rose in temperature but in a manner that diminished its temperature stratification. Stratification was found not to be an important factor in the operation of the particular solar system studied.

REVIEW:

Relates to thermal storage -- use in report.

LBL LITERATURE REVIEW FORM

TITLE: Thermal Energy Storage Subsystems

DATE: December, 1977

SOURCE: DOE/NASA CR - 150574

AUTHORS: F. Ordway

ABSTRACT:

Polypropylene and high density polyethylene are suitable materials for making effective containers for the salt hydrate mixtures used for thermal energy storage. The containers can provide permanent encapsulation, adequate heat transfer and reasonable economy.

REVIEW:

The report describes the process of designing a container in detail. The containerized salt hydrate shows promise as a means of thermal storage for home use.

LBL LITERATURE REVIEW FORM

TITLE: Metal Hydrides as Hydrogen Storage Media and Their Applications

DATE: July 1976

SOURCE: N78-20589

AUTHORS: J. J. Reilly

ABSTRACT: One potentially attractive alternative to conventional storage methods is storage as a metal hydride. Such compounds are of interest because of their high hydrogen density per unit volume which may be substantially greater than that of liquid hydrogen. Our purpose in this chapter is severalfold, i.e., to acquaint the reader with the more salient and pertinent aspects of metal hydride chemistry, to delineate the properties of several individual metal-hydrogen systems of interest and, finally, to discuss their applications, particularly as energy storage media.

REVIEW: Survey article on the fundamentals of metal-hydride chemistry and metal hydrogen systems and on their applications as energy storage media. Metal hydrides are a candidate for solar energy storage and conversion. Cites 62 references. Appears useful and worthy of further study during the technology review.

LBL LITERATURE REVIEW FORM

TITLE: Fiber Composite Flywheel Program/Quarterly Progress Report

DATE: July - September 1977

SOURCE: N78-25 592, LLL UC-946

AUTHORS: J. A. Rinde

ABSTRACT:

This is a progress report discussing

- o Stress-Rupture life--data acquisition
- o Composite Properties - data acquisition
- o Composites with Flexible Matrices -- behavior prediction

REVIEW:

If we want some accurate data this may be useful, but LLL should probably be contacted for more of such information if it is desired.

LBL LITERATURE REVIEW FORM

TITLE: Composite Fiber Flywheel for Energy Storage

DATE: 4 June 1976

SOURCE: N77-19645

AUTHORS: J. A. Rinde, et al.

ABSTRACT:

The use of the flywheel as an energy storage device has received widespread interest in the last two years. Because of their high strength-to-density ratio, relatively inexpensive fabrication process, and low safety hazards, composite materials offer great potential for efficient flywheel design. Key portable and stationary applications of the flywheel are discussed and examples of these presently under consideration at LLL are described in some detail. Design data on key candidate composite material system are reported and areas that require further extensive study are also discussed. In addition, on-going programs, including those of LLL, are summarized.

REVIEW:

Pursue in more detail for final reports.

LBL LITERATURE REVIEW FORM

TITLE: Parametric Study of Rock Pile Thermal Storage for Solar Heating and Cooling

DATE: October 1977

SOURCE: N78-13552

AUTHORS: H. Saha

ABSTRACT:

The objective of this investigation is to present the test data and an analysis of the heat transfer characteristics of a solar thermal energy storage bed utilizing water filled cans as the energy storage medium.

REVIEW:

This paper contains a lot of test data of using water filled cans for thermal storage. The usefulness of the test data should be examined later.

LBL LITERATURE REVIEW FORM

TITLE: High Performance Fuel Cells

DATE: January 1970

SOURCE: Allis Chalmers, AEPD Division

AUTHORS: D. W. Vannatta

ABSTRACT: The objective is to develop the technology required for a high performance hydrogen/oxygen fuel cell system for future Air Force space vehicle applications. During this reporting period, work was continued on analysis, fabrication, and test of two 5-kW fuel cell stacks; and on the procurement of water removal control valves.

REVIEW: This is an aerospace technology which may be used as a terrestrial energy source. Further investigation is warranted.

LITERATURE REVIEW FORM FOR THERMAL TRANSFER

(Section 4)

LBL LITERATURE REVIEW FORM

TITLE: An Inexpensive Economical Solar Heating System for Homes

DATE: July 1976

SOURCE: N76 27671

AUTHORS: J. W. Allred, et al.

ABSTRACT:

This report describes a low-cost solar home heating system to supplement the homeowner's present warm-air heating system. The report is written in three parts: (1) A brief background on solar heating, (2) Langley's experience with a demonstration system, and (3) information for th homeowner who wishes to construct such a system. Instructions are given to the homeowner for solar heating installation in which he supplies all labor necessary to install off-the-shelf components estimated to cost $2000. These components, which include solar collector, heat exchanger, water pump, storage tank, piping, and controls to make the system completely automatic, are readily available at local lumber yards, hardware stores, and plumbing supply stores, and they are relatively simple to install. Manufacturers and prices of each component used and a rough cost analysis based on these prices are given for the homeowner's convenience. This report also gives performance data obtained from a demonstration system which has been built and tested at the Langley Research Center.

REVIEW:

This do-it-yourself approach is interesting. The performance data of the solar houses should be helpful. Further examination is warranted.

LBL LITERATURE REVIEW FORM

TITLE: Transmission of Energy by Open-Loop Chemical Energy Pipeline

DATE: September 1977

SOURCE: N78-27576

AUTHORS: N. R. Baker

ABSTRACT: The primary objective of this program is to evaluate the technical feasibility and, in a preliminary fashion, the economic viability of transmitting and storing energy by an open-loop modification of the reversible chemical energy pipeline system known as EVA/ADAM. The work designed to achieve this objective includes -

- o The preliminary design of a nuclear (HTGR) and methane-based open-loop system (Task 1)
- o Evaluation of energy sources as alternatives to those in the preliminary design (e.g., coal gasification and HTGR/LNG) (Task 2)
- o Assessment of the feasibility of using existing natural gas pipelines and storage systems for the synthesis gas (Task 3)
- o Assessment of existing methanation technologies and interchangeability of the SNG with natural gas (Task 4)
- o Evaluation of the various alternative energy end-uses for heat, SNG, and electricity (Task 5)
- o Development of two conceptual designs and evaluation of their economics and environmental impacts (Task 6)

REVIEW: Assessment of the feasibility of an open-loop version of chemical energy transport, which has been studied earlier as a closed-loop system. This concept might be applicable to passive solar systems and therefore is worthy of further study during the technology review.

LBL LITERATURE REVIEW FORM

TITLE: Simulation Analysis of Passive Solar Heated Buildings - Preliminary Results

DATE: January 1976

SOURCE: Solar Energy, 19, 277 (1977)

AUTHORS: J. D. Balcomb, et al.

ABSTRACT:

Solar gains through windows, walls, modified walls, skylights, clerestory windows, and roof sections provide an opportunity to dramatically reudce the total heating energy requirements of a building. Many such passive solar heating elements are currently available to a designer presenting a large number of possible system designs. A computer simulation analysis has been employed to aid in the selection of components. The results indicate that a performance comparable to that of a conventional active solar heating system should be achievable in an optimized design passive solar heating system. The placement and type of thermal storage is crucial to good performance. Movable insulation of the window increases the performance. When used in conjunction with a conventional heating system, temperature variations in the building can be reduced to those normally experienced.

REVIEW:

The simulation analysis code is a very useful tool in determining the thermal performance of windows, thermal storage, walls and buildings.

LBL LITERATURE REVIEW FORM

TITLE: The Development of a Freeze-Tolerant Solar Water Heater Using Crosslinked Polyethylene as a Material of Construction

DATE: March 15, 1977

SOURCE: N78 15584

AUTHORS: J. M. Bradley

ABSTRACT:

Fifteen 10 foot coils of crosslinked tubing have been subjected to repeated freezing and thawing. The composition of the crosslinked polyethylene and the stress in the wall of the tubing (i.e., "hoop stress") are parameters which are being studied to find a crosslinked polyethylene composition which will be strong and resilient enough to withstand repeated freezing and thawing without necessitating excessively thick walls.

REVIEW:

The tubing showed promise as materials for constructing collectors. Unfortunately, this paper does not give details of the test and thermal properties of the materials.

LBL LITERATURE REVIEW FORM

TITLE: Solar Hot Air Heater

DATE: May 1978

SOURCE: N78 25548, DOE/NASA CR-150697

AUTHORS: W. A. Brooksbank, Jr.

ABSTRACT:

This Design Data Brochure provides information on the design, installation, performance, and application of SEECO Mod-1 Solar Hot Air Heater for residential, commercial and industrial use.

The system has been installed at the Concho Indian School in El Reno, Oklahoma.

REVIEW:

Look into this in more detail.

LBL LITERATURE REVIEW FORM

TITLE: Thermic Controls to Regulate Solar Heat Flux into Buildings

DATE: August 25, 1975

SOURCE: N76 20675, PB 246 364

AUTHORS: S. Buckley

ABSTRACT:

The purpose of this project was to develop thermic controls for regulating solar heat flux into buildings. Thermics is a control discipline which uses temeprature to directly control heat flow. Many independent panels, replacing building walls and roof and controlled internally by thermic devices, would perform three functions: 1) collect solar energy or dissipate internal heat, 2) control the flow of heat into and out of the panel and 3) store heat inside the panel. The panel is to save heating costs in winter by absorbing solar energy and save air-conditioning costs in summer by dissipating internal heat at night. A primary objective of the panel was to make its installed unit cost approximately that of conventional walls and roofs. Early research indicated that a switchable thermic diode was the most economic thermic control for use in the panel.

REVIEW:

The thermic control device sounds like a good idea. A lot of problems will have to be solved to make it practical. However, it should be studied further.

LBL LITERATURE REVIEW FORM

TITLE: Preliminary Design Package for Solar Collector and Solar Pump

DATE: April 1978

SOURCE: N78 22472, DOE/NASA CR-150630

AUTHORS: Calmac Manufacturing Corporation

ABSTRACT:

Calmac Manufacturing is developing a solar-operated pump using an existing solar collector, for use on solar heating and cooling and hot water systems. These systems are for use in single-family, multi-family, or commercial buildings. This report contains the information necessary to evaluate the preliminary design of the Calmac collector and solar-powered pump, and is a collation of the following information: preliminary design drawings, Verification Plans, Hazard Analysis, and other information valuable in defining the design of the subsystem.

REVIEW:

This is an interesting topic but the report contains very little information. It is not worth reading further.

LBL LITERATURE REVIEW FORM

TITLE: High Efficiency, Long Life Terrestrial Solar Panel

DATE: September 1, 1977 through November 30, 1977, First Quarterly Report

SOURCE: N78 24649

AUTHORS: T. Chao, et al.

ABSTRACT:

The design of a high efficiency, long life terrestrial module has been completed. It utilizes 256 rectangular, high efficiency solar cells to achieve high packing density and electrical output. Tooling for the fabrication of solar cells is in house and evaluation of the cell performance has begun. Based on the power output analysis, the goal of a 13 percent efficiency module is achievable.

REVIEW:

This paper reports on the effort in utilizing the technology developed for spacecraft solar panel on terrestrial application. This is what we are primarily interested in.

LBL LITERATURE REVIEW FORM

TITLE: ATTIC Concentrator Type Solar Energy Collector

DATE: February 4, 1976

SOURCE: N77 11539 - BNL 50493

AUTHORS: J. C. Cottingham

ABSTRACT:

Inexpensive tested features of several solar energy collectors have been combined to produce an efficient low cost system. Reflector surfaces supported on metal reinforced corrugated paper redirect and concentrate solar radiation upon an inexpensive shallow pond type receiver formed by simple wooden frame and a plastic liner. The attic with a greenhouse type south facing side forms a wind screen for the concentrator assembly permitting the use of these light weight structures. Component cost and performance estimates are given.

REVIEW:

This low cost and light weight solar energy collector may be practical for home use. It is worthwhile to investigate the quality of this type of collector.

LBL LITERATURE REVIEW FORM

TITLE: Thermoelectrically Cooled Detectors - Another Option

DATE: 1978

SOURCE: SPIE Volume 132, Utilization of Infrared Detectors

AUTHORS: H. Cozine, et al.

ABSTRACT:

Thermoelectrically cooled detector packages offer rugged, lightweight, relatively inexpensive devices to the designer and user of infrared systems operating at intermediate (150°K - 250°K) temperatures. This paper explores some of the more important features of thermoelectrically cooled detector packages, their strengths and limitations in comparison to other cooling modes, and their reliability. A brief survey of some of the many applications of these devices ins included. Additionally discussed are some of the factors which the designer must consider when choosing a cooling technique for an IR system.

REVIEW:

Thermoelectric cooling plays an important role in cooling IR detector, etc., but can only handly very small amounts of heat load. It would not be practical to use this technique for building or home cooling.

LBL LITERATURE REVIEW FORM

TITLE: Dornier Project Solar Thermal 10 KW Power Plant

DATE: May 1978

SOURCE: AD B027052L

AUTHORS: J. Dreyer, et al.

ABSTRACT:

The Dornier Project solar-Arsenal 10KW power plant is presented and discussed. It heats a water cycle to -120°C which drives a freon secondary cycle. The freon cycle runs a turbine which converts the energy to electrical.

REVIEW:

Probably contains no useful information other than the system is actually being tested in Egypt.

LBL LITERATURE REVIEW FORM

TITLE: Flow of Moist Air Near the Ground II

DATE: September 1969

SOURCE: AD-861 980

AUTHORS: J. C. Freeman, et al.

ABSTRACT: The study of the drifting motion of air, clouds and smoke plumes in and around mountains has been overshadowed in meteorology by the study of mountain lee waves and the effect of heating on mountain and valley winds. This drifting motion is guided by the general wind flow, and the interplay of stability and moisture distribution with the air motion. Flow in the monsoon regions, which is characterized by a strong inversion with a wind shift, is the primary concern of this study. Similar effects to those reported here can be expected in other areas but the examples and the assumption here will be aimed toward consideration of a one-half mile to three mile deep inversion over or near mountainous terrain in the low latitudes.

Air motion near mountains is described as being primarily parallel to the mountain contours. This is developed from the practical point of view with reference to theory. The flow of the air in the Northern Hemisphere can be inferred from the cloud distribution on the slope: i.e., where the mountain is on the right of the flow, there will be clouds on the mountain; where the mountain is on the left of the flow, the mountain will be clear. The effects of ground cover on forest canopy give indication of the profile to be expected. Stability of the wind profile can affect the flow. The qualitative effects of these flows on plumes are given.

REVIEW: Description of large-scale atmospheric motions. Because of the large scale, most of the material is not applicable to the LBL windows and passive solar programs. The material on the effects of trees on the atmospheric boundary layer and on wind velocity profiles, however, might be useful for passive solar design. Therefore this report is worthy of further study during the technology review.

LBL LITERATURE REVIEW FORM

TITLE: Solar Heat Transport Fluid

DATE: June 1978

SOURCE: N78 - 27535, DOE/NASA CR-150704

AUTHORS: Houston Chemical Company

ABSTRACT:

This report covers the progress made in the development and delivery of noncorrosive fluid subsystems. These subsystems are to be compatible with closed-loop solar heating or combined heating and hot water systems. They are also to be compatible with both metallic and water systems. At least 100 gallons of each type of fluid recommended by the contractor will be delivered under the contract. The performance testing of a number of fluids is descirbed.

REVIEW:

The test to demonstrate that a solar heat transport fluid will provide corrosion and freeze protection for aluminum, copper and steel solar collector using copper plumbing is being done. The results should be useful.

LBL LITERATURE REVIEW FORM

TITLE: Novel Material and Devices for Sunlight Concentrating Systems

DATE: 1978

SOURCE: IBM Journal of Research and Development, 22, 112 (1978)

AUTHORS: H. J. Hovel

ABSTRACT:

Photovoltaic conversion under concentrated sunlight is a highly promising technique that could make solar-electric power generation economically competitive with fossil fuel power generation by the mid-1980s. An economic analysis has been performed which demonstrates that solar cell efficiency, concentrator efficiency, and concentrator cost are the most important parameters in a concentrating photovoltaic system; solar cell cost is only of secondary importance (at least for Si solar cells). Six novel structures are described, including modified conventional Si cells $Ga_{1-x}Al_xAs/GaAs$ devices, interdigitated cells, vertical and horizontal multijunction cells and "multicolor" devices.

REVIEW:

This paper contains information only on solar-photo energy conversion with photocells. I do not think it is relevant to our windows and lighting project.

LBL LITERATURE REVIEW FORM

TITLE: Comparative Performance of Solar Heating with Air and Liquid System

DATE: August 1976

SOURCE: N77 26676

AUTHORS: S. Karaki, et al.

ABSTRACT:

A performance comparison between an air solar system and a liquid solar system for space heating under nearly equal conditions has been obtained. The Colorado State University Solar House I is a liquid solar system which has been in operation since August 1974. Solar House II, which stands adjacent to and has a comparable heating load to Soalr House I, is equipped with an air solar system. Solar House I has been continuously monitored since August 1974 and Solar House II has been monitored since February 1976.

Performance of the solar systems is reported in terms of the collector efficiency, the amount of space heating and service water heating load provided by solar energy, and the use of electrical energy to operate the solar equipment.

General characteristics of the two types of systems are also compared. Information concerning installation, operation, and maintenance of the systems have been documented and are discussed.

REVIEW:

This paper points out the pros and cons of the two types of system. The information should be valuable to the LBL report and should be further evaluated.

LBL LITERATURE REVIEW FORM

TITLE: Reflector-Absorber Systems for Solar Thermonic Converters (in German)

DATE: 1974

SOURCE: AD-922 869

AUTHORS: S. Kelm

ABSTRACT: Some reflector-absorber-systems are described for attaining temperatures from 1000 - 1300^{o}C in special absorbers by using solar energy. Thermonic converters can operate in this temperature range suitable for production of electric energy. The absorber must be designed such that the absorber is accommodated to the converter concerning the operating temperature and heat transfer. Some applications of solar thermonic energy systems for space and earth are discussed. For large-scale solar energy conversion a conventional steam power station can be added to the thermonic system for producing more electric power.

REVIEW: Involves electric power generation, which is not directly relevant to LBL windows and lighting and passive solar programs. Therefore this report does not warrant further study during the technology review.

LBL LITERATURE REVIEW FORM

TITLE: Solar Energy Subsystems Employing Isothermal Heat Sink Materials

DATE: March 1976

SOURCE: N77-20616, NSF/RA-760202

AUTHORS: G. A. Lane, et al

ABSTRACT:

A group of over 200 potential phase change heat storage materials melting from 10-90°C was identified. Laboratory tests narrowed these to materials recommended for hot faucet water, hydronic heating, forced air heating, heat pump application, radiant wall panels, and stored cold systems. Several encapsulation methods were studied: microencapsulation, encapsulation of powders and granules, and macroencapsulation. Microencapsulation of $CaCl_2.6H_2O$ in polyester resin has been successful, and small wall floor, and ceiling panels have been prepared and tested. Macroencapsulation in plastic film containers appears promising for hot air systems. Preliminary economic analysis studies of heating systems based on heat-of-fusion storage materials have shown several promising approaches.

REVIEW:

The information is useful. It should be used later.

LBL LITERATURE REVIEW FORM

TITLE: Design and Operation of a Solar Heating and Cooling System for a Residential Size Building

DATE: May 1978

SOURCE: N78 25546, DOE/NASA TM-78169

AUTHORS: J. W. Littles, et al.

ABSTRACT:

The first year of operation of the Marshall Space Flight Center's Solar House is discussed. Selected design information, together with a brief system description, is included. The house is equipped with an integrated solar heating and cooling system which uses fully automated state-of-the-art equipment. Overall performance for the first year is summarized. In addition, information pertaining to modifications made to improve performance is provided, and problems encountered during operation are discussed.

Evaluation of data from the first year of operation indicates that the MSFC solar house heating and cooling system is capable of supplying nearly 100 percent of the thermal energy required for heating and approximately 50 percent of the thermal energy required to operate the absorption cycle air conditioner. The lower percentage of energy provided for the cooling mode as compared to the heating mode is due to the significantly higher temperature needed to operate the air conditioner, requiring the solar collector to operate at low efficiencies due to the higher inlet temperatures. Operation of the facility in the cooling mode has shown the need for basic subsystem improvements such as decreasing the operating temperature of the air conditioner and/or improving collector performance.

REVIEW:

The data collected from the solar house can be used as a baseline for future solar house. The data should be evaluated later.

LBL LITERATURE REVIEW FORM

TITLE: Investigation of High Temperature Performance of Thin-Film Solar-Thermal Energy Convertors

DATE: September 1976

SOURCE: N77-28613, PB-265554

AUTHORS: K. D. Masterson, et al.

ABSTRACT:

Discusses $\epsilon = \epsilon$ (wavelength) for said materials:

This is the final report describing work carried out to support Bureau of Mines research on solar energy convertors. The report describes the specular reflectance of zirconium carbonitride surface layers from room temperature to 700°C. Above 500°C permanent degradation of the surface layers occurred. The tests indicate the absorbers may be useful for solar energy conversion when appropriate stabilizing layers are utilized to avoid degradation.

REVIEW:

Use in final report.

LBL LITERATURE REVIEW FORM

TITLE: Energy Integrated Building Envelope

DATE: October 1977

SOURCE: Energy use Management Proceedings of the International Conference Volume I, Tucson, AZ

AUTHORS: G. Meckler

ABSTRACT:

A building envelope forms a boundary between interior space environment for people and a varying external environment created by changes in solar irradiation, air temperature, wind, dust, humidity and rain. The action of this boundary, in achieving a controlled internal environment by maintaining a balance of energy flow, is discussed in relation to three innovative window systems. These are as follows:

- o Thermal louver which reacts to internal window loads and controls sunlight.
- o Thermal panel for absorbing solar energy.
- o Thermoelectric panel for converting solar heat to internal cooling.

REVIEW:

Good Points: Has good discussion of building-envelope design philosophy. Thermal panels and thermoelectric refrigeration unit. These concepts should be discussed in LBL paper.

Negative: Not much technical; this is not aerospace technology.

LBL LITERATURE REVIEW FORM

TITLE: Application of Solar Energy to Air Conditioning Systems

DATE: November 1976

SOURCE: N78-17483

AUTHORS: J. M. Nash, et al

ABSTRACT: The results of a survey of solar energy system applications of air conditioning are summarized. Techniques discussed are both solar powered (absorption cycle and the heat engine/Rankine cycle) and solar related (heat pump). Brief descriptions of the physical implications of various air conditioning techniques, discussions of status, proposed technological improvements, methods of utilization and simulation models are presented, along with an extensive bibliography of related literature.

REVIEW: This report is not directly relevant to the LBL windows and lighting and passive solar programs and therefore does not warrant further study during the technology review. LBL would benefit, however, from obtaining a copy of this report because of its extensive bibliography; judging from their titles, some of the references are relevant to the aforementioned LBL programs.

LBL LITERATURE REVIEW FORM

TITLE: The Effect of Heat Loss on Solar Heating System

DATE: 1976

SOURCE: Solar Energy, Vol. 18, 11 (1976)

AUTHORS: R. T. Nash, et al.

ABSTRACT:

The influence of structural energy loss on the performance of a solar heating system has generally been given limited consideration. Yet failure to account for the character of structural energy loss is equivalent to a naval architect ignoring the drag associated with the hull while concentrating his attention on the propulsion equipment. More attention must be given to this factor if solar heating systems are to become successful in areas of the United States where comfort heating requirements are greatest. In this paper the influence of structural energy loss on the performance of a solar heating system is developed first. Then a general method for determining the most economically desirable combination solar energy gain, structural energy loss, thermal energy storage, and auxilliary energy use is presented.

REVIEW:

The paper presents a good approach to compare solar energy gain and structural energy loss. Buildings can be designed to have more solar energy gain than structural energy loss.

LBL LITERATURE REVIEW FORM

TITLE: Solar Heating and Cooling in Buildings: Air Force Implications

DATE: May 1976

SOURCE: AD-B011 982L

AUTHORS: J. C. Pullium

ABSTRACT: The increasing demand and dependence on energy resources and their finite availability creates a gap that must be satisfied if Western nations are to maintain their economic power. Between one-fourth and one-third of the energy consumed in the United States is in heating and cooling of buildings. This use demands a similar share of the Air Force utilities budget which by its rapid increase is causing drastic reductions in operations and maintenance capabilities of our forces. This paper addresses the implications to the Air Force of one possible energy gap filler, Solar Energy, as it can be used in heating and cooling application. Discussed are the theoretical aspects of solar radiation, solar energy system components, economic considerations, possible applications, plus a method of investigational analysis.

REVIEW: Most of this information is either well known to the solar energy community or is irrelevant to the LBL windows and lighting or passive solar programs. The section on heat storage subsystems (pp. 35 - 39), however, includes some on heat-of-fusion storage materials. This section and its references are worthy of further study during the technology review.

LBL LITERATURE REVIEW FORM

TITLE: Low-Cost Solar Air Heater

DATE: 1977

SOURCE: N78-20639

AUTHORS: D. R. Rask, et al

ABSTRACT: This report is a semi-annual progress report on an ERDA contract which describes the work completed to date on the development of a low-cost solar air heater of unique design.

REVIEW: This report is not relevant to the LBL windows and lighting and passive solar programs and therefore does not warrant further study during the technology review.

LBL LITERATURE REVIEW FORM

TITLE: Development of Water as a High Energy Density Dielectric

DATE: December 1976

SOURCE: AD-B015 609L

AUTHORS: W. E. Schwinkendorf

ABSTRACT: The purpose of this program is to develop a low-cost, high-energy-density, energy storage system capable of storing large amounts of energy at high voltages, and of delivering this energy to a load in very short (sub-microsecond) pulses. The major applications of such a system may be to ground based nuclear weapon simulators, ground and airborne laser systems, and airborne EMP simulators.

REVIEW: This report involves storage of electrical energy, which is not relevant to the LBL windows and lighting and passive solar programs. Therefore it does not warrant further study during the technology review.

LBL LITERATURE REVIEW FORM

TITLE: A Non-Tracking Solar Energy Collector System

DATE: February 1977

SOURCE: N77 19579

AUTHORS: M. Selcuk (Inventor)

ABSTRACT:

A solar energy collector system characterized by an improved concentrator for directing incident rays of solar energy on parallel vacuum-jacketed receivers or absorbers including a plurality of individually mounted reflector modules of a common asymmetrical triangular cross-sectional configuration supported for independent reorientation and defining a plurality of asymmetric vee-trough concentrators.

REVIEW:

The solar collector can be employed on an annual basis without requiring a repositioning of the total system. The system may be economically feasible for home use.

LBL LITERATURE REVIEW FORM

TITLE: Heat Transfer by Conduction and Radiation

DATE: 1978

SOURCE: N78-28383

AUTHORS: L. F. Shampine

ABSTRACT: Mathematical solution of the problem of two infinite, parallel plates which transfer heat by radiation and conduction. Assumes that the physical properties are independent of the position of the temperature.

REVIEW: Applicable to heat transfer in gaps (e.g., spaces between double-pane windows) under conditions for which convection is unimportant relative to conduction and radiation. This situation is of potential interest to the LBL windows and passive solar programs, and the analysis therefore is worthy of further study during the technology review.

LBL LITERATURE REVIEW FORM

TITLE: Dual Shades or Blinds: For Added Solar Collection and Thermal Insulation in Winter and Solar Heat Rejection in Summer

DATE: 1975

SOURCE: AD B015651L

AUTHORS: S. D. Silverstein

ABSTRACT:

The properties of an energy conserving window shade are calculated and described. The shade serves as a quasi-active solar collector during winter daytime; provides added insulation comparable to vented storm windows during winter nighttime; and rejects solar heat gain during summer cooling periods. The results of our numerical modeling shown that the dual shade will be: $\sim$90 percent as energy efficient as an unshaded window during the winter solar collection hours; save $\sim$ 40 percent on energy losses through a single pane window during winter nighttime; and reduce solar heat gain by $\sim$70 percent during summer air conditioning periods.

REVIEW:

Good points: Concept of interest is the use of wavelength dependent emissivities. One side of shade has high absorptance in visible, the other side a high reflectance. Both sides have high absorptance in IR region. In addition, shade has a small transmittance so as to permit a little light to pass through.

Good technical content.

Negative: Not aerospace technology per se.

We should probably take about this variable emittance concept in the LBL paper.

LITERATURE REVIEW FORM FOR OPTICAL PROPERTIES

(Section 5)

LBL LITERATURE REVIEW FORM

TITLE: New Techniques for Far-Infrared Filters

DATE: September 1973

SOURCE: Applied Optics Vol. 12, No. 9

AUTHORS: K. R. Armstrong, et al.

ABSTRACT:

Two new techniques have been developed that permit the construction of high performance low-pass, wide-band, and medium-band filters at wavelengths from 25μm to 300μm. One technique utilizes small particle scattering for short wavelength rejection. The other technique uses cooling of one or more crystalline materials to liquid-He or liquid-N2 temperatures to obtain spectral definition.

REVIEW:

The paper gives references for the design of scatter and cooled crystal filters. A graph is given showing the characteristics of some sample filters. Also a table listing the transmission properties of various far-infrared materials is given. A quality factor for the steepness of cut-on is also defined. Excellent cut-on characteristics may be obtained by stacking liquid-He-cooled crystals in series. Near-infrared leaks can be eliminated by using diamond scatter filters, and the reflection losses may be reduced by using a polyethylene anti-reflection coating.

LBL LITERATURE REVIEW FORM

TITLE: Materials Suitable for Making Far Infrared High-Pass Transmission Filters

DATE: 1973

SOURCE: Infrared Physics, Vol. 13

AUTHORS: M. G. Baldecchi, et.al.

ABSTRACT:

A study has been made of the optical properties of thirty compounds suitable for making far infrared filters of the Yoshinga type. The filters were prepared from powdered reststrahlen crystals mixed with a transparent substrate.

REVIEW:

Yoshinaga filters utilize the most appropriate method of preparing high-pass filters in the far infrared because interference filters are not yet available.

Transmission curves of each compound are given for various thicknesses of the samples. The transmission is measured from 2.5 μm to 300 μm. The thickness variation obeys Beer's law. The substrate material used with all the compounds is polyethylene.

LBL LITERATURE REVIEW FORM

TITLE: Infrared Reflectance and Emittance of Silver and Gold Evaporated in Ultra-High Vacuum

DATE: February, 1965

SOURCE: Applied Optics, 4, No. 2 (1965)

AUTHORS: J. M. Bennett, et. al.

ABSTRACT:

The reflectance of silver and gold evaporated in ultra-high vacuum has been measured in the wavelength range of 0.5 μm to 32 μm. It was found that the reflectance of both materials is higher than previously reported values and the infrared emittance of uhv gold films is smaller by nearly a factor of 3 than previously reported.

REVIEW:

It was found that when silver and/or gold was evporated in a vacuum with a pressure of 5×10^{-10} torr, better reflectance and emittance values could be obtained, along with better reproducibility than standard vacuums of 1×10^{-5} torr.

The procedure for obtaining the coatings is explained and the reflectance and emittance values of Ag and Au are given in tables along with a graph of reflectance for Ag, Au, and Aℓ.

Since the gold is chemically inert, it should find wider application as a low infrared emittance material.

LBL LITERATURE REVIEW FORM

TITLE: Infrared Spectral Emittance of Five Black Coatings

DATE: 1970

SOURCE: AD 870226

AUTHORS: J. B. Bernstein, et. al.

ABSTRACT:

The spectral emittance of Sicon Black, 3M Velvet Coating, Cat-a-Lac Flat Black, platinum black, and platinum black in epoxy were measured in the 3-125 um region at 4.2 and 77K.

REVIEW:

Measurements indicate that there is no apparent temperature dependence in the 3 - 125 μm for the five coatings. Observations do suggest that manner of application, dripping and curing, and mixing all effect the results. Despite sample to sample variations, a 0.1 mm thick coating is opaque.

Though the emittance of platinum black on Au appeared to drop off as λ^2, the platinum black in epoxy did not drop off as radidly as any of the other coatings. Thus the pigment-binder combination has a measurable contribution to the blackness of the coating.

LBL LITERATURE REVIEW FORM

TITLE: Infrared Transparent Polymeric Films

DATE: May, 1975

SOURCE: AD Boo 6264L

AUTHORS: N. Bilow, et. al.

ABSTRACT:

This paper investigates three different chemical groups of polymers: Fluorocarbons, Alkoxy-substituted Polyphosphazenes, and Fluorosilicones, with most of the concentration of Fluorocarbons. Fluorocarbon polymers and cure processes were carried out in an effort to produce infrared (out to 7 μm) transparent polymers which were suitable for the production of glossy, hard, high reflectivity aircraft coatings. The final product was a pigmented coating produced from a mixture of tetrafluoroethylenevinylidene fluoride (Kynar 7201) and hexafluoropropylene-vinylidene fluoride (Viton A-HV) copolymers. An IR reflectance plot is given.

REVIEW:

The reason for using fluorocarbon polymers is to reduce the absorption in the infrared (3.3 μm) due to carbon-hydrogen bonds. Several reactions and curing processes were tried. Different catalyst used for curing were cesium fluoride-magnesium oxide and benzoyl peroxide-diazabicyclooctane. The final product uses a mixture of Vitona-HV, Kynar 7201, barium titanate, magnesium oxide, 2-butanone, and a solvent blend. A procedure to prepare this polymer is given.

Studies of polyphosphazenes were carried out. The most infrared transparent polymer examined in the paper was a polymer of this general type; however, none of the polyphosphazenes examined were curable.

Fluorosilicones were also examined. Dow Corning QR6-2205, a ketoxime-terminated silicone resin was cured alone in moist air at room temperature to give a clear, tough film, but when attempts were made to copolymerize this with two triethoxy compounds, there was no success.

LBL LITERATURE REVIEW FORM

TITLE: Variations in Optical Reflectivity of Sputter Deposited Metal and Semimetal Films

DATE: December 1, 1977

SOURCE: NWC. TP 5997, AD A 050681, N7822210

AUTHORS: H. F. Blazek, et al.

ABSTRACT: The surface structure of vacuum deposited metal and semimetal films can be varied by changing either the substrate bias voltage or the total time of deposition. Corresponding changes in the optical reflectivity can be related to surface scattering and absorption effects. Reflectivity measurements over the infrared range from 1 to 7 microns are presented and discussed for titanium, antimony, bismuth, and copper films. Results for the metal films, copper and titanium, are in agreement with those obtained by Bennett for aluminum films. The contrasting results for antimony and bismuth indicate the influence of enhanced absorption in antimony and titanium.

REVIEW: The article begins with SEM micrographs showing the size and shape of the film surface structures as related to several sputter deposition parameters. Without further discussion, the paper immediately moves on to present reflectivity spectra with respect to film surface roughness. The main test (and Appendix) concerns itself with development of a model to explain enhanced absorption in rough sputtered films of antimony and titanium in the intermediate infrared. The model is basically the drude model with the addition of a broad resonant dipole absorption mechanism (surface plasmon effect) from Decker. The paper also suggests that bias sputtered films with rough surface texture may provide an excellent means for studying surface plasmon absorption. (3 references)

LBL LITERATURE REVIEW FORM

TITLE: The Solar Spectrum at Typical Clear Weather Days

DATE: 1976

SOURCE: N77-30523

AUTHORS: K. W. Boer

ABSTRACT:

The solar spectrum between .3μm and 1.5μm for five model "clear weather" days representing seasonal variations are defined.

REVIEW:

The solar spectrum, .3 m to 1.5 m, is given for five "clear weather" days representing typical seasonal conditions with respect to air mass, water vapor, ozone, and turbidity. The spectral distribution of the irradiance is given for the direct component, scattered skylight, the total flux on a horizontal surface, and the flux on an inclined surface normal to the direct component.

The assumptions made in calculating these results should be considered before applying them to real measurements.

LBL LITERATURE REVIEW FORM

TITLE: Environmental Exposure Tests on Solar Collector Cover Plates

DATE: November 1976

SOURCE: AD B025044L

AUTHORS: C. J. Bryan, et al.

ABSTRACT:

Tests were performed at a corrosive site to determine the effect of environmental exposure on solar collector cover plate materials. Materials evaluated in this testing program were mylar, Teflon FEP, Lexan, Plexiglas, and Tedlar.

REVIEW:

The materials were exposed for a one year period while measurements were made every three months with a spectrophotometer. Teflon FEP appears to be the material least affected by the one year environmental exposure. The results of the UV-visible spectrophotometric measurements are summarized in a table.

In addition, samples were coated with an aluminum film on one side to simulate an infrared reflective coating. Virtually all of the aluminum coatings had weathered away in the first three months, so no discernible differences were noted between the plain and aluminized test specimens.

LBL LITERATURE REVIEW FORM

TITLE: Cloud Properties from Satellite Infrared and Visible Measurements

DATE: 1976

SOURCE: American Meteorological Society Preprints A78-14952 03-47

AUTHORS: J. T. Bunting

ABSTRACT:

Satellite data on the radiative properties of clouds are compared with simultaneous measurements by aircraft. Radiance at 12 - 15μm are used to estimate cloud altitude and IR transmissivity.

REVIEW:

Data from two radiometers, with narrowbands at 14.1, 13.8, 13.4 and 12.0μm and broadbands of .5 to .7μm and 10 - 12μm, aboard a NOAA ITOS satellite were used to determine the altitude of various cloud types. These results were compared with actual observations from aircraft. When the four narrowbands were used to determine altitude the agreement with observation was generally good. Data from these four bands and a vertical temperature profile were used to calculate cloud transmissivity.

Results from the wideband radiometer were used to determine cloud thickness and cloud mass. The results indicate that the clouds which are coldest in the IR and brightest in the visible when viewed from space have the greatest thickness and mass.

LBL LITERATURE REVIEW FORM

TITLE: Anomalous Infrared Emission from Condensing and Cooling Steam Clouds

DATE: September 1977

SOURCE: AD E400066

AUTHORS: H. R. Carlon

ABSTRACT:

The infrared emission from condensing and cooling clouds of saturated steam at atmospheric pressure is measured at 10μm. Radiant emittance values three to four times those calculated for water droplets and water vapor are observed.

REVIEW:

A radiometer operating in the null condition was used to measure the emission from condensing and cooling clouds of saturated steam at 10μm wavelength. The radiometer was capable of detecting radiant emittance changes corresponding to changes in temperature of .2°C or less.

Strong infrared emission at 10μm was observed. The strength of the emissions could not be accounted for by water vapor or droplets or other commonly known atmospheric constituents. Near 100°C under non-equilibrium conditions radiant emittance values exceeded those of a blackbody. This phenomena suggests luminescence-like activity in the water.

LBL LITERATURE REVIEW FORM

TITLE: Photoelectric Charging of Partially Sunlit Dielectric Surfaces in Space

DATE:

SOURCE: N78-10154

AUTHORS: B. R. De, et al.

ABSTRACT:

A spacecraft surface that is of dielectric material may experience photoelectric charging when a section of the surface is sunlit and the rest is in darkness.

REVIEW:

On a partially sunlit dielectric surface, the sunlit area tends to become positively charged and the dark area negatively charged, with both charges concentrating near the sunlight-shadow boundary. This boundary is thus the site of intense multiple electric fields. If the sunlit area is contracting or expanding it may experience a "supercharging". The effect of the presence of an ambient plasma is not discussed.

LBL LITERATURE REVIEW FORM

TITLE: A Performance Evaluation of Various Coatings, Substrate Materials, and Solar Collector Systems

DATE: September 1976

SOURCE: N77-15489

AUTHORS: F. J. Dolan

ABSTRACT: This paper describes a method of testing and evaluating solar panel coatings and designs and solar collector subsystems.

REVIEW: This method of testing uses a recirculating water flow through the solar collector samples and measures the inlet and outlet temperatures to determine the efficiency of the samples. Tests are performed with 2 different substrate materials, 5 different coating/substrate combinations, and 9 different coatings/panel designs utilizing an insulated box (flat plate) collector. Tests were made primarily with a Xenon lamp as a solar simulator, but some were also performed in direct sunlight. The insulated box collector with a low cost non-selective coating appears satisfactory for heating and hot water systems.

LBL LITERATURE REVIEW FORM

TITLE: Solar Absorption Properties of a High Temperature Direct-Absorbing Heat Transfer Fluid

DATE:

SOURCE: N78-15577

AUTHORS: William D. Drotning

ABSTRACT: Particulate metallic oxides are added to a molten salt heat transfer fluid; the optical absorption properties of the resultant mixture are then measured.

REVIEW: A molten salt, an eutectic mixture of KNO_3, $NaNO_2$, and $NaNO_3$, is used as a heat transfer fluid in many solar energy systems. The salt mixture alone absorbs approximately 8% of the solar spectrum per cm of path length, while the addition of a small amount (.05 wt %) of oxides of Co or Cu increases the absorption to over 80% per cm. Absorption spectra of the mixture were determined as a function of dopant concentration. The oxide CO_3O_4 appeared to be the most suitable dopant for a direct-absorbing heat transfer fluid.

LBL LITERATURE REVIEW FORM

TITLE: Wavelength - Selective Surfaces for Solar Energy Utilization

DATE: 1976

SOURCE: SPIE Vol. 85 Optics in Solar Energy Utilization II

AUTHORS: J. C. C. Fan

ABSTRACT:

The selective (spectral) characteristics of Cr black and MgO/Au absorbers; $TiO_2/Ag/TiO_2$ and Sn doped In_2O_3 transparent heat mirrors; and Sn doped In_2O_3 micrograids are presented.

REVIEW:

Comparisons of solar absorption and infrared emissivity are made for Cr black coatings on Cu and on Ni and A MgO/Au coating on Mo. Spectral curves are presented for each. The MgO/Au coating is stable to 400°C while Cr black degrades at between 200 and 300°C. A possible mechanism for the failure at these temperatures is discussed.

Transparent heat mirrors of $TiO_2/Au/TiO_2$ on glass and Sn doped In_2O_3 conductive films are compared. The effects of A MgF_2 antireflection coating on Sn doped In_2O_3 and different thicknesses of TiO_2 and Ag are discussed. The transmission and reflection of Sn doped In_2O_3 grids on glass are shown and compared to theoretical results using a perfect conducting grid. A formula for calculating the reflection coefficient for a wire mesh is given.

Wire grids appear to work well as transparent heat mirrors but the cost of fabrication is high. A material which has a low deposition temperature ($\lesssim 100^{\circ}C$) would be desirable so that the grids could be placed on plastic or polyester films. The $TiO_2/Ag/TiO_2$ coating seems to be a good candidate for both grids and totally coated heat mirrors.

LBL LITERATURE REVIEW FORM

TITLE: Electrically Conductive Paints for Satellites

DATE:

SOURCE: N78-10165

AUTHORS: J. E. Gilligan, et. al.

ABSTRACT:

A variety of organic and inorganic coatings are formulated and tested on the basis of electrical conductivity, physical properties, and stability of spectral reflectance in a space environment.

REVIEW:

This paper explains the need for electrically conductive thermal-control coatings on satellites. Paints that are highly transparent and highly conductive are needed. Tables show the results of tests of organic and inorganic paints, as well as aluminized Teflon and Kapton and Astroquartz. The results show that many inorganic coatings, such as potassium, lithium, and sodium silicates, are suitable, but much developmental work is needed before organic coatings can be made suitable.

LBL LITERATURE REVIEW FORM

TITLE: Multiphenon Absorption in Chalcogenide Glasses

DATE: February, 1975

SOURCE: Vitreous State Labs
Catholic University of America

AUTHORS: R. E. Howard, et. al.

ABSTRACT:

Multiphonon absorption in chalcogenide glasses As_2S_3 and As_2Se_3 are observed in the infrared region (200 - 1500 cm^{-1}) as a function of frequency, The variation of absorption as a function of temperature is observed in As_2Se_3. Measurement of absorption on various mixtures of As_2S_3 - As_2Se_3 and As_2Se_3 - $GeSe_2$ glasses are studied.

REVIEW:

The "Molecular Model" of lucovsky and co-workers for vibrational properties of chalcogenide glasses suggests that multiphenon absorption in these materials should be analogous to overtone and combination vibrational bands in isolated molecules. This paper contains the experimental verifaction of the model.

A graph of the ramen spectrum of As_2S_3 glass at 15K is given. Also, a graph of absorption coefficient versus freqdency is given for As_2S_3 and AS_2Se_3. The temperature dependence of absorption coefficient along with a formula is given for As_2Se_3.

When different chalcogenide glasses are mixed it is observed, in the 2-phonon region with high coordination center atoms mixed, that the total absorption coefficient can be found by knowing the individual absorption coefficients and the volume fractions; the formulas are given.

LBL LITERATURE REVIEW FORM

TITLE: Optical Characteristics of a Water Aerosol in the Infrared Spectral Region (Attenuation, Scattering and Absorption Efficiency Factor)

DATE: 1970 (1975)

SOURCE: AD B013523L

AUTHORS: L. S. Ivelev, et al.

ABSTRACT:

The efficiency factors for attenuation, scattering and absorption by water aerosols in the near infrared are presented.

REVIEW:

The Mie coefficients for a number of complex refractive indices of water between 2.8μm and 6.0μm and for relative dimensions corresponding to the dimensions of atmospheric aerosol particles were calculated. From these the efficiency factors for attenuating scattering and absorption were obtained. It was found that the absorption efficiency factor changes regularly as a function of the imaginary part of the refractive index while the effect of changing the real part is not great. For practical purposes by using the absorption efficiency for the Re m it is possible to interpolate the different complex m without special calculation of the Mie formulas.

LBL LITERATURE REVIEW FORM

TITLE: Properties of Conductive Coatings for Thermal Control Mirrors and Solar Cell Covers

DATE: Post 1974, not otherwise specified except it is also pre-"mid-76"

SOURCE: N76 11130

AUTHORS: D. E. Joslin, et. al.

ABSTRACT:

Conductive transparent coatings have been considered for space applications (i.e., allowing the even distribution of charge over a spacecraft surface). Optical and electrical measurements (as functions of T and/or λ) have been made on an OCLI coating, which is basically indium oxide.

REVIEW:

Resistance vs. temperature curves for six samples of the OCLI coating indicate little temperature dependence. However, there is a factor of 6 variation in the sample to sample resistance. Use of AR coatings on the conductive coating for solar cell covers is discussed. It is concluded that it is worthwhile since it can increase the transmission in the 300 - 600 nm region. However, due to the AR coating's high resistance, the effect of the conducting coating is reduced. The space environment and the MgF_2 AR coating's electrical properties must be considered more thoroughly.

LBL LITERATURE REVIEW FORM

TITLE: Solar Collectors Using Total Internal Reflections

DATE: 1976

SOURCE: SPIE Vol. 85 Optics in Solar Energy Utilization II

AUTHORS: N. S. Kapany

ABSTRACT:

Various configurations of solar collectors and components employing the phenomenon of total internal reflection are described. A qualitative approach is taken in describing the various components; some tables of efficiency are given.

REVIEW:

This paper describes the critical angle occurring at a dielectric interface and the necessity for a clean surface at the interface. It is qualitative with one or two simple equations and diagrams illustrating various geometries. The main thrust of the paper is the efficiency achievable by using total internal reflections (TIR) in dielectric materials to replace metallic reflecting surfaces.

A double glazed window using "optical ribs" has been developed to yield high light transmission and ruggedness. Conical wedges are developed for use as energy concentrators as well as "optical valves". Dielectric compound concentrators with flat, parabolic, and elliptical reflecting surfaces are described with various applications, such as coupling with fiber optics to solar cells or use as internal lighting.

LBL LITERATURE REVIEW FORM

TITLE: Researchers on Color Matching Functions

DATE: December 1977

SOURCE: N78-22893

AUTHORS: Kanji Katori, et al.

ABSTRACT: This paper is a synopsis of another paper concerned with color matching functions examined on Japanese subjects.

REVIEW: This synopsis gives a short chapter by chapter review of the original paper. Studies were conducted to measure the characteristics of color vision, using several different types of colorimeters on Japanese subjects. Color matching functions and the additivity of color matching are investigated.

LBL LITERATURE REVIEW FORM

TITLE: Light Transmittance and RF Shielding Effectiveness of a Gold Film on a Glass Substrate

DATE: November 1975

SOURCE: IEEE Transactions on Electromagnetic Compatibility. Vol. EMC-17, No. 4

AUTHORS: Samuel Y. Liao

ABSTRACT: Light transmittance and the RF shielding effectiveness of a gold film on a glass substrate is investigated. The theory applied may be used for other metal films besides gold.

REVIEW: The dependence of the transmittance of visible light upon the thickness or surface resistance of a gold film on a glass substrate is determined numerically by the optical properties of the gold film and glass substrate.

Some graphs are given which pertain to the gold film, and a table of refractive index and extinction index at wavelengths from 2000 Å to 10,000 Å is given for Al, Cu, Ag and Au.

LBL LITERATURE REVIEW FORM

TITLE: Infrared Optical Materials for 8 - 13 um - Current Developments and Future Prospects

DATE: 1974

SOURCE: Infrared Physics, Vol. 14

AUTHORS: K. J. Marsh, et. al.

ABSTRACT:

The current state of development of materials for 8 - 13 μm optical components is reviewed and the prospects of finding improved or cheaper materials are discussed. The two main interest areas are broad band refracting optics and high energy single wavelength lasers.

REVIEW:

The refractive index and absorption mechanism for various materials is discussed. A table listing mechanical, chemical and various other properties of different materials is given. The article also gives a survey of different materials such as polymers, halides, oxides and chalcogenides.

In general, chlorides and selenides offer the most hope for a new material. The chlorides would be very good materials for low power broad band systems, but would have inferior chemical and thermo-mechanical properties compared with germanium. For high power requirements both the halide and chalcogenide routes are worth exploring.

LBL LITERATURE REVIEW FORM

TITLE: Optical Materials for Solar Energy Applications

DATE: May 1976

SOURCE: N77-19628

AUTHORS: D. M. Mattax

ABSTRACT: To have significant input on the U. S. energy economy, hundreds of square miles of optical materials would be needed, requiring development of high-volume, low-cost production processes.

REVIEW: This paper describes many different types of collection systems for solar energy and different optical techniques, such as interference films, bulk selective absorbers, scattering films, and radiation trapping surfaces. Photovoltaic, photogalvanic, and photoelectrochemical materials are discussed, as are fabrication techniques. Tables and graphs show the optical properties of various materials. Some tradeoffs must be made between desirable properties and economical considerations.

LBL LITERATURE REVIEW FORM

TITLE: Transmittance of Optical Materials from 0.17μ to 3.0μ

DATE: November 1967

SOURCE: Applied Optics; Vol. 6, No. 11

AUTHORS: Donald E. Mc Carthy

ABSTRACT: The transmittance of thirty-one optical materials is given from 0.17μm to 3.0μm.

REVIEW: The materials which were measured are Na Cl, KBr, CsBr, CsI, CaF_2, NaF, TlBr, TlCl, KRS-5, KRS-6, T-12, KC, CuC, TO_2, ADP, KDP, BaF_2, $SrTiO_3$, GaP, $CaCO_3$, CdSe, AS_2S_3, ruby, Al_2O_3, IRTRAN 1-6, and quartz. All are synthetic with the exception of $CaCO_3$. The transmittance is better for the synthetic materials than the naturally occurring materials.

LBL LITERATURE REVIEW FORM

TITLE: Black Chrome on Commercially Electroplated Tin as a Solar Selective Coating

DATE: September 1977

SOURCE: NASA TM-73799

AUTHORS: G. E. McDonald

ABSTRACT: A study was made of the technical feasibility of achieving high solar absorption and low infrared emittance of black chrome plated on a commercially plated tin/steel substrate.

REVIEW: The reflectance properties of electroplated black chrome on tin were measured for various black chrome plating times for both the solar and infrared spectrum. From the reflectance values the solar absorptance and infrared emittance were calculated. The optimum plating time was between one and two minutes. A plot of solar absorptance and infrared emittance as a function of plating time is given for black chrome on tin and on nickel; a more expensive alternative.

LBL LITERATURE REVIEW FORM

TITLE: Selective Coating for Solar Panels

DATE: Filed 22 December 1975, Registered at U.S. Patent Office 25 Oct. 1977

SOURCE: U. S. Government Patent Office #4,055,707

AUTHORS: G. E. McDonald

ABSTRACT:

Solar heating panel performance is improved by use of a selective solar coating, black chrome on nickel, giving a chrome/nickel/substrate sequence. This results in a high solar absorption and a low emissivity.

REVIEW:

The coating techniques and materials are described, as are some variations (dull nickel versus bright nickel, different plating durations, rough surface versus smooth surface, etc.). However, some of the description is not completely clear, especially where emissivity is discussed; it is not clear whether the author is referring to the black chrome or the nickel undercoating.

LBL LITERATURE REVIEW FORM

TITLE: Optimized Selective Coatings for Solar Collectors

DATE: 1976

SOURCE: N77-11529

AUTHORS: G. E. McDonald, et. al.

ABSTRACT:

The effect of plating time on the solar absorptance and emittance of five different black coatings are examined.

REVIEW:

The spectral reflectance of black nickel, black copper, black chrome, and chromatic and chloride converted black zinc from .35 to 18 μm are presented. The variation of emittance with absorptance is shown for each of the black coatings with respect to the plating time.

The results show that increases in plating times lead first to increases in the solar absorptance. When the absorptance 'saturates' the emittance then increases for further increases on the plating times.

LBL LITERATURE REVIEW FORM

TITLE: Low Infrared Reflectance Paint Coating Program

DATE: April, 1975

SOURCE: AD-B004543

AUTHORS: R. Peterson

ABSTRACT:

This paper carries out a feasibility study to produce a forest green paint with 10 percent reflectance in the 1.5 to 2.7 μm region (MIR) and a high reflectance in the 0.7 to 0.9 μm region (NIR). In the present program a paint was produced with a reflectance of 18 to 32 percent in the MIR region. If the requirements were dropped in the NIR region, a lower reflectance coating in the MIR region could be obtained.

REVIEW:

Tungsten Oxide, WO_3, was found to be essentially the only inorganic pigment with a strong absorption near 20 μm which did not absorb in the visible and NIR. The WO_3 was combined with several other pigments to achieve the final coating.

Forest green is the most difficult color to make with low MIR reflectance, so improved IR performance could be expected with other colors. It was also noted that the primer used, on the surface, was very important in reducing the MIR reflectance.

The total hemispherical and specular reflectance (the flatness) of the coatings were studied. Various tables and graphs are given showing the different trials of paint coatings.

LBL LITERATURE REVIEW FORM

TITLE: Optical Characteristics of Transparent Insulation as a Function of Surface State

DATE: February, 1967

SOURCE: Geltoteknika

AUTHORS: N. B. Rekant

ABSTRACT:

Gives brief description of effect ethanol and distilled water have on the roughened surface of plexiglas and window glass.

REVIEW:

The article describes how ethanol or distilled water fills the micropores and causes some index matching of roughened plexiglas and window glass surfaces. Two tables are given for the transmittance and reflectance of these surfaces.

LBL LITERATURE REVIEW FORM

TITLE: Aluminum or Copper Substrate Panel for Selective Absorption of Solar Energy and the Method of Producing Said Panel

DATE: August 31, 1977

SOURCE: N77-31610

AUTHORS: Marion L. Roberts, et al.

ABSTRACT: The authors have invented a panel for absorption of solar energy. This paper describes the panels and how to produce them.

REVIEW: Two types of panels were developed: one consisting of a substrate of aluminum with layers of zinc, nickel, and nickel oxide added; the other a copper substrate with layers of nickel and nickel oxide. A selective absorptance of greater than .91 and emittance of less than .07 can be achieved. NASA owns the invention but encourages its licensed commercial utilization.

LBL LITERATURE REVIEW FORM

TITLE: Infrared Continuum Absorption by Atmospheric Water Vapor in the 3 - 12μm Window

DATE: April 1976

SOURCE: AD A025377

AUTHORS: R. E. Roberts, et al.

ABSTRACT:

Three modifications to the Lowtran 3 atmospheric model for the water vapor absorption continuum in the 8 - 12μm window are discussed.

REVIEW:

By analyzing recent experimental data, it was determined that the N_2 - H_2O broadening team can be either eliminated or greatly reduced in the 8 - 12μm region. This broadening term appears to be more significant at longer wavelengths, however. Using this data an improved fit for the absorption coefficient, C^o (ν), was found using linear regesssion techniques. An expression for C^o (ν) is given. A strong temperature dependence of the absorption coefficient is defined, and an expression for this dependence is given. The temperature dependence appears to be most applicable in the 8 - 12μm region.

(It should be noted that these modifications are incorporated in the Lowtran 3B model.)

LBL LITERATURE REVIEW FORM

TITLE: Measurements of Net Atmospheric Irradiance in the 0.7 to 2.8 Micrometer Infrared Region

DATE: May 1977

SOURCE: AD-A041076

AUTHORS: R. Rubio, et al.

ABSTRACT:

The net atmospheric irradiance in the .7 to 2.8μm region were measured from a balloon platform at altitudes ranging from 5 to 39 kilometers.

REVIEW:

The net atmospheric irradiance was measured with a spectral pyranometer. The spectral pyranometer had a 7^o field of view and pointed downward at 17.6^o below the horizontal plane defined by the platform base. The minimum sensitivity was 2.79×10^{-2} mw/cm^2.

The results indicate that for low solar zenith angles and in the absence of clouds the irradiance values remain between 1.53 mw/cm^2 and 1.81 mw/cm^2. No significant variations were noted with changes in altitude above 5 kilometers or terrain viewed.

LBL LITERATURE REVIEW FORM

TITLE: FTIR Electro-Optic Beam Switch

DATE: July 1977

SOURCE: ADB020584L

AUTHORS: Ronald R. Selleck

ABSTRACT: The purpose of this project is to demonstrate the feasibility of using an FTIR device to switch a CO_2 laser source between multiple outputs in a controllable fashion.

REVIEW: A 10.6 micron optical switch is constructed using the frustrated total internal reflection (FTIR) principle. If light strikes a surface at an angle greater than the critical angle, it experiences total internal reflection. If two surfaces of like index come into contact, the surface effects tend to disappear. The two surfaces can thus form a switch: "open" if separated (total internal reflectance), "closed" if in contact (transmission through the surfaces). The FLIR switch uses two prisms, the separation of which is varied by means of piezo-electric transducers. The prism material chosen was zine selenide (Zn Se), the paper explains the theory and construction of the switch, shows its performance in graphs and tables, and contains, in appendix form, the FTIR mathematical equations and operation instructions.

LBL LITERATURE REVIEW FORM

TITLE: Formulation of Electrically Conductive, Thermal-Control Coatings

DATE:

SOURCE: N78-10166

AUTHORS: M. C. Shai

ABSTRACT:

Electrically conductive, thermal-control coatings were formulated for use on the International Sun Earth Explorer spacecraft.

REVIEW:

After many false starts, promising results were obtained by using fired-oxides as pigments in sodium or potassium silicate binders. This report focuses on coating formulation and application techniques. The optical and electrical properties of various coatings are measured, and the coatings are environmentally tested.

LBL LITERATURE REVIEW FORM

TITLE: Formulation of Electrically Conductive Thermal-Control Coatings

DATE: April, 1978

SOURCE: N78-21216

AUTHORS: M. C. Shai

ABSTRACT:

Thermal-control coatings that are electrically conductive are developed to meet the requirements for use on the International Sun-Earth Explorer (ISEE) spacecraft.

REVIEW:

The coating for the ISEE spacecraft was to have a solar absorptance of 0.55 to 0.59, thermal emittance of 0.90, area resistance less than 1×10^{5} ohm-m^2, and an environmental lifetime of 2 years in solar wind. To meet these specifications, sodium and potassium silicates are used as binders, and contain fired-oxide pigments in proportions to optimize absorptance and conductance. Tables and graphs summarize the optical, thermal and electrical properties of the coatings. The coatings have passed environment tests, including UV, low-energy proton (solar wind), thermal-vacuum cycling, and humidity tests. Coatings with the potassium silicate binder had greater chemical stability, while those with sodium silicate binder had greater stability in optical properties.

LBL LITERATURE REVIEW FORM

TITLE: Method of Forming Metal Hydride Films

DATE: Filed 20 February 1976, Completed 25 October 1977

SOURCE: U. S. Patent Office, #4,055,686

AUTHORS: R. Steinberg, et al.

ABSTRACT:

A method of forming a continuous, thin film of stoichiometric metal hydride (titanium dihydride, titanium dideuteride, titanium ditritride, or similar compounds of zirconium, ytrium, scandium, etc.) on metal, glass, and/or plastic substrates is described.

REVIEW:

No diagrams, but a detailed step-by-step process description including information on equipment required, typical substrate cleaning procedures, etc.

LBL LITERATURE REVIEW FORM

TITLE: Spectral Radiance of the Atmosphere in the 3 to 20μm Spectral Region

DATE: July 1976

SOURCE: AD B013448

AUTHORS: W. Tam, et al.

ABSTRACT:

The predictions of the McClatchey atmospheric emission models are compared with experimental results in the 3 to 20μm spectral region. The discrepancy occurring in the 10μm region is investigated.

REVIEW:

McClatchey's atmospheric models are reviewed including the methods employed to calculate the transmission and irradiance of the atmosphere, measured at sea level, for various viewing angles. Predictions of the mid-latitude summer and mid-latitude winter atmospheric emission models at several viewing angles are compared to experimental data taken at Elk Park station, Colorado.

The predictions of the models and the experimental data show good agreement except in the region of the 9.6 ozone emission band. The ozone absorption coefficient calculated by McClatchey is compared to laboratory measurements. The empirical model is found to overestimate the measured absorption. An alternate method of calculating the 9.6μm band ozone absorption coefficient is presented, which gives an excellent fit to the empirical data.

A similar modification would also be necessary in calculating the transmission of the atmosphere in the 10μm region. Because of the smaller absorption coefficient indicated by experiment for ozone the transmission would be higher than predicted by McClatchey in the 10μm region.

LBL LITERATURE REVIEW FORM

TITLE: Reflective Solar Control Film on Windows Gains Acceptance

DATE: October, 1968

SOURCE: Ashrae Journal

AUTHORS: D. R. Theissen

ABSTRACT:

Examines heat flow through windows and hot it may be reduced by applying a reflective surface.

REVIEW:

The paper describes the shading coefficient and uses it as a figure of merit for good insulation of windows. Transparent polyester films with aluminum coatings that adhere to windows are mentioned briefly. The psychological effects of light and heat are mentioned. Different properties of various windows are compared in a small table. References with more detailed explanations of the shading coefficient and heat transfer are given.

LBL LITERATURE REVIEW FORM

TITLE: Infrared Radiation of Thin Plastic Films

DATE: February 1972

SOURCE: Journal of Heat Transfer

AUTHORS: C. L. Tien, et al

ABSTRACT: A combined analytical and experimental study is presented for infrared radiation characteristics of thin plastic films with and without a metal substrate. A band averaging technique is used to find the complex refractive index.

REVIEW: The complex refractive index is found in different band regions by measuring the average transmittance of two films having different thicknesses.

The band-averaged optical constants of mylar and kapton were obtained from transmittance measurements of films with thicknesses in the range of 0.25 to 3 mils. Graphs of transmittance vs. wavelength are given for kapton and mylar.

The spectral normal reflectance and total normal emittance of the film side of singly aluminized films are calculated; the results compare favorably with measured values.

LBL LITERATURE REVIEW FORM

TITLE: Reflectivity of Metals of High Temperatures

DATE: May, 1972

SOURCE: Journal of Applied Physics, Vol. 43, No. 5

AUTHORS: K. Vjihara

ABSTRACT:

The reflectivity, complex refractive index and skin depth of metals at high temperatures are discussed on the basis of the Drude theory and the theory of electron-phonon collision. Numerical calculations of the above variables are carried out for Ag, Aa, Ca, Al, Na and K at a few wavelengths (0.69 μm, 1.06 μm and 10.6 μm) and at temperatures from room temperature to their melting point.

REVIEW:

Equations are presented from the Drude and electron-phonon collision theories and graphs of reflectivity, complex refractive index and skin depth are given. Some tables of constants are also given for the different metals.

As the temperature increases the reflectivity decreases. Curves of reflectivity show that the absolute value of the temperature coefficient of reflectivity is greater for metals having a lower room temperature reflectivity. Calculated values of the reflectivity at room temperature are in reasonable agreement with handbook data.

LBL LITERATURE REVIEW FORM

TITLE: Investigation of Conductive Thermal Control Coatings by a Contactless Method of Vacuo

DATE:

SOURCE: N78-10169

AUTHORS: W. Viehmann, et. al.

ABSTRACT:

Large discrepancies are found between measurements of conductivity of coatings obtained by a contactless method and measurements obtained using metallic contacts.

REVIEW:

Electrically conductive thermal control coatings were developed for spacecraft use and tested for their conductivity. Measurements using silver contacts produced much higher values of conductivity than did measurements by a contactless method. Both methods show that conductance is dependent upon voltage and temperature. Measurements with the silver contacts are considered to be of questionable value in deciding the suitability of coatings for electrostatic charge control.

LBL LITERATURE REVIEW FORM

TITLE: Solar Energy-Thin Film Coatings

DATE: 1975

SOURCE: SPIE Vol. 68, Solar Energy Utilization

AUTHORS: Richard M. Winegarner

ABSTRACT: The paper describes how various solar collecting surfaces may be improved by the use of antireflection coatings, selective absorber coatings, and transparent-low emittance coatings. The economics of solar energy versus conventional energy sources is also discussed.

REVIEW: By using a single layer of magnesium fluoride as an anti-reflection coating the efficiency of a flat collector and a linear focusing collector can be increased from 33% to 39% and from 40% to 42%, respectively. A selective absorber coating can give an increase in efficiency for a flat collector and a linear focusing collector from 33% to 45% and from 40% to 62%, respectively. Transparent-low emittance coatings otherwise known as heat mirrors can give an increase in efficiency for flat collectors from 33% to 43% and is an attractive alternative relative to selective absorbers because of their extreme durability.

For the increase in performance just discussed, a simple economic analysis is performed in order to determine the marginal cost for adding the coatings.

LBL LITERATURE REVIEW FORM

TITLE: Solar Optical Properties, Heat Transfer Coefficients and Shading Coefficients for Architectural Glass

DATE: March, 1971

SOURCE: Ashrae Journal

AUTHORS: J. I. Yellott

ABSTRACT:

Examines how solar-optical properties(transmittance, reflectance and absorptance)effect the transfer of heat and how different surfaces on glass change these properties.

REVIEW:

Some equations are given which allow one to find the heat transfer through single unshaded glass. A brief mention of a tra-scope for measurement of the properties of architectural glass is provided. The shading coefficient is defined and graphs are given for high longwave emittance and low longwave emittance materials. The conclusion briefly talks about spectral properties and how they effect heat transfer.

LITERATURE REVIEW FORM FOR HUMAN ENGINEERING

(Section 6)

LBL LITERATURE REVIEW FORM

TITLE: Isolation and Confinement: Considerations for Colonization

DATE:

SOURCE:

AUTHORS: F. R. Akins

ABSTRACT:

The paper discusses three types of isolation (sensory/perceptual, temporal, and social) that could adversely affect mankind in space. Also, consideration is given to the potential effects of physical confinement and the need for usable space.

REVIEW:

Although this paper deals with problems of space colonization, many of these problems could exist in underground, confined work spaces. Suggestions for design of work/living quarters to offset feelings of isolation and artificality of surroundings could be applied to underground or other confined work areas. The bibloigraphy contains several references to articles dealing with problems of underground confinement that might prove more useful to the LBL study.

LBL LITERATURE REVIEW FORM

TITLE: The Use of Modeling Human Response in the Analysis of Thermal Comfort of Indoor Environments

DATE: September 1977

SOURCE: AD A050008

AUTHORS: N. Z. Azer, et al.

ABSTRACT:

Modeling the thermoregulatory system is used in evaluating the threshold WBGT values of OSHA Heat Stress Standards. It is shown that physiological reactions within or above the tolerance limits can be experienced during exposure to environments having the same threshold WBGT values, particularly at heavy work loads. Also, the use of modeling human subjective reactions in planning energy conservation strategies in buildings is also discussed.

REVIEW:

This paper is basically a discussion of various models of thermal comfort, and how and why they were developed. There are several tables illustrating threshold WBGT values based on combinations of dry bulb temperature and air velocity; these may be of some value in the LBL Project as guidelines for indoor environmental temperatures. Appendix A - Determination of the WBGT in Terms of Environmental Factors, and Appendix C - A Summary of the Thermal Sensation Prediction Model, provide further explanation of these models.

LBL LITERATURE REVIEW FORM

TITLE: Heat Stress, Work Function and Physiological Heat Exposure Limits in Man

DATE: September 1977

SOURCE: AD A05008

AUTHORS: A. R. Dasler

ABSTRACT:

Various operational trials using tolerance criteria available in the literature revealed that predictions of physiological exposure limits were rarely compatible with the observed status of men in a wide range of heat stress and work conditions. Computer integration of laboratory and industrial-type data led to establishing a comprehensive set of physiological criteria for tolerance limits appropriate to man at work within time-weighted-mean metabolic rates. These criteria and work rates were integrated with industrial-type heat stress conditions which resulted in developing the Physiological Heat Exposure Limit (PHEL) concept. Comparisons of over 200 sets of environmental and physiological data supported the PHEL concept and permitted more definitive identification of material areas requiring corrective engineering actions in the industrial type setting.

REVIEW:

Good points - good, thorough discussion of related studies used to help develop the PHEL concept. Tables and graphs illustrate various experimental findings. Appendix contains mathematical models of environmental and physiological conditions used in developing the PHEL scale. This paper could be a worthwhile reference in the consideration of human comfort with respect to work environments created by the use of solar energy as described in the LBL draft statement of work. The Proceedings from the Symposium at which this paper was presented might also be considered for further reference.

LBL LITERATURE REVIEW FORM

TITLE: Performance of a Maintenance Task in a High Temperature Environment

DATE: June 1976

SOURCE: ADA029798

AUTHORS: T. L. Durren

ABSTRACT:

The purpose of the research is to determine the effect temperature has on an individual's ability to perform a maintenance task; determined by the statistical comparison of the mean task completion times of two treatment levels: normal (72°F dry bulb), and high (110°F dry bulb). The 10 subjects were divided into groups A and B. Group A performed the prelearned task first in the normal temperature level and then at the high temperature level; group B performed them in the reverse. All factors pertinent to the experiment were held relatively constant except for temperature. Results indicated that the decrease in performance in the high temperature environment was statistically significant.

REVIEW:

The 110°F temperature of the high heat condition is 10°F higher than the maximum temperature that could be obtained by the presence of thermal energy storage systems in a work area (temperature range 80°F - 100°F), affecting the significance of this data as applied to the conditions described in the LBL statement of work.

LBL LITERATURE REVIEW FORM

TITLE: Regenerative Polymeric Amine Fibers for Carbon Dioxide Sorption

DATE: October 1971

SOURCE: Naval Ship Research and Development Center, Annapolis, MD. AD 913887.

AUTHORS: R. W. Fuest, et al.

ABSTRACT: A device which can efficiently remove CO_2 from air with minimal power consumption, space requirements and maintenance is needed for CO_2 control in submarines. The concept of using high-molecular-weight amine containing polymers and CO_2 sorbents is the basis of the present investigation. Polyethylenimine (PEI) was chosen as the polymeric amine sorbent, and Dacron 62 was selected as the substrate fiber. The Dacron 62 fibers were prepared with 25% to 30% chemically bound PEI, and showed a CO_2 capacity of 4% of their own weight of a 0.5% CO_2 air mixture, and are capable of sorbing 2.7% by weight of this same mixture in 10 minutes at a rate of 2000 ml/min through a 12 cm long, 1.04 cm diameter bed of the chopped fiber. Complete desorption of CO_2 was accomplished at 110^o steam within 75 seconds, and overdipping with epichlorohydrin improved resistance to atmospheric oxidation at regeneration temperatures without serious loss of capacity. Rejuvenation of heat-aged fibers is accomplished with a mild sodium borohydride treatment.

REVIEW: This document is the final report of an evaluation of various materials considered for use as CO_2 sorbers in submarines. The discussion of test sample selection, experimental apparatus, and test procedures is fairly detailed yet easily understood, and the various graphs and tables presented throughout the text illustrate the procedures. Because the requirements call for minimum power consumption this design might be feasible for use in an environment where conventional energy sources are at a minimum, or, as in the LBL study, alternative energy sources are being explored.

LBL LITERATURE REVIEW FORM

TITLE: Prediction of Human Heat Tolerance

DATE:

SOURCE: AD A051276

AUTHORS: R. F. Goldman

ABSTRACT: Human tolerance to heat exposure is limited by body heat storage, as the body is unable to eliminate all the heat it produces and/or receives from the environment, and by the physiologic consequences of such storage. As the difference between skin and air temperature decreases, the demand for evaporative cooling (E_{req}) increases, which may be greater than the maximum evaporative cooling (E_{max}) allowed. The ratio E_{req} /E_{max} reflects the percentage of skin that must be sweat wetted, and this ratio was also adopted as a Heat Stress Index to define heat strain. Using these same parameters, a different approach has been adopted; the prediction of the deep body temperature (T_{re}) at which a balance can be struck between heat load and heat loss as it is driven toward the final equilibrium rectal temperature (T_{ref}). We have indicated how to predict the time course of T_{re} to reach T_{ref} during any schedule of rest, work, and recovery; how heart rate (HR) can be predicted from this approach; also how day by day acclimitization to heat modifies the T_{re} and HR responses. We are working on adjustments for sex, age, and physical condition. (Summary of author's introduction)

REVIEW: This report is a technical discussion of mathematical models used in the prediction of heat tolerance and how they are defined. As a useful reference in the LBL study it is perhaps too technical since it provides only the methods for predicting human heat tolerance under various conditions rather than what these limits are.

LBL LITERATURE REVIEW FORM

TITLE: The Role of Clothing in Achieving Acceptability of Environmental Temperature Between 65° and 85°F

DATE: February 1978

SOURCE: N7824803, AD A052563

AUTHORS: R. F. Goldman

ABSTRACT:

The paper was presented by the author at a symposium honoring a Mr. A. Pharo Gagge, and is primarily a discussion of literature on thermal comfort and their contributions toward the formulation of a clothing insulation unit (clo). A table is provided showing the clo insulation units for various items of men's and women's clothing.

REVIEW:

The clothing insulation unit (clo) concept could be applied to the LBL project in consideration of the thermal comfort of employees who might be working near thermal energy storage systems, in "greenhouse" type areas or low air flow environments; where special clothing or clothing not generally regarded as "appropriate" for a business environment (ie., shorts, T-shirts) could be more comfortable. Several journal articles listed as references could provide additional information useful to the LBL project.

LBL LITERATURE REVIEW FORM

TITLE: Mental and Perceptual Performance in Heat

DATE: 1975

SOURCE: N76-29915

AUTHORS: C. R. Johansson

ABSTRACT:

Physiological strain, thermal sensation, and mental and perceptual performance of 24 ten-year-old school children were investigated during exposure to environmental heat of 30°, 36°, and 41°C for three hours at each temperature. Rectal temperature, pulse, and sweat rates increased significantly under heat load, and the physiological effects and performance changes appeared after a short period of exposure. Adverse effects of heat load averaged 10% on practiced numerical tasks, and an inverted U-shaped relation was found between heat load and perceptual performance.

REVIEW:

The paper deals with effects of heat stress on physiology and performance of children, covering a variety of physiological and phychological variables that are outlined in the Table of Contents. The differences in exposure limits between adults and children could affect the applicability of this report to the LBL study.

LBL LITERATURE REVIEW FORM

TITLE: Psychophysiological Aspects of Stress and Adaptation in a Technological Society

DATE: January 1977

SOURCE: AD B021721

AUTHORS: G. Johansson, et al.

ABSTRACT:

The paper reports data from a long-term project concerned with human psychological and physiological adaptation to the psychosocial environment. Subjective and cognitive aspects of various stressful conditions have been investigated in relation to physiological reactions such as sympathetic-adrenal medullary activity and heart rate. Experiments show increased adrenaline excretion are associated with good performance and short-term adaptation to acute stress situations, yet produce harmful long-term effects if demands for readjustment are frequent. Work conditions associated with modern technology are often characterized by overstimulation or understimulation, which impose a heavy load on human adjustment mechanisms indicated by increased catecholamine levels and poor work satisfaction. Psychophysiological responses to other real-life stressors are illustrated by studies on urban commuting and noise.

REVIEW:

This paper addresses the stress created by modern technology regarding work conditions, urban commuting and noise. In the broadest sense, the study on commuting may provide useful information in the area of confinement. For it was found that the perceived degree of crowdedness for train passengers was a square function of the actual increase in the number of passengers.

LBL LITERATURE REVIEW FORM

TITLE: Solar Energy Research at Sandia Laboratories and its Effects on Health and Safety

DATE: October 1977

SOURCE: Sandia Laboratories, Safety Engineering Div. 3442

AUTHORS: L. Young Lawrence III

ABSTRACT: This paper disucsses various solar energy research and development projects at Sandia Laboratories, with emphasis on the primary health and safety hazard associated with solar concentration systems. This limiting hazard is chorio-retinal damage. We cannot yet measure the unique safety and health hazards associated with solar energy collector and receiver systems, but we are rapidly making progress. Research is continuing, especially for eye hazards, with more extensive work planned. (Author's abstract)

REVIEW: As indicated in the abstract the primary health concern of this research was eye damage that might result through exposure to the reflecting dishes used in collecting solar energy. Eye damage was not included in the health and safety concerns of the LBL project; perhaps it should be addressed.

In addition to the discussion of the eye damage hazard, this report also contains an overview of some of the major solar energy projects being conducted at Sandia. Of particular interest is the Solar Total Energy System Test Facility, which will use solar heat to generate electrical power and thermal energy for heating and air conditioning. All discussions of these projects include a description of the components in each system and how they work. This paper should be worthwhile as a reference of other solar energy programs.

LBL LITERATURE REVIEW FORM

TITLE: Measurement of Heat Stress - Kiowa and Musketeer Cockpits

DATE: July 1977

SOURCE: N78 15686, AD A046388

AUTHORS: S. D. Livingstone, et al.

ABSTRACT:

During hot summer weather at CFB Portage la Prairie, measurements were made of the heat stress experienced in the cockputs of the Musketeer aircraft and the Kiowa helicopter while stationary (not running) on the runway and during flight. Heat stress occurred in both cockpits when closed, either on the ground or in flight, and could lead to dire physiological strain in less than one hour. Use of air vents in the Musketeer aircraft did not completely ameliorate the heat stress and caused communication difficulty because of wind noise. No difference was found between ambient heat stress and cockpit heat stress when the Kiowa helicopter was flown without its doors.

REVIEW:

A greenhouse effect was produced in both aircraft when stationary and in the closed configuration, causing cockpit temperatures exceeding 100^{o}F WBGT, although the outdoor ambient temperature was 74^{o}F WBGT, $\pm 1^{o}$F. This high temperature was reached after 15 minutes on the tarmac, 5 minutes after the doors were closed. The rapid rise in temperature would be a matter of concern if greenhouse systems are proposed as a method of solar heating. A similar study could be performed using an actual greenhouse system that would relate more closely to environmental conditions considered in the LBL study.

LBL LITERATURE REVIEW FORM

TITLE: Human Performance - A Pilot Study

DATE: April 1973

SOURCE: Journal of IES, April 1973. Paper presented at annual IES Conference July 24 - 27, 1972.

AUTHORS: J. F. McNelis.

ABSTRACT: The primary objective of this investigation, undertaken at the request of the IERI, is to develop experimental procedures and techniques for studying overall human performance. The results of many studies on visual performance are available, but relatively few comprehensive studies have been done on human performance.

REVIEW: The study concerned visual perception as a factor in human performance; the other factors being thinking and responding. The experimental procedure involved the perceptual accuracy of viewing two sets of lower case letters separated by 10 degrees and viewed at different levels of contrast and background luminance. This study of visual perception is of little importance to the LBL project since our concern with human performance is primarily in the area of confined or semi-isolated working conditions.

LBL LITERATURE REVIEW FORM

TITLE: The Conduct and Experience of Miners Under the Acute Stress of Incarceration

DATE: August 1977

SOURCE: AD B025874

AUTHORS: W. Mende, et al.

ABSTRACT: Eleven miners were imprisoned for 14 days at a depth of 55m in the pit disaster at Lengede in 1963. For 10 days they had no contact with the outside world whatsoever. Shortly after their rescue they were subjected to psychiatric and neurological examinations. The observational data obtained provide important indications for the occurrence of psychopathological phenomena (e.g. illusory perceptions), for social behavior in extreme situations and also for the question of the psychic endurance limit. The conduct and experience of these men is described with particular emphasis on the hallucinatory experiences of some of the miners. Particular weight is attached to the phenomenon of fear and defense against fear.

REVIEW: Although this is an interesting account of the effects of isolation on a group of people, the nature of their experience makes it unsuitable for the LBL project. The stress suffered by these men was due to the total darkness, their inability to escape, and the continuous threat of death by more cave-ins. The conditions of their confinement are not likely to be present in an underground building, so there is nothing in this report that could be applied to the LBL project.

LBL LITERATURE REVIEW FORM

TITLE: The Effect of Breathing 4.5% CO_2 on Vigilance

DATE: September 1969

SOURCE: AD 867113

AUTHORS: Major P. S. Newberry, et al.

ABSTRACT: Each of 18 subjects breathed each of six gas mixtures (20%, 45%, and 100% oxygen in nitrogen and the same three concentrations of oxygen, each with 4.5% of carbon dioxide in nitrogen) while performing a clock watching vigilance test. There was no significant effect on vigilance degradation with time attributable to breathing the different gas mixtures.

REVIEW: This study was conducted following reports of the effects of breathing increased amounts of CO_2 on aircrews at high altitudes and when subjected to accelerated G forces. These reports indicated that added CO_2 prevented alkalemia at high altitude, and decreased the negative effects of G forces on animals. Because this study seems to be concerned with the effects of CO_2 on aircrew under special conditions not likely to be encountered by the normal working person, it is not applicable to the concerns of the LBL study.

LBL LITERATURE REVIEW FORM

TITLE: Physiological and Psychological Effects of Heat Stress Simulating Cockpit Conditions

DATE: 1978

SOURCE: Aviation, Space, and Environmental Medicine. 49(6):763-767

AUTHORS: S. A. Nunneley, et al.

ABSTRACT:

Experiments were designed to determine the effects of thermal conditions similar to those occurring in aircraft cockpits in warm climates, where high air temperatures and radiant heat play important roles. Thirteen subjects were exposed to heat for 2 hours, had a 30-minute break, then repeated the exposure. Conditions were T_{OB} = 35°C and T_{WB} = 26°C, with or without infrared lamps which raised globe temperature to 47°C. Subjective Fatigue Estimates (SFE) and Repetitive Psychometric Measures (RPM) were performed before, during, and after each heat stress. Both thermal conditions induced marked subjective fatigue and altered the learning curve for some subtests of the RPM. Similar conditions in the aircraft can be associated with impaired performance, particularly in new or emergency situations.

REVIEW:

The results showed that radiant heat was more fatiguing than "regular" heat in the second exposure, that radient heat affected primarily the head and upper torso, and that water taken during the first recovery period aided in the recovery from heat stress. These were the only significant results that might be applied to the LBL project.

LBL LITERATURE REVIEW FORM

TITLE: Development of a Prototype Regeneration Carbon Dioxide Absorber

DATE: October 1977

SOURCE: NASA Ames Research Center, CA. NASA-CR-152063

AUTHORS: P. S. Patel, et al.

ABSTRACT: A prototype regenerable carbon dioxide absorber was developed to maintain the environmental quality of the Portable Life Support System (PLSS). The absorber works on the alkalai metal carbonate-bicarbonate solid-gas reaction to remove carbon dioxide from the atmosphere of the extra vehicular activity (RVA) life support system.

The prototype sorber module was designed, fabricated, and tested at simulated EVA conditions. The unit maintains sorber outlet concentration below 5 mm Hg. The smallest sub-unit of the module was life tested for 160 cycles of absorption-thermal regeneration-cooling with no appreciable drop in activity. An optimization study was made with respect to heat transfer, temperature control, sorbent utilization, sorber life and regenerability, and final size of the module. Important parameters influencing the capacity of the final absorber unit were identified and recommendations for improvement have been made.

REVIEW: This was one of three articles reviewed on methods of carbon dioxide removal from air in an enclosed environment - in this case, as part of a Portable Life Support System (PLSS) for use in space. The description of the device, how it works, and test results are detailed and supported by illustrations, tables, and graphs. In relation to the LBL program this article could be considered appropriate simply because it addresses the problem of carbon dioxide removal from the environment. However, its usefulness to the program as a reference might best be determined by someone with an engineering or other technical background.

LBL LITERATURE REVIEW FORM

TITLE: Flight Prototype CO_2 and Humidity Control System

DATE: September 1977

SOURCE: NASA Space Center. NASA-CR-151591

AUTHORS: Karen M. Rudy

ABSTRACT: A regenerable CO_2 and humidity control system is presently being developed for potential use on shuttle as an alternative to the baseline lithium hydroxide (LiOH) system. The system utilizes a sorbent material (designated "HS-C") to absorb CO_2 and water vapor from the cabin atmosphere and desorb the CO_2 and water vapor overboard when exposed to a space vacuum. Continuous operation is achieved by utilizing two beds which are alternately cycled between absorption and desorption. A flight prototype system was fabricated, and system performance was proven by simulated mission testing over the full range of shuttle crew sizes and metabolic loadings.

REVIEW: This was a large technical report on the prototype CO_2 and humidity control system. The contents include discussions of the flight prototype design, fabrication, and testing; four appendices on the system requirements and components specifications, master test plan, and HS-C publications; and a large number of tables and figures illustrating the design, test phases, and test results of the system. The document is well written, and, since it deals with CO_2 removal from an enclosed environment, is applicable to the LBL project.

LITERATURE REVIEW FORM FOR LANDSCAPE AND BUILDING MATERIALS

(Section 8)

LBL LITERATURE REVIEW FORM

TITLE: Terrestrial Solar Engineering Applications and Technology

DATE: April 1978

SOURCE: U. S. Army Foreign Science and Technology Center
AST-1860W-100-78

AUTHORS: J. D. Busie, et al.

ABSTRACT:

This working paper provides U. S. military research and development organizations with a description and analysis of significant advances made by free world and Eurasion Communist countries in their efforts to employ solar energy in terrestrial applications. A further objective is to provide the basis for estimates, long-range forecasts, and threat assessments in this field in response to the technical requirements of U. S. military estimators, planners, and designators.

REVIEW:

This survey of the foreign research and development in energy technology provides a brief description of the activities in the foreign country. The information is not detailed enough to be helpful to us.

LBL LITERATURE REVIEW FORM

TITLE: The Solar Reflectance of a Snow Field

DATE: January 1978

SOURCE: N78 30575

AUTHORS: B. J. Choudhury, et al.

ABSTRACT:

Using an approximation (modified Schuster-Schwartzchild) the radiative transfer equation is solved to obtain an expression for the solar reflectance of a snow field.

REVIEW:

The single scattering albedo and the fraction of energy back-scattered are the parameters in the reflectance expression. By varying the crystal size, the effects of aging have been modeled. Numerical results for reflectance are obtained for visible and near infrared. Good agreement is found between these results and experimental results obtained by O'Brient and Munis (NASA-SP-391).

LBL LITERATURE REVIEW FORM

TITLE: Data Compilation of Target and Background Characteristics

DATE: July 1966 - November 1969

SOURCE: Defense Document Center; AD 489 968; AD 819 712; AD 840 091; AD 856 343; AD 379 650.

AUTHORS: D. Earing, et al.

ABSTRACT:

The data compilation is in five unclassified volumes. The data is composed of reflectance measurements in the .2 to 15 m region, polarization of the reflected light, and radar measurements from a wide variety of materials. They range from tree leaves to building materials to clothing.

REVIEW:

LBL LITERATURE REVIEW FORM

TITLE: Effect of Angular Variation on Terrain Spectral Reflectivity

DATE:

SOURCE: Center for Research, Inc.
University of Kansas

AUTHORS: D. D. Egbert, et al.

ABSTRACT:

This paper develops and tests a practical and inexpensive technique for obtaining spectral reflectivity curves in the visible and near infrared regions for any desired type of target; as a function of sun altitude angle, incidence look angle, and the azimuth angle.

REVIEW:

This paper is about remote sensing missions with multi-band photography. A geographic study mapping roads from multi-spectral space photographs is carried out. Some reflectance curves, as a function of angles, is given for asphalt and grass.

A Minolta 1^{o} Autospot Light Meter was used in conjunction with some Wratten narrow band absorption filters to obtain good general spectral reflectivity curves over the 400 to 800 nm region.

LBL LITERATURE REVIEW FORM

TITLE: Solar Heating and Cooling

DATE: 1977

SOURCE: Hemisphere Publishing Corporation

AUTHORS: J. F. Kreider, et al.

ABSTRACT:

Engineering, practical design and economics of solar heating and cooling.

REVIEW:

This book has data on therma properties of building materials.

LBL LITERATURE REVIEW FORM

TITLE: Principles of Heat Transfer

DATE: 1976

SOURCE: Dior - Donnellay Publisher

AUTHORS: F. Kreith

ABSTRACT:

Principles of heat transfer text book.

REVIEW:

This book has data on thermal properties of building materials.

LBL LITERATURE REVIEW FORM

TITLE: Red and Near-Infrared Spectral Reflectance of Snow

DATE: March 1975

SOURCE: N75 24085, AD A007 732

AUTHORS: H. W. O'Brien, et al.

ABSTRACT:

The spectral reflectance of snow from .60μm to 2.50μm was measured. Measurements were taken at angles from 5^{o} to 30^{o} from the normal with incident angles of 0^{o} to 10^{o}.

REVIEW:

In the visible region, new snow shows very high reflectance (nearly 100%). This is decreased to 80% by aging either by repeated melting and freezing or by wind compaction.

In the near-infrared, the reflectance of new snow decreases rapidly with increasing wavelength with the exception of a peak in the region around 1.8 μm and one around 2.25 μm. Aging the snow decreases those two regions drastically. The results indicate that the reflectance is strongly effected by changes in both particle size and density due to aging.

LBL LITERATURE REVIEW FORM

TITLE: Evaluation of a Low Density Polyimide Foam in a Dynamic High Temperature Environment

DATE: December 1977

SOURCE: N78-12223, NASA TP 1049

AUTHORS: C. M. Pittman, et al.

ABSTRACT:

A low-density (64 kg/m^3), polyimide foam material was tested in an arc tunnel to determine its potential for heat-shield application on aerospace vehicles. The results show that the material has some reuse potential at surface temperatures as high as 750 K (0.43 cm recession in 12,000 sec). When a black refractory paint was applied to the surface of the material, the surface recession was negligible at 750K. An analytical thermal conductivity was derived for this material which, combined with measured thermal property values, can be used to make preliminary-design thickness calculations for heat-shield applications.

REVIEW:

This material is good for high temperature applications such as a heat shield on a space vehicle. Its usefulness for solar systems and buildings is probably very limited due to cost.

LBL LITERATURE REVIEW FORM

TITLE: Handbook of Heat Transfer

DATE: 1973

SOURCE: McGraw-Hill Inc.

AUTHORS: Edited by W. M. Rohsenow (MIT) and J. P. Hartnett (Univ. of Illinois)

ABSTRACT:

Handbook of heat transfer.

REVIEW:

This handbook has data on thermal properties of building materials in Table 29.

LBL LITERATURE REVIEW FORM

TITLE: Parameter Study on Thermal Properties of Buildings

DATE: 1977

SOURCE: Proc. Intern. Conf. on Energy Use Management, Tucson, Arizona, October 1977.

AUTHORS: M. F. Simon, et al.

ABSTRACT:

In 1975, heating in buildings consumed 35 percent of the French total primary energy needs. Therefore thermal insulation in buildings is one of the most important vector for energy conservation policy in France. Since 1965 "Electricite de France" started to recommend insulation practice with its electric space heating systems, and today, no contradiction occurs with the law edicted in 1875 by French government.

This paper describes the different thermal parameters which have to be considered in buildings and explains an optimization method which can help the building contractor during the different stages of the building design.

REVIEW:

Not a discussion of technology but rather a mathematical optimization technique.

Should be considered for final report.

LBL LITERATURE REVIEW FORM

TITLE: Solar Energy System - Survey of Materials Performance

DATE: October 1977

SOURCE: PB 273 305

AUTHORS: L. F. Skoda, et al.

ABSTRACT:

A study was performed to obtain data on the performance of materials in operational solar energy systems, to identify and assess available standards for evaluating materials, to provide recommendations for the development of test method standards for materials and to provide guidelines to aid the selection of materials for use in solar energy systems.

REVIEW:

The process of selecting materials for specific applications within solar energy systems is hindered by the lack of an adequate data base of materials performance under the conditions experienced in solar systems and subsystems. Recommendations are made that would help in establishing an improved data base. Studies of material properties are proposed. Tests are suggested. However, this report only recommends an approach to acocmplish the objective but does not provide any data on material properties, etc., which we need.

LBL LITERATURE REVIEW FORM

TITLE: Extrusion of Self Reinforced Thermoplastic Composites

DATE: January 15, 1978

SOURCE: N78-19215

AUTHORS: A. E. Zachariades, et al.

ABSTRACT:

A method is described for solid state coextrusion of self-reinforced and transparent composites of high density polyethylene composed of core and sheath phases. The high density polyethylenes are coextruded below their melting points. The cocylindrical composites have a high tensile modulus and strength, a high orientation for both core and sheath components and possess considerable resistance to core/sheath separation. This resistance to pull out due to compressive and radial stresses developed during the composite coextrusion and not to bonding by epitaxial crystallization.

REVIEW:

The method of coextrusion is interesting but does not have direct relationship with this study.

LITERATURE REVIEW FORM FOR MEASUREMENT AND DIAGNOSTIC TECHNIQUES

(Section 9)

LBL LITERATURE REVIEW FORM

TITLE: Use of Control Technique in the Development of A Constant Temperature Hot-Wire Anemometer. Part I

DATE: June 1963

SOURCE: AD-910 896

AUTHORS: E. Berger et al.

ABSTRACT:

REVIEW: 15-year old report by German government laboratory (German equivalent of NASA). In view of its age and relative accesibility, results of work are probably known to more recent researchers. Therefore this report is not worth translating into English and studying during the technology review.

LBL LITERATURE REVIEW FORM

TITLE: Anwendung Der Regeltechnik Bei Der Entwicklung Elnes Konstant-Temperatur-Hitzdrahtanemometers, Teil II*(in German)

DATE: August 1963

SOURCE: AD-910 897

AUTHORS: E. Berger, et al.

ABSTRACT:

REVIEW: 15-year old report by German government laboratory (German equivalent of NASA). In view of its age and relative accessibility, results of work are probably known to more recent researchers. Therefore this report is not worth translating into English and studying during the technology review.

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* Use of Control Technique in the Development of a Constant Temperature Hot-Wire Anemometer.

LBL LITERATURE REVIEW FORM

TITLE: Sunstations

DATE: 4 June 1977

SOURCE: Solar Energy, 20, 465

AUTHORS: Berman, et al.

ABSTRACT:

A method of obtaining insulation data is described which provides information directly useable in the sizing of solar equipment. The method is particularly valuable for the collection of data at a large number of sites where equipment cost and availability of technically trained personnel are critical. The device consists of a calibrated solar cell, and electrochemical accumulator and associated electronic equipment having the following characterisitcs: capacity 13 GJ/m^2 (3600 kW hr/m^2); temperature range -55 to +71^oC; low cost; no field maintenance; reproducibility ±5 percent.

REVIEW:

Good Points: Good explanation of electrochemical conversion process and how it interfaces with the environment and the recording device (schematically). Obviously applicable to our measurement section of report. It is a device which integrates Power x dt for a given period of time, so it is not directly a rate measuring device.

Negative: Doesn't have good physical description. Total energy meter, not rate meter (as mentioned above) though this is not necessarily a drawback.

This is not aerospace technology.

Possibly follow up on where device can actually be obtained, otherwise the information will be useful for our report (in any case).

LBL LITERATURE REVIEW FORM

TITLE: Application of Pulsed-Source Spectrophone to Absorption of Methane at DF Laser Wavelengths

DATE: December 1976

SOURCE: Applied Optics, Vol. 15, 2970

AUTHORS: C. W. Bruce, et al.

ABSTRACT:

As part of a larger program to identify absorption by atmospheric gaseous constituents at DF laser wavelengths, pulsed-source spectrophone measurements of methane absorption coefficients were made and compared with measurements made in other laboratories.

REVIEW:

Does not appear to contain material relevant to windows and lighting and therefore is not worthy of further study during the technology review.

LBL LITERATURE REVIEW FORM

TITLE: Applications of Thermal Imagery for Energy Conservation and Environmental Surveys

DATE: Mid 1976

SOURCE: N78-14603

AUTHORS: J. R. Carney, et al.

ABSTRACT:

This report documents the results of a U. S. Government interagency study designed to determine the feasibility of using remote sensing technology to reduce the number of manhours currently required for energy conversation and environmental surveys. The survey procedures, developed during the winter and summer of 1976, employ color and color infrared aerial photography, thermal infrared imagery, and a handheld infrared imaging device. The resulting imagery was used to detect building heat losses, deteriorated insulation in built-up type building roofs, and defective underground steam lines. The handheld thermal infrared device, used in conjunction with the aerial thermal infrared imagery, provided a method for detection and locating those roof areas that were underlain with wet insulation. In addition, the handheld infrared device was employed to conduct a survey of a U. S. Army installation's electrical distribution system under full operating loads. This survey proved to be a cost-effective procedure for detecting faulty electrical insulators and connections that if allowed to persist could have resulted in both safety hazards and loss in production.

The color and color infrared aerial photography aided in the interpretation of the thermal infrared imagery, provided a baseline of environmental conditions for future comparison, and provided a means to detect environmental problem areas.

The report also discusses the most efficient image scales and time of image acquisition, and concludes that remote sensing technology can reduce the cost and time required to conduct energy and environmental surveys.

REVIEW:

This report references W. L. Wolfe, Handbook of Military Infrared Technology, Office of Naval Research, Department of Navy, 1965. This contains emissivity data on various man-made materials, such as asphalt, concrete, window glass, steel, etc. Indicates that reliable and cost effective measurements can be made from the air (using IR) to determine heat losses through roofs, walls, etc. Also heat leaks from other sources (underground steam pipes, electrical power lines, etc.). Use in report!

LBL LITERATURE REVIEW FORM

TITLE: The Use of the NTC Thermistors for Measurement of the Sun's Radiation and of Wind Speed

DATE: June 1977

SOURCE: Royal Aircraft Establishment Library Translation 1916

AUTHORS: Translated by Barbara Crossland

ABSTRACT:

A method of measuring solar radiation and the Georgi pyrheliometer are discussed. By using negative temperature coefficient (NTC) thermistors a simpler more rugged pyrheliometer may be designed. The article also contains a second section which discusses the measurement of wind velocity with a NTC thermistor.

REVIEW:

The Georgi pyrheliometer utilizes the non-equilibrium variation of temperature with time of a small copper block which is heated by the sun. An equation is given to find the radiation intensity.

An equation is given, which when plotted, shows the linear region over temperature for different value resistors (R1 in paper). A circuit diagram of a Georgi pyrheliometer is given. The design of a copper block is shown with the NTC thermistor mounted. The second section which discusses the measurement of wind velocity was not reviewed because of its irrelevance.

LBL LITERATURE REVIEW FORM

TITLE: Absorption Coefficient Measurements of Nitrous Oxide and Methane at DF Laser Wavelengths

DATE: 15 March 1975

SOURCE: Applied Physics Letters, Vol. 26, 300

AUTHORS: T. F. Deaton, et al.

ABSTRACT:

The absorption coefficients for methane and nitrous oxide have been measured at 17 DF laser wavelengths in the region of 3.8 μm using a spectrophone. Concentrations of the absorbing gases very near their atmospheric concentrations were used. The absorption coefficients for the two gases at standard sea level atmospheric conditions are presented. The spectrophone device developed for this work is a differential cell which produces an equivalent absorption background signal of only $3.3X10^{-7}$ m^{-1}/W.

REVIEW:

Does not appear to contain material relevant to windows and lighting and therefore is not worthy of further study during the technology review. The data in this paper are already summarized in the literature review contained in the report by Kallis, et al, the paper also is cited in Pao's book.

LBL LITERATURE REVIEW FORM

TITLE: Aerial Infrared User's Manual

DATE: August 1978

SOURCE: D.O.E. Report No. HCP/M4161/D

AUTHORS: M. J. Dick, et al.

ABSTRACT:

The handbook covers most of the major points involved in implementing an aerial IR survey. Its intent is to disseminate information to those who are considering such a survey. Data collection and processing, program evaluation are considered. Example programs are included for comparison and suggestion.

REVIEW:

This report demonstrates the real feasibility of an aerial IR scan in order to determine possible heat leaks in houses and businesses. Its technical content is negligible.

LBL LITERATURE REVIEW FORM

TITLE: An Improved Anemometer for Room Air Measurements

DATE: August 1976

SOURCE: N78-14378

AUTHORS: D. J. Dickson

ABSTRACT: Following a brief discussion of methods of measuring air velocity, a heated thermistor anemometer developed at ECRC for room air measurements in the range 0.02 to 1 m/s is described. Unlike existing cooling-effect anemometers, the calibration is independent of ambient air temperature in the range 10^{o}C to 25^{o}C. Calibration procedures are described. Directional dependence is minimized by appropriate design of the sensing probe.

REVIEW: This report discusses air velocity measurements, heated-thermistor anemometers, probe design, calibration, directional characteristics and performance. It appears very useful to LBL and therefore warrants further study during the technology review.

LBL LITERATURE REVIEW FORM

TITLE: Static and Dynamic Calibration of a Corona Discharge Anemometer

DATE: December 1976

SOURCE: N77-29712; AD-A040 038

AUTHORS: F. H. Durgin, et al.

ABSTRACT: A Corona Discharge Anemometer (CDA) which is to be used in some balloon experiments designed to measure clear air turbulence, was tested in the Wright Brothers Wind Tunnel at the Massachusetts Institute of Technology. First a modified version of the ansmometer commercially made by Thermo Systems Inc. was tested statically to determine its sensitivity, its ability to resolve the x and y components of velocity and the effect of out of plane flow on its sensitivity.

REVIEW: This report discusses MIT tests of a commercially made CDA. It discusses aerodynamic noise generated by the device and design modifications that essentially eliminated this unwanted noise. The data might be useful for future velocity and turbulence measurements of interest to LBL and therefore is worth further study in the technology review.

LBL LITERATURE REVIEW FORM

TITLE: Flir Systems Today

DATE: 2 - 5 April, 1974

SOURCE: 2nd. European Electro-Optics Markets and Technology Conference, Montreux, Switzerland

AUTHORS: C. W. Ferguson

ABSTRACT:

FLIR systems have evolved since 1964 to the point that they represent a proven extension of man's sensory perception. Understanding of the technologies relevant to this sensory extension has also developed to an advanced point. For each generic application of thermal imaging there are peculiar tradeoffs relative to detectors, image formation, signal processing, and display. While in the past FLIR has been added to existing systems, today systems are being designed to best exploit the capability of FLIR. Improved performance and increased reliability have made feasible new applications of thermal imaging. Cost however remains to be reduced before many of these new systems will find wide acceptance. Techniques do exist to significantly reduce FLIR cost without sacrificing performance. All of this will be discussed and FLIR imagery will be shown to validate many points.

REVIEW:

Application to LBL report:

Good points: A "low cost" FLIR system (8-12k$) is available with present technology and production techniques. Such a system can detect a man-sized object at 1 km and recognize a man at 500m. Possibly at closer ranges (say 100m max) we should be able to detect temperature anomalies of several inches size. This could be useful for measurement of heat loss, etc. from structure.

Negative: Qualitative only and very general. I'm not sure how if we could get specific enough info to make this useful to LBL.

LBL LITERATURE REVIEW FORM

TITLE: A Double-Beam Recording Instrument for Measurements of the Spectral Transmission of the Atmosphere in the Infrared

DATE: April 1972

SOURCE: Atmospheric and Oceanic Physics, Vol. 8

AUTHORS: Lu. S. Georgierskii, et al.

ABSTRACT:

A brief description of a double beam infrared spectrometer for atmospheric transmission measurements is given. Measurements from 5000 to 400 cm^{-1} may be made using automatically interchangeable NaCl, KBr, and LiF prisms. The unit also allows transmission measurements on ground and slant paths.

REVIEW:

The behavior of the 100% line in response to the inevitable misalignment of the mirrors is studied. Some graphs of atmospheric transmission are given for both slant and horizontal path measurements. A reproducibility analysis indicated that the device is capable of recording relative-transmission spectra on horizontal paths with an error no greater than 5%, except when the radiation from the measuring stop becomes a large factor. The article is very short, only giving a brief description of the unit. For further information, the instruction manual of the UR-20 may be referenced.

LBL LITERATURE REVIEW FORM

TITLE: Thermoelectrically-Cooled Infrared Imagers

DATE: 1978

SOURCE: PSIE Volume 132, Utilization of Infrared Detectors

AUTHORS: W. Grant

ABSTRACT:

The attractions of using thermoelectric (TE) coolers in IR imagers, as compared to cooling with either a Joule-Thomson cryostat or mechanical type refrigerator, are their relative light weight, low life cycle costs, and excellent reliability. The vitality of TE technology derives from a coincident maturation in three "sub-technologies": TE coolers, Intermediate-Temperature-Operation (ITO) detectors, and integrated focal plane electronics. TE coolers are available which provide 30-50 milliwatts cooling power at 195 K using less than 3 watts of input power. Small-geometry detectors sensitive to 3-5 micron radiation are thermal noise limited when operated above 170 K but still exhibit respectable detectivities of near 1.0×10^{11} cm-$Hz^{1/2}$/W at 193 K. Large detector arrays with integrated focal plane signal processing are now being developed which will improve system sensitivity beyond that of our first-generation devices. This paper briefly reviews the status of TE coolers, ITO detectors, and focal plane electronics, and presents the problems and trends in TE technology.

REVIEW:

The thermoelectric cooling technique is excellent for very small heat load. It does not appear practical for home use.

LBL LITERATURE REVIEW FORM

TITLE: High Accuracy Sun Sensor

DATE: August 1977

SOURCE: N78-11375

AUTHORS: A. Hammerschlag, et al.

ABSTRACT: The aim of the reported work was to arrive at a system definition for a high accuracy sunsensor intended for the pointing of advanced instruments for solar research. This work has been carried out in two steps. In the first part of the study (phase IA) several principles on which the sensor could be based were investigated and compared. In the second part (phase IB) the selected concept was analyzed in more detail and an appropriate design undertaken.

REVIEW: This report is not relevant to the LBL windows and lighting and passive solar programs and therefore does not warrant further study during the technology review.

LBL LITERATURE REVIEW FORM

TITLE: Development of a Thermistor Anemometer for the Measurement of Air Velocities in Ventilated Rooms

DATE: 1974

SOURCE: N75-26358

AUTHORS: L. Hardeman

ABSTRACT:

This paper describes a thermistor anemometer which is being developed for use in full-scale tests for the determination of air flow conditions in various premises. In order to make possible computer processing of the test readings, a general mathematical expression has been derived. The document also gives instructions for calibration and a description of the measuring equipment used.

REVIEW:

It looks like ± 10 percent accuracy can be obtained with this thermistor anemometer for flow speeds as low as 28 fpm (0.14 m/s). It was designed primarily for indoor use but would seem to be applicable to convection flow speeds on the outside of windows and walls if the flow speeds are high enough.

LBL LITERATURE REVIEW FORM

TITLE: Infrared Thermography Requirements Study for Energy Conservation

DATE: April 1977

SOURCE: DOE, ERDA Report No. CONS/2109-1

AUTHORS: R. B. Headley, et al.

ABSTRACT:

A study was performed for ERDA which delineates the thermography and measurement requirements necessary to make IR thermography (IRT) a viable technique for energy conservation works building codes, potential use and demonstration opportunities, and current IR technology are all considered.

REVIEW:

This is an excellent report, particularly as far as IR technology is concerned. It supplies in one sweep much of the data needed to understand the advantage and limitations of IRT in large-scale type use for energy conservation. Though the report is as vast in scope as the entire windows and lighting survey, it can probably supply crucial technical information.

LBL LITERATURE REVIEW FORM

TITLE: APT Pointing Assembly Thermal Blooming Investigation Volume I-Gas Investigation

DATE: August 1976

SOURCE: Hughes Aircraft Co. Report No. P76-322

AUTHORS: J. M. Kallis, et al.

ABSTRACT:

The absorption coefficients of gas samples taken from the Airborne Pointer Tracker pointing assembly at CO_2 laser lines in the wavelength range from 9.3 to 10.6μm were measured with a spectrophone that is sensitive to absorption coefficients as small as approximately 10^{-8} cm^{-1}. Published data on the absorption coefficients of the gas constituents of interest at infrared laser lines in the wavelength range from 3 to 12 μm were also reviewed and correlated with the experimental results.

REVIEW:

Describes gas sampling techniques and mass-spectrometer composition-measurement techniques that are sensitive to concentrations as small as approximately 1 ppm. Compares absorption-spectra measurements by IR spectrometers (wavelength range 3-23 μm, sensitivity 5×10^{-7} cm^{-1}) with those by spectrophones (individual laser lines, sensitivity 10^{-8} cm^{-1}). Contains extensive literature search of IR absorption coefficients of atmospheric constituents and various impurities. Worthy of further study during technology review because of possible interest to several aspects of windows and lighting programs.

LBL LITERATURE REVIEW FORM

TITLE: Solar Energy Meter

DATE: September 1977

SOURCE: N78 14630

AUTHORS: R. M. Masters

ABSTRACT:

An instrument was developed to continually integrate the enrgy available in incident light on a specifically oriented surface. The unit was designed for outside use in remote locations and is capable of operation over a temperature range of -20^{o} to +60^{o} centigrade with good accuracy. The unit is weather resistant, requires low power, has a high input impedance, is inexpensive, and has a visual readout and an analog output for recording.

REVIEW:

Good Points: Device receives and integrates total solar energy received, but in principle can be easily altered to integrate any kind of energy received (thermal, wind, etc.) with the proper sensor.

Lacks good description of physical construction but pictures are included which help.

Relates to measurement devices needed in LBL report. Use this info for our report, particularly if ways can be determined to use it with other sensors.

Negative: Again, lacks physical device description.

This is not necessarily aerospace technology, but coming from NASA it could have originally been designed for satellite data acquisition.

LBL LITERATURE REVIEW FORM

TITLE: Laser Absorption Studies

DATE: November 1975

SOURCE: AD-A018 900

AUTHORS: F. S. Mills, et al.

ABSTRACT:

This report covers progress on the various tasks which comprise the subject research program. These tasks include DF laser measurements for HD_0 and H_2O absorbers and CO_2 laser absorption measurements on the P(20) and R(20) lines. Additional topics include spectrophone calibration techniques, improvements in calculation programs and design of CO, CO_2 and DF probe lasers.

REVIEW:

Does not appear to contain material relevant to windows and lighting and therefore is not worthy of further study during the technology review. The data in this paper are already summarized in the literature review contained in the report by Kallis, et al.

LBL LITERATURE REVIEW FORM

TITLE: Infrared Thermography of Buildings

DATE: September, 1977

SOURCE: AD A044942

AUTHORS: R. H. Munis, et. al.

ABSTRACT:

An interior, infrared thermographic survey of single-pane, aluminum-frame, projected windows was performed to pinpoint locations of excessive infiltration. Infrared thermographic inspection accomplishes this more quickly and more accurately than conventional techniques of studying window infiltration. This report presents 32 thermograms and photographs which in many cases dramatically illustrate infiltrations (1) around the mullions, (2) along the top opening cracks, and (3) under the frame/sill interfaces. Poor glazing seals were easily detected and the exact points of glass/frame leakages were pinpointed. Plumes of warm air on the window glass, rising from the convectors, were dramatically captured by the infrared camera system. In several cases, the plumes were noted 12 ft. above the convectors on the top window panels. Heat loss from the convectors was noted through the walls of the building in thermograms taken from the outside. Several recommendations were prepared for the General Services Administration, owner of this Federal Office Building in Burlington, Vermont.

REVIEW:

This report contains some very useful information. An AGA Thermovision IR camera was successfully used to show that heat losses through windows can be measured very easily and effectively, particularly "infiltration" heat loss (actual air leaks around windows. Measurements were made from both inside and outside the test building. Also reference was made to earlier CRREL work which showed that 1/4 inch spaces in storm windows did not provide reasonable improvement over single pane windows, but that 3/4 to 1-1/4 inch gaps did.

LBL LITERATURE REVIEW FORM

TITLE: Optoacoustic Spectroscopy and Detection

DATE: 1977

SOURCE: Academic Press, New York

AUTHORS: Y. H. Pao (ed.)

ABSTRACT:

This book is an introduction to optoacoustic spectroscopy and consists of 8 articles: 1) physics of signal generation and detection, 2) energy transfer mechanisms, 3) design of optoacoustic systems, 4) tunable radiation sources in the UV and visible spectral regions (0.1 - 1.0 μm), 5) tunable IR laser sources for optoacoustic spectroscopy, 6) IR optoacoustic spectroscopy and detection, 7) photoacoustic spectroscopy of gases in the visible and UV spectral regions, and 8) solid state photoacoustic spectroscopy.

REVIEW:

According to Dr. D. A. Depatie of the Air Force Weapons Laboratory, this book is the most up-to-date reference on photo-acoustic techniques. It contains references up to 1976. I recommend studying this book during the technology review, telephoning some of the chapter authors, and possibly reading some of the references cited i the book.

LBL LITERATURE REVIEW FORM

TITLE: Subtle Source of Contamination in Spectrophones

DATE: December 1976

SOURCE: Applied Optics, Vol. 15, pp. 2974-2976

AUTHORS: J. C. Peterson, et al.

ABSTRACT:

On occasion, an apparent contaminant in gas samples has interfered with spectrophone absorption measurements. The source of the contamination was traced to a fluid used ot clean a mirror in the spectrophone system. This cleaner, primarily methanol (CH_3OH), has a strong absorption in the 10-μm spectral region. This investigation indicates that extreme caution must be taken in selecting a cleaning fluid to ensure that the cleaner does not interfere with the experiment.

REVIEW:

The result of this paper are consistent with those of Kallis, et al., who concluded that freon 113 (commonly used as a solvent and cleaner) can contaminate a gas sample sufficiently to cause significant IR absorption. The Peterson, et al., paper is therefore worthy of further study during the technology review because of its applicability to high-sensitivity measurements of the type of interest to the windows and lighting programs.

LBL LITERATURE REVIEW FORM

TITLE: Preliminary Design Package for RS600 Microprocessor Control Subsystem

DATE: January 1978

SOURCE: N78 24611, DOE/NASA CR-150528

AUTHORS: Rho Sigma, Inc.

ABSTRACT:

Rho Sigma, under NASA/MSFC Contract NAS8-32256, is developing three identical microprocessor control subsystems which could be used in heating, heating and cooling, and/or hot water systems for single family, multi-family, or commercial applications. The controller is to incorporate a low cost, highly reliable (all solid state) microprocessor which can be easily reprogrammed.

The report contains the information necessary for the evaluation of the preliminary design of the subsystem. Included are the Verification Plan, Hazard Analysis, Specifications and other information helpful in the evaluation of the preliminary design.

REVIEW:

The concept of using a microprocess to control heating and cooling of a building is very attractive. This approach can conserve energy if the problems associated with using this technique can be solved.

LBL LITERATURE REVIEW FORM

TITLE: Photoacoustic Spectroscopy

DATE: 1978

SOURCE: Advances in Electronics & Electron Physics, Vol. 46, L. Marton (ed.), pp. 207 - 311.

AUTHORS: A. Rosencwaig

ABSTRACT: This review article consists of 10 sections: 1) introduction, 2) early history of the photoacoustic effect, 3) photoacoustic effect in gases, 4) theory of the photoacoustic effect in solids, 5) theory of the photoacoustic effect in liquids, 6) experimental methodology, 7) photoacoustic spectroscopy in physics and chemistry, 8) photoacoustic spectroscopy in biology, 9) photoacoustic spectroscopy in medicine, and 10) future trends.

REVIEW: This article complements the book edited by Pao and was written by the author of one of the articles in Pao's book. It contains references up to 1978, whereas Pao's book contains references only up to 1976. The book appears worthy of further study during the technology review.

LBL LITERATURE REVIEW FORM

TITLE: Radiation Absorption Measurement System

DATE: October 1978

SOURCE: Industrial Research/Development, p. 116

AUTHORS: H. Schlossberg

ABSTRACT: A new measurement system has been developed for measuring ultralow levels of bulk and surface absorption in a solid material in any wavelength region where a coherent radiation source is available. The system uses acoustic transducers mounted directly on the specimen to measure the periodic heating of the sample upon absorption of a chopped input beam by means of the photo-acoustic effect. The system price is approximately $5,000 plus laser.

REVIEW: This system has been used extensively for the evaluation of potential window materials for high-energy lasers. It also can be used for studying bulk and surface properties of materials in the UV through non wavelength range. This system may be valuable to the LBL window program and therefore is worth further study in the technology review.

LBL LITERATURE REVIEW FORM

TITLE: Soil Moisture Sensing with Aircraft Observations of the Diurnal Range of Surface Temperature

DATE: January 1977

SOURCE: N77 19564

AUTHORS: T. Schmugge, et al.

ABSTRACT:

Aircraft observations of the surface temperature were made by measurements of the thermal emission in the 8-14 µm band over agricultural fields around Phoenix, Arizona. The diurnal range of these surface temperature measurements were well correlated with the ground measurement of soil moisture in the 0-2 cm layer. The surface temperature observations for vegetated fields were found to be within 1 or 2°C of the ambient air temperature indicating no moisture stress. These results indicate that for clear atmospheric conditions remotely sensed surface temperatures can be a reliable indicator of soil moisture conditions and crop status.

REVIEW:

This thermal emission moisture measurement technique maight be useful for determining the moisture content of yards in residential areas, e.g., or for measuring moisture on roofs of houses, thus supplying information valuable in energy conservation analysis and predictions. We should look into this function (if possible) for our windows and lighting report.

LBL LITERATURE REVIEW FORM

TITLE: Reliability Screening Using Infrared Radiation

DATE: October, 1966

SOURCE: AD 642112

AUTHORS: B. Selikson, et. al.

ABSTRACT:

A program was conducted to determine the feasibility of developing a process whereby transistors which have a high probability of failing during their operating lifetime can be screened from a lot of similar but reliable transistors on the basis of their infrared output while operating under normal electrical conditions. The program was based on the design of a process whereby very large numbers of units could be screened in a short amount of time. The experimental procedure is detailed. A full discussion is included of the mode of operation of the primary investigative device, an evaporographic imaging camera, and difficulties experienced with this device are detailed. Many refinements in infrared measurement techniques and methods were made. Operating life tests conducted using both normal transistors and infrared "glowers" show a greater percentage of failures among the glowers than among the normal units. The Evaporograph is compared as an infrared microscope to both a bolometer detector infrared microscope and an indium antimonide detector infrared microscope. Microscopic scanning investigations of transistor and integrated circuit structures are described, and use of an X-Y recorder to display results is described. Infrared measurement of case temperature and correlation of this measurement to thermal resistance characteristics and determination of heat loss mechanisms by infrared means are also included. Comparison of infrared results with further life test studies was undertaken. Failures from all life tests were analyzed, and a discussion of these failure analyses has been included herein. A screening efficiency index has been calculated as a result of these studies, for which the derivation is given.

REVIEW:

This paper seems to be mostly useless to the windows and lighting project, except that it points out that emissivity differences play a noticeable role in apparent temperature measurement (a non-negligible role).

LBL LITERATURE REVIEW FORM

TITLE: Remote Infrared Spectrocopy of the Earth

DATE: 1976

SOURCE: N78-14543

AUTHORS: C. R. Steinmann

ABSTRACT:

An airborne IR laser spectrometer was used to remotely sense surface minerals by measuring the reflectance of a CW CO_2 laser. Measurements were made in the 8 - 12 μm atmospheric window.

REVIEW:

A tunable CO_2 laser operating between 9.1 and 11.6 μm was used to illuminate the earths surface from an aircraft. By heterodyne detection, the reflection signatures of surface minerals were measured. Reflection curves for several minerals are included. It was found that most of the rock forming minerals and clay minerals could be determined by this method. Further work using differential spectrocopy was proposed.

LBL LITERATURE REVIEW FORM

TITLE: Solar Energy and the Heat Pump in a Northern Climate

DATE:

SOURCE: N78-27583

AUTHORS: R. Stewart, et al.

ABSTRACT: The Alumni House-Conference Center (AHCC) on the campus of the State University of New York at Albany, combines 2300 sq. ft. of copper solar panels with a water-to-water heat pump, an air-to-water heat pump, an electric boiler and two eight thousand gallon storage tanks. The building is instrumented to provide data for the time variant electric power demands, the impact of meteorological variables, peak storage capabilities, the efficiency of the solar panels, coefficient of performance of the heat pumps and the heating system performance factor. Computer simulations of the heat budget of the AHCC have been prepared and verified. A series of economic analyses provide Return on Investment comparing the air source heat pump to the solar assisted water-to-water heat pump and using a base case of electric heating peak shaving. Incremental costs are included but the peak saving capability was not tested.

Computer analysis, unverified, indicates that the air source heat pump has a higher COP than the solar assisted water-to-water heat pump. The solar system, however, during peak winter operating conditions provides 33% of the heating load of the AHCC.

REVIEW: Section 5 (Data Acquisition and Analysis Procedure) of this report describes the data acquisition system and sensors used. This information is worth further study during the technology review.

LBL LITERATURE REVIEW FORM

TITLE: Survey of Anemometers

DATE: March 1977

SOURCE: AD-A040 649; N77-30703

AUTHORS: R. J. Stone, et al.

ABSTRACT: A survey of the field of anemometry was made to assess recent advances in instrumentation. The purpose was to find commercially available wind systems which could replace, on a cost-effective basis, the F420C wind system which is presently used by the FAA for aviation observations.

A search of the pertinent literature for the past ten years was conducted. Over 30 manufacturers of wind sensing equipment were contacted, and discussions were held with research groups who have used the new generation equipment in field studies. It was found that most of the advances have resulted in lower starting speeds and greater instrument bandwidth, since much of the recent meteorological effort has been directed twoard micro-meteorological (turbulence) measurements. While the ruggedness, reliability, and range necessary for aviation use have not been primary considerations of manufacturers, there are several commercially available wind systems which could replace the F420C on a cost effective basis.

It is recommended that: (1) for the near future, any one of several suitable cup and vane or propeller on a vane wind systems be used for aviation purposes; (2) the vortex wind sensor mounted on a vane be thoroughly field tested; and (3) that the nonmoving part vortex vector anemometer and hot-film anemometer undergo testing and their continued development be monitored.

REVIEW: Appears to be a good review of anemometry and survey of sensor types and of commercially available sensors. Therefore appears worthy of inclusion in library of anyone involved in wind measurement. Recommend further study during technology review.

LBL LITERATURE REVIEW FORM

TITLE: Evaluation of Hand-Held Infrared Thermometer for "R" Measurement

DATE: April 10, 1978

SOURCE: D.O.E. (letter to D.O.E. from N.B.S.)

AUTHORS: S. J. Treado, et. al.

ABSTRACT:

Three different hand-held infrared (IR) non-contact thermometers were tested to evaluate their effectiveness in determining the R-value of walls. Two phases of the test were performed, first a laboratory test of a wood-frame wall, followed by a field test of a brick veneer wall. Additional measurements of R-value were made for comparative purposes using multijunction thermopiles and heat flow meters. An appendix is included concerning detailed error analysis of the spot radiometer measuring technique.

REVIEW:

The report casts a negative vote for the use of hand-held IR thermometry insofar as the uncertainties in temperature measurement are too great for a trustworthy analysis of the thermal resistance of walls. I imagine that the only value this report has to us is to point out the grave difficulties that IR thermometry has to overcome to be a viable tool.

LBL LITERATURE REVIEW FORM

TITLE: U. S. Army Test and Evaluation Command Materials Test Procedure 4-2-820, Common Engineering Test Procedure - "Humidity Tests"

DATE: 15 May 1970

SOURCE: AD-872 140

AUTHORS:

ABSTRACT: This Engineering Test Procedure describes test methods and techniques for evaluating the effects of high and low humidity on various types of military equipment. Humidity tests of two types are described: (1) High Humidity and Temperature and (2) Low Humidity and High Temperature.

REVIEW: The objective of this test procedure is to standardize the evaluation of the effects of high and low humidity on all types of material. It is primarily written for military equipment. It does not discuss how to measure relative humidity, which is the only factor of potential interest ot LBL. Therefore it is not worthy of further study during the technology review.

LBL LITERATURE REVIEW FORM

TITLE: Reversing the Trend and Infrared Testing is Simplicity Itself

DATE:

SOURCE: ASCC Record 72

AUTHORS: R. Vanzetti, et. al.

ABSTRACT:

Infrared automated testing of printed-circuit cards, as opposed to conventional testing, brings about a welcome trend reversal. Equipment, programming, operation are simple and easy. A quick sweep of the scanner performs simultaneously inspection, test and troubleshooting. The data pinpointing a failure condition (either present or future) is immediately printed out by teletype. And as long as the p.c. card can be electrically energized and inserted in the target area, it makes no difference to what system it belongs or whether it contains analog, hybrid or digital circuitry, discrete components, or integrated circuits. Infrared fundamentals, infrared signature, infrared test equipment operation are described in the paper. The substantial savings yielded by infrared automated testing are discussed in the final section.

REVIEW:

Good points - Very nice qualitative description of IR testing on a mass-production scale and on a design scale

Negative - Glosses over some of the tough implementation problems of absolute (true) temperature measurement

Perhaps a way can be though of and use the IR scan ⟶ A/D processor ⟶ temperature output operation format as the testing of certain photovoltaic devices. Otherwise I see little hope for applying this particular scheme and our LBL task.

LBL LITERATURE REVIEW FORM

TITLE: Indoor Test for Thermal Performance Evaluation on the Sunworks (Air) Solar Collector

DATE: January 1978

SOURCE: N78 24613, DOE/NASA CR-150666

AUTHORS: Wyle Laboratories

ABSTRACT:

This report describes the test procedure used and the results obtained from an evaluation test program conducted to obtain thermal performance data on a Sunworks single-glazed air solar collector under simulated conditions. These tests were made using the Marshall Space Flight Center's solar simulator. A time constant test and incident angle modifier test were also conducted to determine the transient effect and the incident angle effect on the collector. These results and the results of the collector load test are also discussed.

The Sunworks "Selector", solar energy collector is an air-type, single-glazed flat plate. The absorber is copper sheet with selective black coating. Outside dimensions are 36 inches by 84 inches by 4 inches. Collector weight is 111 pounds.

REVIEW:

The test results should be useful to evaluate the suitability of the solar collector fur use on buildings.

APPENDIX F

TAP-3 THERMAL ANALYSIS PROGRAM

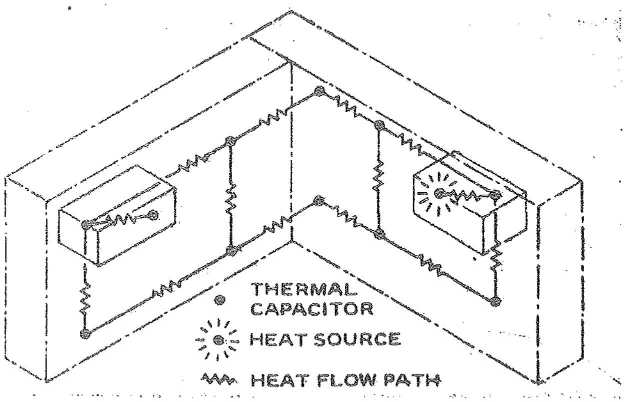
TAP-3
Thermal Analysis Program

HUGHES
HUGHES AIRCRAFT COMPANY
COMPUTING AND DATA PROCESSING

PRODUCT PROFILE — 6350.107 * ISSUED 7-76 * ENGINEERING APPLICATIONS * HUGHES AIRCRAFT * COMPUTING & DATA PROCESSING

KEY FACTS

TAP-3 is a computer program that analyzes conduction, convection, radiation, and phase change heat transfer in physical systems. A physical system is simulated by a lumped parameter network consisting of thermal capacitors, heat sources and heat flow paths. Finite difference methods are used to calculate both transient and steady-state solutions. TAP-3 is available on either the C&DP IBM 370/165 or S&CG IBM 370/158 computer.



BACKGROUND

TAP-3 is an IBM 370 program derived from an IBM 7094 program developed by the Atomics International (AI) Division of North American Rockwell Corporation. The AI program is a descendant of the Lockheed Thermal Analyzer Program, which has been in use since 1961. Since 1966, many revisions of the AI program have been made at Hughes Aircraft Company. These program revisions have evolved into the TAP-3 program which is now unique to HAC.

CAPABILITIES

- Standardized input or free format input
- Data is input to the program via ten basic input data blocks as follows:

BLOCK	TYPE OF INPUT
001	Titles and Messages
010	Network Description
020	Initial Values
030	Functions
040	Tables
050	Latent Heat
060	(not used)
070	Special Constants
080	Variables to be Printed
090	Printout Intervals
096-099	Variables to be Plotted (data case processing)

- A thermal network is described by nodal points joined to one another by connector elements.
  - Nodal points represent the lumped parameters of the physical system subvolume.
    - Capacitance (C)
    - Temperature (T)
    - Heat Source (Q)
  - Connector elements reference the type of heat flow path between these subvolumes.
    - Conduction
    - Convection Y
    - Radiation
  - Nodal points are characterized as:
    - Diffusion (T, Q, C . . . .)
    - Arithmetic (T, Q . . . . C = 0)
    - Boundary (T = constant or function . . . . Q = C = 0)

- Node and connector numbers are assigned by the user. These user numbers are directly referenced within the program. Compact data entry is possible if there is an arithmetic progression to the node numbers connected by consecutively numbered connectors.
- The program parameters are uniquely identified as follows

Parameter	Definition	Units
T	Temperature of a Node	degrees
C	Thermal Capacitance of a Node	energy per degree
Q	Internal heat Generation Rate for a Node	energy per unit time
Y	Thermal Conductance of a Connector	energy per unit time per degree
D	Dummy Parameter which may be used for Optional Variables or Constants	units depend on what the variable represents

- Any consistent system of units may be used for these parameters.
- All parameters are initialized as either a program constant or a starting point for a variable in the 020 block.
- Any parameter may be specified to be a function of any one or two of the other parameters or a function of time. This functional dependence is specified by:
  - Monovariant or bivariant tables (040)
  - Built-in mathematical and thermal functions (030)
- In addition to the built-in functions, user coded FORTRAN subprograms can be designated for execution at different phases of program operation as follows:
  - At the start of the temperature calculation phase (FUN41, FUN 91, SUB98, UROWN)
  - Immediately after the temperature calculation phase (AFTTEM)
  - Before each temperature printout (BEFPRI)
  - After the end of all computation and printing for the case, but before saved plot data are processed into plots (AFTEND)
- The phenomena of phase change (heat flow to or from a node without temperature change) is easily simulated via Block 050. The program keeps track of whether a node is solid, liquid, or gaseous and integrates the heat flow rate during phase changes to establish when the change is complete.
- At most, only twelve program constants are required for the execution of each transient or steady-state problem. Some constants are physical quantities and others are merely "yes-no" flags.
- Any number of program parameters (T, C, Q, Y, D) up to a total of 500, may be requested for printout. Parameters are printed, 5 to a line, in the order requested. The user may override the standard output labels (example — T012, Q034, Y429, D306) and assign his own labels.
- Printout intervals between the problem start and stop times are specified by the user. Eight variations of printout interval with time are permitted.
- Stacked data cases can be set up in the following ways:
  - The present case is identical to the previous one except that some parametric values are changed before starting again.
  - The present case begins where the previous one ended except that some parametric values are changed before continuing.
  - The present case is completely different from the previous case.
- The results of a data case can be plotted on a CalComp plotter. Each case generates up to 20 graphs, each consisting of a pair of labeled axes and a set of curves. The independent and dependent variables may be any of the program parameters (T, C, Q, Y, D, TIME).

LIMITATIONS

- The thermal network is limited to 500 nodes and 999 connectors.
- The D parameter matrix is limited to 500 elements.
- Only 500 built-in function specification cards are allowed in the 030 data block.
- A node may not have more than 500 connections. This situation could arise when a boundary node is connected to many different nodes.

(Continued on next page)

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- If a node radiates, then its total connections must not exceed "1100 minus the total number of network connectors". This restriction:
  - Always applies to arithmetic nodes
  - Only applies to diffusion nodes during steady-state runs
  - Never applies to boundary nodes
- The user must input an initial temperature for every node in the network, even if the initial temperature is 0.
- The total number of tables entered in the 040 data block may not exceed 99, and the total number of cards in the block may not exceed 500.
- All tables are linearly interpolated.
- An energy balance covergence capability is not available. The network solution is dictated only by a user supplied delta-temperature criterion.
- Each CalComp graph is limited to 225 points per curve. The maximum number of curves on any graph is 6.
- The program's built in plotting capability does not allow the user to select the plot scales. However, user supplied FORTRAN subprograms which directly use IBM 370 plot packages can remove this restriction.
- Multiple cases which reference an initial case are not directly programmable.

GENERAL DESCRIPTION

The program solves both transient and steady-state problems by analyzing a mathematical network which approximates the physical system under consideration. Both an explicit forward differencing technique and/or Newton's Second Order Method are incorporated in the solution.

The mathematical network consists of nodal points connected to one another by heat flow paths. These heat flow paths have characteristic values which are referred to as admittance (Y). The heat flow rate along any path is defined as the product of the admittance and the temperature difference of the connecting nodes. Heat flow rate may be due to one of three phenomena — conduction, convection, and radiation. The admittance identities for each phenomena are either input directly or "Pre-Calculated" during execution of the program.

Nodal points are also classified into three groups based upon their ability to:

- Change their temperature in accordance with the heat flows to and from them (Diffusion)
- Stay in thermal equilibrium, at all times, with the connecting nodes (Arithmetic)
- Maintain a specified temperature (Boundary)

Diffusion and Arithmetic nodes can consider an internal heat generation rate which is denoted by Q. It is meaningless to think of a boundary node as having a Q.

The order of program execution for either a transient or steady-state problem is shown in the TAP-3 Flow Diagram. For transient analysis, the following sequence of steps is defined:

- Evaluate functions and perform table interpolations.
- Apply the explicit forward differencing technique to yield diffusion node temperatures at the end of a stable time interval.
- Replace previous diffusion node temperatures with those just calculated.
- Perform phase change calculations, if any.
- Evaluate functions and perform table interpolations.
- Apply Newton's Second Order Method to obtain arithmetic node temperatures.
- Compare largest arithmetic temperature change with user supplied differential temperature convergence criterion to ensure convergence. Otherwise, repeat the previous two steps, using the last temperatures calculated as new initial temperatures, until convergence is obtained.

Steady-state analysis proceeds in the same manner, except that diffusion nodes are always treated as arithmetic nodes. The final convergence criterion in the transient analysis also holds, except that convergence implies the end of the analysis rather than just the end of the time step.

COST

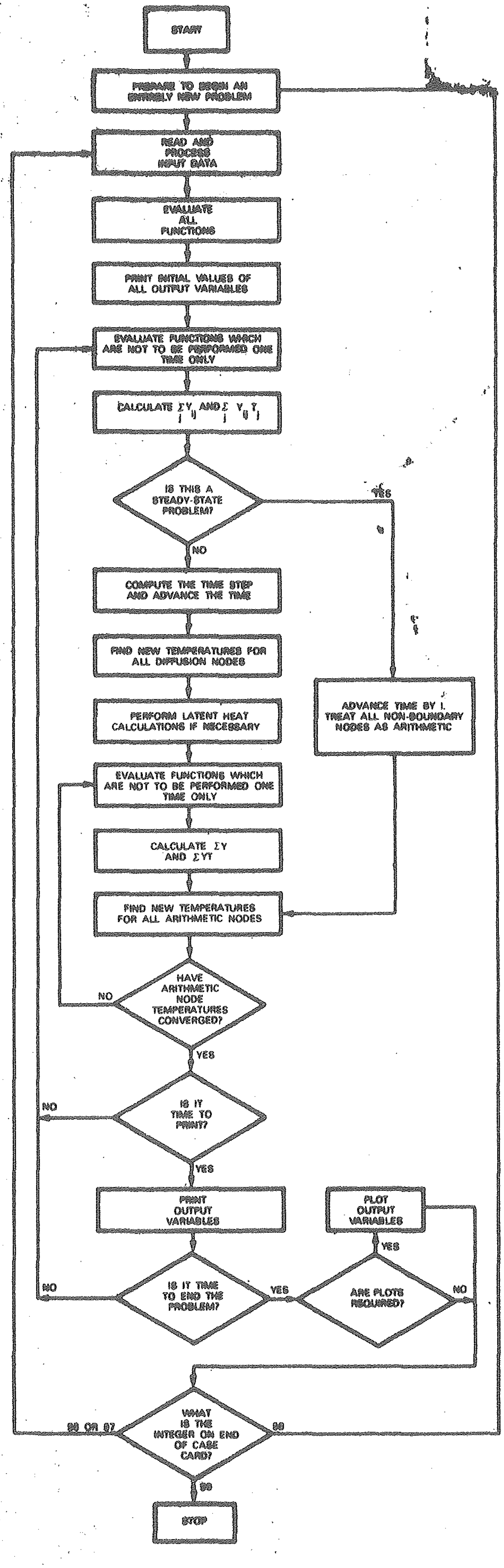
The cost of a TAP-3 run is dependent upon the nature of the problem. A steady-state run will typically average a few dollars. A transient run can be more costly since stable time requirements dictate the problem run time.

FURTHER INFORMATION

For further information, obtain the 370 TAP-3 User's Manual by completing and sending a C&DP Document Requisition Form (13206DP) to the C&DP Publications Library, Building 606, M/S D119.

The Engineering Applications Section of the C&DP Engineering Computing Department is responsible for the maintenance of TAP-3. Any questions or comments regarding the usage or performance of this program should be directed to:

L. Gaudreau • Extension 82154 • Building 3668 M/S W215



TAP-3 FLOW DIAGRAM

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