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HEATING/DAYLIGHTING PROTOTYPE DEVELOPMENT

Phase I, Passive & Hybrid Solar Manufactured Building Project

Interim Topical Report and Project Status Report No. 1

By

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March 31, 1980

Work Performed Under Contract No. FC02-80CS30367

Butler Manufacturing Company

Research Center

Grandview, Missouri

and

Princeton Energy Group

Princeton, New Jersey

U.S. Department of Energy

Solar Energy

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Price: Paper Copy \$7.00
Microfiche \$3.50

INTERIM TOPICAL REPORT and PROJECT STATUS REPORT #1
Cooperative Agreement No. DE-FC02-80CS30367
covering the period
1 October 1979 through 29 February 1980

Butler Manufacturing Company
HEATING/DAYLIGHTING PROTOTYPE DEVELOPMENT
Phase I, Passive & Hybrid Solar Manufactured Building
Project

31 March 1980

by
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Butler Manufacturing Company Research Center

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INTRODUCTION

The graphic analyses comprising Sections I and II of this report were used to guide the early design phase of passive/hybrid solar prototypes (Section III) now under construction at the Butler Research Center.

Section I presents climatological data, both representative ("typical") and extreme conditions, relevant to building energy use in Grandview, Missouri. These data describe the building environmental control requirements in this locale. They also help identify ways to satisfy building energy needs by "natural" means, taking advantage of special opportunities inherent in local weather patterns. The climate analyses are useful in establishing, at an early point in the design process, those conditions which will critically affect the building's energy performance.

Section II goes a step further, merging the energy-related characteristics of a particular building and its use with ambient weather conditions. The graphs depict daily fluctuations in the major categories of building heating/cooling load for the experimental building (Roof Runner facility) at Butler Research Center. Data input include hourly weather and building occupancy schedules, the geometry and fixed thermal characteristics (component R-values, heat capacities, etc.) of the prototype structure, and variable conditions (status of moveable insulating shutters, HVAC operating modes, etc.). These load analyses direct attention to important issues in the design, and to aspects of anticipated performance which are of special interest in the upcoming test phase. Simulations of this type assist in defining critical points for instrumentation; they provide feedback for design improvements; they guide the selection and design of back-up HVAC equipment; they aid the formulation of control strategies incorporating both conventional and prototype systems.

Section III shows the prototype systems to be incorporated in the new Roof Runner building. Both warehouse (no ceiling) and office (suspended ceiling) system types are included. The diagrams conceptually depict the heat flows in several representative operating modes, sampling the wide variety of operating conditions which will be evaluated during the testing phase of this project.

The development of Butler's passive/hybrid solar components has received partial support from the U.S. Department of Energy (Cooperative Agreements Numbers DE-FC02-80CS30366 and DE-FC02-80CS30367). The materials in this report were prepared as part of the U.S. DOE Reporting

Requirements. They were presented and discussed at an Interim Design Review at Butler Research Center on 28 February 1980. Marvin Snyder and Research Center staff, major project consultants Princeton Energy Group and Desert Research Institute, and Bruce Baccie, U.S. DOE Technical Monitor, were present. Feedback both during and after the Review was strongly positive. A Proposal for Phase II (covering prototype construction and testing) of the Grandview project (DE-FC02-80CS30367) was submitted at the same meeting, and approval for Phase II expenditures was received shortly afterwards.

Complete construction documents, encompassing more than three design alternatives to be tested in Phase II, were presented at the 29 February Interim Review. Prints of drawings selected by the Technical Monitor, including documentation of earlier, discarded design alternatives, were subsequently mailed to his office. Cost estimates for the designs selected for construction are provided in Section IV of this report.

SECTION I

CLIMATIC ANALYSIS KANSAS CITY

GRAPHIC ANALYSIS: CLIMATE

The following graphs and charts characterize Kansas City weather data applicable to the design and engineering of the solar building at Butler Research Center. Most of the charts are self-explanatory, however particular attention is directed to those on pages I.2 and I.10.

Simultaneous occurrence of dry bulb, wet bulb, and dew point temperatures provide a critical data base for assessing the potential for using evaporative cooling techniques. Evaporative cooling is dependent on the difference between dry bulb and dew point temperatures, and the SUMMER curves depicted on this graph indicate greater evaporative cooling potential in Grandview than formerly recognized.

Similar weather conditions generated from a representative year (1974) for Kansas City show typical monthly positions on the psychrometric chart. The human "comfort zone," drawn as a polygon on this chart, is useful in identifying heating and cooling requirements, as well as appropriate alternative energy techniques, in the various seasons.

Temperature Range

Record High

Max. Avg. High

Monthly Mean

Min. Avg. Low

Record Low

Diurnal Temperature Cycle

Air Temp.

Wet Bulb

Dew Point

Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec

Relative Humidity

Clear and Cloudy Days

Precipitation

Precipitation Days

Solar Radiation

BTU/(S.F. Day)

60 Degrees

Vertical

Horizontal

Hours of Sunshine

Maximum Possible

Actual

Percent of Possible

Wind Speed & Direction

Summer Pattern

July 21-30, 1974

Dry Bulb

Wet Bulb

Dew Point

Hourly Temp. - °F

Cloud Cover - tenths

Wind Velocity - mph

Winter Pattern

Jan 11-20, 1974

Dry Bulb

Wet Bulb

Dew Point

Hourly Temp - °F

Cloud Cover - tenths

Wind Velocity - mph

Psychometric Chart

SECTION II

LOAD ANALYSIS R & R BUILDING

GRAPHIC ANALYSIS: DIURNAL HEATING/COOLING LOAD

The following curves present daylong load analyses for the Butler R&R building in Grandview, Missouri.

The weather conditions assumed are based on statistical coincidence of major factors affecting heating/cooling load, and selected to represent normal operation in each season. Heating and cooling loads are graphed for the OFFICE/MAINTENANCE space and the WAREHOUSE, each for a hypothetical base case and for the solar case as being built for testing at the Research Center. The solar building includes roof aperture and shutter with a south wall collector. The base case examines a standard LandmarkTM building of the same size and configuration.

The graphs identify, on an hourly basis, the envelope and air infiltration losses/gains, solar gains and internally generated heat gains from lighting and people. Summertime analyses include a curve for latent cooling loads (energy used for dehumidification). Abrupt steps in the curves correspond to the turning on of lights, thermostat setbacks, and opening or closing of thermal shutters in the roof aperture.

The effect of each load category on the energy profile of the building has been color coded for a quick visual understanding of its role in total diurnal heating/cooling load. The Net Load is shown as a line interrupted by a rectangle at each hourly value.

The information thus supplied by each graph is valuable in the design process for assessing the effectiveness of the solar systems, coordinating operational modes of shutters, storage components, and backup HVAC equipment, and for identifying the most effective areas for attention in further development of the prototypes.

SAMPLE INTERPRETATION OF ENERGY LOAD GRAPHICS

Office/Maintenance Heating Loads

A glance of the energy profile for the BASE CASE Office/Maintenance Zone (II.4) shows the heating load for a typical winter day. Internal gains (yellow), decrease the heating requirements (blue, turquoise), but the building nevertheless requires backup throughout the day.

The corresponding SOLAR building (II.10) receives heat gain from the south aperture and southwall collector sufficient to offset the building heating load during the day. Excess solar gains will be stored. Analyses of this type provide one input to the sizing and configuration of storage subsystems in this climate.

Thermostatic Setback and Shutter Operation

All the graphs model step conditions at 8 am and 5 pm to correspond with a nighttime thermostat setback. These steps also coincide with the operation of the roof aperture shutters. The setback and closing of shutters reduce heating requirements at night, when the building is unoccupied. The increased daytime load, created by opening the shutters, is more than compensated for by the large solar contribution of the aperture and southwall collector.

Warehouse Heating Load

On a cold, clear day in winter the BASE CASE Warehouse Zone (II.20) has a net heating load approximately twice that required by the Office/Maintenance Building (II.4). Internal gains in the warehouse satisfy only a minor portion of that load. Thus, a larger portion of the warehouse solar heating gain (II.25) is used for daytime heating, and a smaller proportion of the solar gain is diverted to storage. On a cold-cloudy day (II.26) the solar gains are at a minimum, and the graph shows that additional heating will be required. This, in conjunction with the cloudy day charts of Section I, provide requisite information for sizing storage.

Average summer Cooling Loads

Average summer Office/Maintenance cooling loads are displayed by graphs on pages II.7 and II.16 for the BASE and SOLAR building cases. They show that nearly all of the internal gains in artificial lighting for the BASE case have been eliminated in the SOLAR building; natural, diffuse daylighting through the north aperture replaces the electric lights. Under the weather conditions graphed, this substitution produces about the same cooling load. Direct savings are realized, however, by the reduction in electricity required for lighting.

Similar comparisons can be made for the warehouse building (II.20 & II.29). Since the warehouse has less stringent demands on the level of lighting, the graphs for an average summer day suggest that only a few of the north aperture shutters be opened for daylighting, allowing solar heat gains to be minimized.

Spring and Fall Conditions

Seasonal analyses for Spring and Fall include graphs for several modes of operation. Given a set of weather conditions, the graphs are useful in selecting the desired operating mode. For example, on a cool-clear Spring day, only the north aperture would be open, limiting solar heat gain. On a clear Fall day the south roof aperture and collector might be operating (as in the winter), to charge thermal storage in preparation for colder days to come.

Butler R&R Building, Grandview, Missouri

BASE CASE, Office Zone (ceiling)

Butler R&R Building, Grandview, Missouri

BASE CASE, Office Zone (ceiling)

Butler R&R Building, Grandview, Missouri

BASE CASE, Office Zone (ceiling)

Butler R&R Building, Grandview, Missouri

BASE CASE, Office Zone (ceiling)

Butler R&R Building, Grandview, Missouri

BASE CASE, Office Zone (ceiling)

Butler R&R Building, Grandview, Missouri

BASE CASE, Office Zone (ceiling)

Butler R&R Building, Grandview, Missouri

SOLAR CASE, Office Zone (ceiling)

Butler R&R Building, Grandview, Missouri

SOLAR CASE, Office Zone (ceiling)

Butler R&R Building, Grandview, Missouri

SOLAR CASE, Office Zone (ceiling)

Butler R&R Building, Grandview, Missouri

SOLAR CASE, Office Zone (ceiling)

Butler R&R Building, Grandview, Missouri

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Butler R&R Building, Grandview, Missouri

SOLAR CASE, Office Zone (ceiling)

Butler R&R Building, Grandview, Missouri

SOLAR CASE, Office Zone (ceiling)

Butler R&R Building, Grandview, Missouri

SOLAR CASE, Office Zone (ceiling)

Butler R&R Building, Grandview, Missouri

BASE CASE, Warehouse Zone (no ceiling)

Butler R&R Building, Grandview, Missouri

BASE CASE, Warehouse Zone (no ceiling)

Butler R&R Building, Grandview, Missouri

BASE CASE, Warehouse Zone (no ceiling)

Butler R&R Building, Grandview, Missouri

BASE CASE, Warehouse Zone (no ceiling)

Butler R&R Building, Grandview, Missouri

BASE CASE, Warehouse Zone (no ceiling)

Butler R&R Building, Grandview, Missouri

SOLAR CASE, Warehouse Zone (no ceiling)

Butler R&R Building, Grandview, Missouri

SOLAR CASE, Warehouse Zone (no ceiling)

Butler R&R Building, Grandview, Missouri

SOLAR CASE, Warehouse Zone (no ceiling)

Butler R&R Building, Grandview, Missouri

SOLAR CASE, Warehouse Zone (no ceiling)

Butler R&R Building, Grandview, Missouri

SOLAR CASE, Warehouse Zone (no ceiling)

Butler R&R Building, Grandview, Missouri

SOLAR CASE, Warehouse Zone (no ceiling)

Butler R&R Building, Grandview, Missouri

SOLAR CASE, Warehouse Zone (no ceiling)

Butler R&R Building, Grandview, Missouri

SOLAR CASE, Warehouse Zone (no ceiling)

Butler R&R Building, Grandview, Missouri

SOLAR CASE, Warehouse.Zone (no ceiling)

SECTION III
PASSIVE SYSTEM TYPES

**Passive/Hybrid Solar Buildings Research
Status Report**

February 1980

**Butler Research Center, Grandview, Missouri
Princeton Energy Group, Princeton, New Jersey
Desert Research Institute, Boulder City, Nevada**

The design of the Grandview Roof Runner building has been guided by several important criteria. The innovations embodied in our passive/hybrid solar development program must address both the energy/cost concerns of purchasers, and their related construction realities. An effective solar alternative must utilize the reliable components and assembly/erection procedures with which Butler builders are already familiar. Prototypes being tested at the Research Center rely as much as possible on existing materials, components, and construction methods. The prototype components use standard Butler fabrication techniques and erection procedures. The solar system concepts are fully integrated with the conventional heating/cooling/lighting systems most commonly used in Butler buildings.

Careful merging of technical performance with production concerns is also required. The solar systems must be standardized, yet capable of high solar performance in varied climates. The systems must address many combinations of building mechanical/electrical loads, ambient temperatures and sunlight conditions, building sizes, compass orientation and other site factors, yet utilize a standard kit of parts in nearly identical system configurations. The development program to date has moved through a number of important technical breakthroughs, and we are well along the way to achieving these very demanding design goals.

Our initial concept, shown in the section drawing above, employed a single-sided, south-facing roof aperture, with a reflective/insulating shutter lowered at night to reduce heat loss. Subsequent work by PEG and Research Center designers has produced a more sophisticated, and much more effective, aperture and shutter assembly. The new aperture (detailed on the cover page of this report) provides a much higher daylighting contribution. Glass is used in two directions, using the entire sky dome as a light source and reducing the sensitivity of solar performance to building orientation. Multiple shuttering modes permit daylight utilization in a wider variety of weather and heating/cool-

ing load conditions. This increased flexibility also provides better integration with the cooling techniques to be tested in our second prototype building at Desert Research Institute. The double-sided roof aperture and shutter assembly are currently being examined for patentability by Butler and PEG.

A second solar collection component, the southwall air collector, has been under consideration since the earliest stage in the Grandview Roof Runner building design. This subsystem uses familiar and reliable flat-plate solar collector technology. Since the air collector can use existing wall panels for air passages or absorber surfaces, it is also applicable as an inexpensive retrofit to existing buildings. This could expand Butler builders' capability to assist past clients in reducing their building operating costs. The test installation at Grandview is being used to optimize cost/performance of the southwall collector in both active (fan-driven) and passive (natural thermosiphoning) versions, as well as to establish component detailing and erection procedures for both original construction and retrofit application.

The Roof Runner building also expands our initial system concept to test not only primary heat storage (components located in the plenum, struck directly by incoming solar radiation), but also secondary thermal storage (in a rock bed below the floor slab, through which warmed plenum air is circulated). Several plenum storage components and materials are to be tested at Grandview, including water-filled bags (standard waterbeds) suspended between the truss purlins, and polymer concrete ceiling tiles containing special high heat capacity (phase change) materials. The below-slab rockbed is primarily an "active" subsystem, since it uses fan power to transfer solar heat and nighttime "coolth" to and from storage. This indirect thermal storage mechanism, though less effective in the narrowest viewpoint than directly-irradiated thermal mass, has strong advantages in low cost and overall system efficiency. Basic system operating modes are illustrated by examples on the following pages.

BUILDING TYPE: WAREHOUSE (WITHOUT CEILING)

SYSTEMS:
1. ROOF APERTURE - DIRECT GAIN
STORAGE - SLAB
2. WALL COLLECTOR - THERMOSIPHON
STORAGE - INTERIOR MATERIALS

BUILDING TYPE: WAREHOUSE (WITHOUT CEILING)

SYSTEMS:
1. ROOF APERTURE - DIRECT GAIN
STORAGE - WATERBAGS
2. WALL COLLECTOR - THERMOSIPHON
STORAGE - INTERIOR MATERIALS

BUILDING TYPE: WAREHOUSE (WITHOUT CEILING)

SYSTEMS:

1. ROOF APERTURE - DIRECT GAIN.
STORAGE - SLAB & ROCKBED DRAWDOWN
2. WALL COLLECTOR - THERMOSIPHON
STORAGE - INTERIOR MATERIALS
3. NIGHT COOLDOWN

BUILDING TYPE: OFFICE (WITH CEILING)

SYSTEMS:

1. ROOF APERTURE - DIRECT GAIN
STORAGE - ROCKBED DRAWDOWN
2. MECHANICAL DISTRIBUTION - FROM ROCKBED
3. NATURAL RADIATION

BUILDING TYPE: OFFICE (WITH CEILING)

SYSTEMS:

1. ROOF APERTURE - DIRECT GAIN
STORAGE - ROCKBED DRAWDOWN

2. WALL COLLECTOR - FORCED AIR
STORAGE - ROCKBED

3. MECHANICAL DISTRIBUTION - FROM PLENUM TO ROCKBED
- FROM ROCKBED TO SPACE

BUILDING TYPE: OFFICE (WITH CEILING)

SYSTEMS:

1. ROOF APERTURE - DIRECT GAIN
STORAGE - WATERBAGS

2. MECHANICAL DISTRIBUTION - FROM PLENUM WATERBAGS

3. WALL COLLECTOR - THERMOSIPHON
STORAGE - INTERIOR MATERIALS

SECTION IV
COST ESTIMATES

ROOF APERTURE ADD-ON COST ESTIMATE

	<u>MATERIALS & SUBCONTR. LABOR</u>	<u>IN-HOUSE LABOR</u>
--	--	---------------------------

1. Skylight Housing and Glazing		
a. support framing (285 LF @ \$21.14)	6,025	
b. glazing units & adapters (114 glazed units @ \$83.30)	9,497	
c. erect support framing, skylight glazing units, insulation & misc. perimeter flashings (330 M.H. @ \$12.00)	3,000	960
d. insulation: isolate building plenum zones (80 M.H. @ \$12.00)	200	
2. Skylight insulating & Reflecting Shutter System		
a. gasket perimeter seal (tooling \$800) + (2500 LF @ \$.55)	2,175	
b. hanger loop & clips (228 assy's @ \$4.55)	1,038	
c. lower latch unit (228 @ \$5.00)	1,140	
d. metal edging - shutters (25000 LF @ \$.35)	875	
e. Yhermax/1-1/4" (2280 sf @ \$.56)	1,277	
f. pulleys & misc. rigging hdwe. (114 @ \$1.75)	200	
g. control line (2000 LF @ \$.30)	600	
h. motors, misc. controls, mounts (6 units @ \$415)	2,490	
i. steel pipe shaft (600 LF @ \$.75)	450	
j. shaft supports & misc. hardware (24 x 3 @ \$8.00)	576	
k. shutter preassembly (114 x 4 M.H. @ \$12)		5,472
l. shutter & rigging installation (54 M.H. @ \$14)		756
m. install mounts & pipe shafts, control lines, pulleys, etc. motors, wiring & testing (120 M.H. @ \$14)		1,680
n. shutter seal angle material	406	
Subtotals	29,949	9,823
3. Subcontract Management, Materials Shipping & OH @ 10%	2,995	
4. Labor OH @ 25%		2,457
Subtotals incl. OH	32,944	12,285
TOTAL EST. COST	\$45,229	

CEILING AND PLENUM STORAGE ADD-ON COST ESTIMATE

<u>MATERIALS & SUBCONTR. LABOR</u>	<u>IN-HOUSE LABOR</u>
--	---------------------------

1. Increased Structural Cost - Bldg. (ceiling/roof load 20# over conventional construction)	9,884	576
2. Water Bag Support Structural a. structural angle framing	1,550	
b. metal decking "Tensilform 75" (42 pcs/30" x 84" x 1" deep)	540	
c. installation & test modification framing & decking (21 units x 12 M.H. @ \$12)	1,512	1,512
3. Water Storage Bladders a. water bags/54" x 75" x 6", 3 material types (21 bags @ \$50, 10 bags @ \$300, 10 bags @ \$400)	8,050	
b. bladder installation, fill & test modification (41 bags x 8 M.H. @ \$12)		3,936
4. Phase Change Storage a. phase change tiles @ \$11.50/sf x 300 sf	3,450	
b. support framing @ \$2/sf x 300 sf	600	
c. installation (40 M.H. @ \$12)		480
5. North Wall Manifold/Plenum (40 LF @ \$5.90)	236	
6. South Wall Plenum Return (44 LF @ \$3.75)	165	
7. Junction Box w/2 Motorized Dampers (1 preassembly @ \$450)	450	
8. Transition Box w/unit Fan (4 preassemblies @ \$501)	2,004	
9. Ceiling to Floor Ductwork (4 runs 10' long @ \$2.70)	108	
10. Ceiling Translucent Lay-In Panels, 3-lamp ballasts and lighting fixture modifications	1,270	
11. Install North & South Wall Ductwork to Floor (Rockbed) (45 M.H. @ \$13)	585	
12. Electrical Service for Operation of Shutter System, Special Selectable Switching, Unit Fans & Movable Dampers, Additional HVAC Interface Controls	1,600	
Subtotals	32,004	6,504
13. Materials shipping @ \$OH @ 10%	3,200	
14. Labor OH @ 25%		1,626
Subtotals inc. OH	35,204	8,130
TOTAL ESTIMATED COST		\$43,334

WALL PANEL COLLECTORS ADD-ON COST ESTIMATEMATERIALS
& SUBCONTR.
LABOR

1. Manifold System at Rockbed and Eave	
a. fabricated manifolds (80 Lin Ft. @ \$15.00)	1,200
b. porthole volume dampers (10 units @ \$25.00)	250
c. insulation & plaster outside area (40 lin. Ft. @ \$6.00)	240
d. install dampers & manifolds (88 M.H. @ \$12.00)	1,056
e. apply insulation & plaster (24 M.H. @ \$14.00)	366
2. Absorber Paneling	
a. sheet metal/28 Ga. Galv. (1152 sf @ \$.47)	541
b. sheet metal preassembly - shear-form-prime/paint (80 M.H. @ \$14.00)	1,120
c. insulated sheet metal headers (64 Lin Ft. @ \$12.00)	768
d. gaskets/sealants (712 LF @ \$.39)	278
e. absorber panel erection (768 sf @ \$1.25)	960
f. fabricate supply/return ports through wall collector panels, dampers, finish trim (22 units @ \$39)	858
3. Glazing	
a. unit frames - factory glazed (16 (4x12) = 768 sf @ \$7.00)	5,376
b. unit frame installation (120 M.H. @ \$12.00)	1,440
4. Miscellaneous Components	
a. edge and base flashings (200 LF @ \$.90)	180
b. automatic passive vents - overheat protection (16 @ \$25)	400
c. installation, vents & flshgs. (16 x \$24) + (200 LF @ \$.81)	546
d. unit support angle - wshe. (24 LF @ \$5.00)	120
	<hr/>
Subtotal	\$15,669
Subcontract management, Materials shipping and OH @ 10%	1,567
	<hr/>
TOTAL EST. COST	\$17,236

FLOOR SLAB STORAGE ADD-ON COST ESTIMATE

MATERIALS
& SUBCONTR.
LABOR

1. Additional site preparation, excavate 12" additional below slab	200
2. Corrugated pipe ducting	1,279
3. Rockbed crushed stone (30 tons @ \$11.75)	1,410
4. Installation of stone (including equipment mobilization)	2,200
5. Extra below-slab and sub-base insulation, vapor barrier	<u>1,680</u>
Subtotal	6,769
6. Subcontract management, materials shipping and OH @ 10%	<u>677</u>
TOTAL COST	\$7,446

SUMMARY: ADD-ON COST OF SOLAR CONSTRUCTION

MATERIALS
& SUBCONTR.
LABOR

IN-HOUSE
LABOR

Roof Aperture	32,944	12,285
Ceiling/Plenum Storage	35,204	8,130
Wall Panel Collectors	17,236	--
Floor Slab Storage	7,446	--
TOTAL EST. SOLAR CONSTRUCTION COST	<u>92,830</u>	<u>20,415</u>