RESEARCH REPORT

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MASTER

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BUTLER MANUFACTURING COMPANY
HEATING/DAYLIGHTING PROTOTYPE DEVELOPMENT, Phase I
Passive & Hybrid Solar Manufactured Building Project

covering research and component design, conducted during the
period February 1979 - May 1979

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INTRODUCTION

This report describes the Phase I design process and energy analyses, conducted under subcontract to Butler Manufacturing Company by the Princeton Energy Group, regarding the wall (air) collector component for the passive/hybrid solar test building located at Butler Research Center in Grandview, MO. This work is part of a product development program aimed at providing passive/hybrid system building alternatives for commercial, industrial, and community purchasers of Butler's Landmark™ pre-engineered metal buildings.

At the outset it was determined that a Wall Air Collector System would strongly improve the heating performance of the Grandview test building. Based on the arrangement of the programmed interior spaces - Office, Maintenance, and Warehouse - a fundamental decision was made to outfit this test facility with two collector types:

1. A Hybrid Collector coupled to the rockbed storage and ceiling plenum of the Office and Maintenance Spaces.
2. Thermosiphon Collector coupled directly to the interior space of the Warehouse.

A conscious effort was made to develop the Hybrid and Thermosiphon systems simultaneously in the belief that similarity in component design would facilitate prototype fabrication in the short term, and enhance long range market viability.

SCHEMATIC DESIGN

Early decisions conceptualized a collector whose configuration recalled materials and techniques previously employed and field tested by the design team. Initially, the broad range of possible products was limited to those materials that had performed satisfactorily on earlier projects. Reflecting the tight construction schedule, serious consideration was given to various proprietary items readily available within the Kansas City area; none were found satisfactory. Another consideration that further influenced early design concepts was the capability of mockup fabrication within the Research Center's on site shop facility.

The air collector was conceived as a modular unit whose cross-section consisted of an outer layer of clear glazing, a 2" "dead" air space, an inner absorber panel, 2" "live" air space for forced or convective air flow, and the base building's pre-engineered metal panel envelope. (See Attachment 1: Dwg. SK-2, Detail 5.)

As a point of departure, the collector design, responding to the programmatic material limitations, was characterized by these decisions:

Module

The basic unit module was chosen to be four feet. This dimension is widely used throughout the construction industry as a standard building component module. Holding to this modular decision provided the desirable option of replacing any one component with a substitution at a later date for the purposes of comparative performance testing. Further, the module maintained dimensional

consistency with the Thermal Monopanl™ Wall System specified for the building. Formed as a pre-engineered one foot wide full height segment, the Monopanl™ box rib dimension offered frequent opportunities for modular interface with a 4' wide solar collector. Finally, the 4' capacity of the Research Center's in-house vacuum forming equipment provided the potential for molding many different plastic glazing profiles for product development consideration.

Glazing

Heading the list of glazing choices was Exolite, Cy/Ro Industries' double wall acrylic sheet. Experienced with its use and ease of handling in previous work, the team was most attracted by this material's economic advantage. However, the availability of Butler's plastic vacuum forming equipment introduced a new and unexplored dimension to the glazing issue. Not only could the glazing configuration be varied, but also through innovative forming the opportunity to eliminate a mullion, batten or cap bar became a real possibility. (See Att. 1: Dwg. SK-2, Detail 2.) The forming equipment also offered Butler the inherent advantage of developing and controlling its own product design.

Conventional glazing materials were not ignored during early stages of the design process. Low-iron content glass was recognized as a safe, albeit more expensive, alternate collector glazing. It was evident that a glass product could always be selected to satisfy applicable code flammability criterion, without sacrificing high-transmittance standards. In light of issues of availability, economics and quality control, the design team chose to proceed with designs for vacuum formed plastic sheets.

Absorber Panel

The obvious choice for an absorber panel was a rolled metal sheet of an optimized cross section cut into appropriate lengths. However, as a practical matter it was unrealistic to bear tooling expense to produce untested shapes based only on simulated performance. For this reason, it was evident that the absorber panel would be an improvised prototype. Taking a cue from Butler's Monopanl™ configuration, it was thought that an absorber panel could also be fabricated by braking sheet metal into a full-sized component to outfit the four foot by twelve foot required module. The resulting absorber plate would then be rigidized through its edge attachment detail. One of the absorber panel's vertical legs would be inserted into the formed reveal of its adjacent absorber module (recalling the Monopanl™ system), the remaining leg secured to the receding surface of the back-up wall panel. The absorber panel's interlocking four foot module would easily be synchronized to the one foot Monopanl™ module. (See Att. 1: Dwg. SK-2, Detail 2.) Cap flashing and sill flashing would close the panel top and bottom.

Much investigation went into determining the absorber panel's configuration (footprint). Graphic studies limited the panel's configuration to symmetrical bends, while increasing the surface area. Triangular 45° bends (see Att. 1: Dwg. SK-2, Detail 2) demonstrated better simulated performance than rectangular 90° bends. Undulating rectangular shapes cast shadows on the recesses. The triangular bends, however, presented a difficult closure detail for top and bottom edges. A sheet metal sill plate was drafted with a series of cuts and crossed scorings from which two adjacent triangular tabs could be bent upward to engage, rigidize and seal the panel's bottom edge. (See Att. 1: Dwg. SK-2, Details 3 and 5.)

In the detail for the Hybrid Collector this sill plate would sit on the perforated cover of the manifold below. (See Att. 1: Dwg SK-2, Detail 1.) Almost any hole shape or perforation pattern was available for use, provided sufficient evenly distributed air flow could be maintained without jeopardizing the structural integrity of the metal cover. To determine the appropriate manifold cover perforation, the team studied squares, ellipses, ovals and circles. No shape showed significant performance advantages, and the circle was found to be easiest to fabricate or punch out. (See Att. 3: Dwg SK-4, Detail 1.) The Thermosiphon Collector sill detail was slightly different to allow for retrofit application. Without the manifold for support, the tabbed sill closure sat directly on a plane of stiff base flashing.

The same top closure sheet was planned for both collector types. Utilizing a cut and scoring pattern similar to that of the sill component (see Att. 1: Dwg. SK-2, Details 4 & 7), triangular tabs were bent downward to engage, rigidize and seal the absorber panel's top edge. Next, a cap flashing piece covered this tabbed retainer to seal the entire layered assembly against the back up Monopanl™ surface.

Trims, Seals, and Connectors

Transition edges or points of interface between the air collector and Monopanl™ wall were detailed to incorporate closure trim pieces, fabricated as variations of stock Butler components. (See Att. 1: Dwg SK-2, Detail 2.) Flanged legs of closure trim pieces were attached to the Monopanl™ with standard Butler connectors. Stock fiberglass batts and expandable foams were included to prevent thermal bypasses. Stock tapes, sealants, caulking, and Butler's Panlastic™ sealant strips introduced thermal breaks, closed joints, separated materials and interrupted inside to outside thermal paths, thus minimizing infiltrative and conductive losses. (See Att. 3: Dwg. Sk-4, Details 3 & 4.)

One weather seal could not be accomplished with a conventional material installed in a routine method. Sealing the collector's cap flashing against the Monopanl's™ surface, which undulates in 6" increments, was difficult. Although compressible foam inserts could thermally seal the "live" air space, it would not keep the rain out. Even if conventional cap flashing were painstakingly pieced around the Monopanl's™ rectilinear hills and valleys, the securing of the flashing's vertical leg would require a continuous reglet cut into the panel's surface (impossible) or at the very least a continuous counter flashing cleat strip (impractical). Consequently, the most straightforward closure solution ran the cap flashing's vertical leg up the face of the Monopanl's™ projecting segments while bridging its recessed segments. At the eave, the metal flashing interlocked with the building's endwall roof trim. (See Att. 3: Dwg SK-4, Detail 3.)

Although the flashing detail was technically sound and reflected good building practice, it was subject to economic second guessing. The ENDWALL of a Butler Building, as distinguished from a SIDEWALL, varies in height, being subject to the 1/4 inch per foot slope of its roof. Depending on a building's orientation, it is reasonable to expect the situation where a wall collector is fitted to an endwall, as is the case in Grandview. Consider the result - a collector array of extensive length, the collector head at constant height and the endwall roof trim at constant slope. The flashing material necessary to weather seal the increasing space between collector head and roof trim is extensive. Adding a foot to the flashing length for each fifty feet of building length yields several feet of flashing sheet. Such is the case with the test building's

Warehouse collector, where some 5' of sheet goods is required for top closure. (See Att. 2: Dwg SK-3, South Elevation.) Further product development will aim to improve the economics of this situation.

DESIGN DEVELOPMENT

Once the design concept was established, materials and fabrication methods were studied and modeled at the on-site shop. Much emphasis was placed on component interchangeability, which would facilitate substitutions of alternative materials for comparative test purposes. However as an initial cost control measure, it was necessary to work within the limitations of the shop equipment.

Redesign became necessary. First, a length limitation of the on-site metal brake changed the absorber panel's nominal length from twelve feet to ten feet.

Next, repetitive bends on opposite sides of a metal sheet were not possible to brake with sufficient quality control. A new panel design resulted. It consisted of a completely flat absorbing surface with 1" rear projections perpendicular to the absorber plane, running full height at 4" on center (similar to Att. 3: Dwg SK-4, Detail 2). This component could be fabricated as 10' long by 4" wide flat sections of panel, with 1" bends returning the full length of both edges. In appearance each unit resembled a channel or a typical unpunched metal stud. 4' wide panel components required that adjacent 4" wide segments be physically interlocked by dimple punching together its 1" projections.

Vacuum forming the collector glazing in full height single pieces, was beyond the capacity of the shop equipment. Butler's vacuum forming equipment could only accommodate 4' x 4' squares or 6' x 4' rectangles. Guided by these alternatives, the collector glazing was revised to consist of three separately formed rectangles, nested vertically (similar to Att. 2: Dwg. SK-3, South Elevation). This change appeared to improve the scale and aesthetics of the unit, as well.

Since the Wall Collector array was not vital to the general construction of the test building, further development and refinement of its components were postponed to a later period in the critical path of the project. The design team shifted its effort to those passive components that were integral to closing the envelope of the building. The immediate priority was placed on rockbed and roof aperture details.

PERFORMANCE ANALYSIS

The Office and Maintenance sections of Butler's Building are essentially a "hybrid" prototype design. The conditioned space is thermally separate from the wall collector and the collector areas are separate from the storage, but the storage is integrated with the space (rock bed). There are basically three methods for modeling the building: 1) a generalized thermal network dynamic simulation, 2) a correlation developed for an active flat plate collector system, and 3) a correlation developed for various passive systems, alone or in various combinations. There are advantages and disadvantages with each method as a design tool. A thermal network is probably the most accurate, but also the most time consuming to set up and run, being better suited to study daily fluctuations than annual performance, and therefore has limited usefulness as a method for comparing different configurations. Modeling the Butler Building as

an active system (with the f-chart method) requires modifications such as treating the back loss of the collector as useful heat rather than a loss (since the collector is part of the building). The thermal storage is also not treated as an integral part of the building, so the heat transfer is strictly convective via hot air drawn through the bed with no radiant contribution. However, modeling the components as passive elements is a more realistic approach as the wall collector is an integrated part of the building, and the storage is directly coupled to the space. The wall collector was therefore treated as a glazed masonry thermal wall; even though it is actually a light metal panel wall, its storage is masonry in the form of a rock bin (albeit detached from the collector) and it experiences the high temperature differentials characteristic of both air collectors and masonry thermal walls. At night, as the storage is separate from the glass and the wall is insulated, a value of R-10 (4" Monopanl™) was considered in the model as equivalent to night insulation on a masonry wall. The building was modeled with various amounts of wall collector area in order to determine the sensitivity of thermal performance to the amount of solar glazing. Results are presented in Tables 1 and 2.

Wall collector performance was examined with varied amounts of collector area in order to determine the most cost effective ratio of collector to load. As Figure 1 for annual energy performance indicates, the energy saved by the wall collector alone increases linearly with the amount of glass used. Due to the law of diminishing returns, the increase is successively less at each increment, but only for a small amount. As the lighting doesn't vary with the amount of wall used, the internal gains are constant, and the savings is due only to an increase in the solar gains from the glazed area of the wall. At 431 square feet of net glass area (which is the amount actually used in the prototype building) the wall collectors provide 51% of the heating needed by the base building. However it is significant that even with half the amount of glazing, the system would still deliver roughly 34%. It would require twice the amount of collector area (an impossibility for the actual case, as there is not sufficient south wall unless the roofline is raised) to achieve better than 80% reduction in auxiliary energy used.

On a monthly basis, it is important to note that the energy saved per month is greatest in January. This is primarily due to the fact that with a vertical wall (assuming no reflector or snow cover), the greatest radiation transmitted will be during months when the sun angle is lowest, and secondly, that the additional layer of glass reduces the back loss, which is greatest in January. The solar heat provided by 431 square feet of wall collectors only fluctuates 15% or so over the heating season, from a high of 4.8 MMBtu in November (providing half of the heat needed) to a low of 4.2 MMBtu in January (one third of the load). Figure 3 shows the relationship between total heating load, internal gains, solar heat provided and auxiliary required.

Several other analyses and performance estimates were made during design development, and used to guide both general system design and detailing. Other significant results, treated in context with overall building performance calculations, will be reviewed in the Final Report of Phase I work.

Table 1. ANNUAL HEATING PERFORMANCE

System Type	Glass Area (sf net)	Solar Heat (MMBtu)	Useful* Internal Gains (MMBtu)	Auxiliary Required (MMBtu)	Heat Saved (MMBtu)	Savings % of base
Base Building (BLC=14,780)	-	-	33.9	41.5	(Reference)	
Wall Collector (BLC=13,780)	215	16.5	26.5	27.3	14.2	(34%)
	431	29.8	20.3	20.2	21.3	(51%)
	647	40.4	17.2	12.7	28.8	(69%)
	862	48.1	15.0	7.2	34.3	(83%)

*Gross Internal Gains are constant at 160,000 Btu/day

Table 2. MONTHLY HEATING PERFORMANCE

		Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Year
BASE BUILDING										
Gross Heating Load	(MMBtu)	3.47	9.49	14.99	17.04	13.20	11.01	4.64	1.64	75.48
Useful Int. Gains	(MMBtu)	3.47	4.80	4.96	4.96	4.48	4.96	4.64	1.64	33.91
Aux Required	(MMBtu)	-	4.69	10.03	12.08	8.72	6.05	-	-	41.57
WITH WALL COLLECTOR - 431 sf net										
Gross Heating Load	(MMBtu)	3.24	8.84	14.00	15.90	12.30	10.26	4.32	1.53	70.32
Useful Int. Gains	(MMBtu)	.23	2.86	4.31	4.39	3.61	3.59	1.24	.07	20.31
Solar Heat	(MMBtu)	3.01	4.80	4.19	4.58	4.32	4.35	3.09	1.45	29.79
Aux Required	(MMBtu)	-	1.17	5.46	6.91	4.37	2.32	-	-	20.22
Heat Saved	(MMBtu)	-	3.52	4.57	5.17	4.35	3.73	-	-	21.35
Savings (% of Base)			(75%)	(46%)	(43%)	(50%)	(62%)			(51%)

BUTLER BUILDING - OFFICE AND MAINTENANCE AREA

FIGURE #1

ANNUAL HEATING SAVED vs. SIZE OF WALL COLLECTOR

FIGURE #2

RATIO OF CAPITAL COST TO ANNUAL HEAT DELIVERED

NOTE: 431 s.f. is the actual amount used in the prototype building at Grandview

BUTLER BUILDING - OFFICE AND MAINTENANCE AREA

FIGURE #3
MONTHLY HEATING PERFORMANCE

Scale	AS NOTED
Dwn.	SJA
Chkd	
Date	8 MAR 79
Rev.	30 APR 79
Rev.	
Rev.

Scale	AS NOTED
Dwn.	BC-SJA
Chkd.	LL
Date	FEB 28, 79
Rev.	27 APR 79
Rev.	
Rev.	
Rev.

SOUTH ELEVATION 1/4" = 1'-0"

WEST ELEVATION 1/4" = 1'-0"

SENSOR LOCATIONS
B
1/4" = 1'-0"
COLLECTOR Nos 1, 4, 7, 10, 11, 14
(3 SENSORS REQ'D @ EA COLLECTOR)

SENSOR LOCATIONS
A
1/4" = 1'-0"
COLLECTOR No 16
(10 SENSORS REQ'D)

1 PLAN @ TOP OF MANIFOLD 3" = 1'-0"

2 PLAN THRU AIR COLLECTOR 3" = 1'-0"

3 PLAN OF ABSORBER PANEL CLOSURE (BOTTOM) 3" = 1'-0"

4 PLAN OF ABSORBER PANEL CLOSURE (TOP) 3" = 1'-0"

5 DETAIL 3" = 1'-0"

Scale	3" = 1'-0"
Dwn.	SJA
Chkd.	LL
Date	13 FEB 79
Rev.	21 FEB 79
Rev.	
Rev.	

SK 2

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AIR COLLECTOR DETAILS
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