Session VII No. 4

Thermal Window Louver System Reduces Heating and Cooling Loads and Uses Excess Solar Energy and Building Waste Heat

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ABSTRACT

A thermal window louver system that circulates nonrefrigerated water has been tested in both the laboratory and actual applications. This system acts as a dynamic interior solar collector and intercepts 88% of the radiant solar heat before it enters the occupied space, becoming a load on the air-conditioning system. The design combines thermodynamic and systems-integration concepts to maintain environmental stability and comfort while significantly reducing energy consumption, refrigerated air, fan horsepower, and the size of ductwork and equipment. In the summer, when envelope temperature exceeds interior temperature, non-refrigerated louver-water absorbs and carries away 60% of the radiant energy, while 28% is reflected back through the window and 12% enters the space. In a design application, this achieves a 52% savings in the total central plant refrigeration load and a 40% savings in total air distribution. In winter the temperature of the louver water is maintained by building waste heat to offset envelope heat losses and maintain perimeter thermal balance. In exposures with high wintertime solar intensity, the louvers eliminate the need to design for simultaneous heating and cooling. The system eases the capacity problems of utilities by significantly shaving summer peak refrigeration requirements.

INTRODUCTION

Building envelopes are viewed increasingly as dynamic boundaries modulating energy flows between inside and out to minimize purchased energy requirements, rather than as static barriers. The thermal louver system described in this paper, which is located adjacent to windows on the inside, demonstrates that perspective. It uses nonrefrigerated water, circulating through hollow vertical louvers, to control radiant heat gain in the summer and transmission heat loss in the winter.

Solar radiant energy cannot be prevented from entering a space by a refrigerated air system. Unless intercepted by a physical object, the radiant heat enters and is absorbed by people and objects. Only then can it be removed by relatively large quantities of cold air. During this process, people are often caught in an uncomfortable crossfire of radiant heat and cold air.

An issue of continuing concern is how to retain large window areas without the penalty of heavy fluctuating solar heat loads, which require expensive, high-capacity air-conditioning systems. Ideally, for comfort and energy savings, the radiant load should be diverted before striking the occupied space and requiring refrigerated removal. The thermal window louver system responds to this need. In summer it acts as a dynamic solar collector to (1) prevent 88%

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of the radiant heat from becoming a load on the air-conditioning system and (2) make the solar energy available for productive use. In winter the circulating louver water, warmed by building waste heat, offsets heat loss through the glass, reducing the space heating load. During the entire year, the system responds automatically to variations in solar intensity, maintaining a thermal stability at all window orientations comparable to the stability of a north wall.

The energy efficiency of the water-cooled window louver system results from two basic design approaches: thermodynamic efficiency and integrated systems design. The systems approach evaluates and interrelates all building subsystems and their components as functional elements of a single integrated environmental system. The thermodynamic approach evaluates the temperature levels as well as quantities of all energy flows and uses these as guidelines for efficient integration.

This paper describes the problems posed by solar fluctuations and radiant heat gain through windows, presents the thermal window louver solution and design methodology, and summarizes test procedures and results as well as a user evaluation of an actual application.

PROBLEM

Solar radiation through glass represents a significant portion of the total heat gain for a typical building. A major challenge for energy efficient design is controlling the size of this load and its fluctuations. Figure 1 highlights the problem, depicting geographic and seasonal variations in solar intensity. It indicates solar heat gain for different orientations throughout the United States (30^{o}-40^{o} north latitude) during peak monthly solar intensity. For example, solar gain on a north wall is thermally stable throughout the year with little variation between northern and southern parts of the country; but solar intensity from east and west peaks in spring and summer, reaching a maximum of around 140 Btu/ft^2 (1,589,914 $^J/m^2$). Significantly for energy analysis, the southern exposure experiences the greatest seasonal variation, with the peak intensity coming in winter for all parts of the country. The result can be simultaneous heating and cooling requirements with concurrent southern solar gains and northern thermal losses.

Aggravating this problem is the phenomenom of rapid load reversal caused by fluctuations in sunshine. For example, consider a perimeter office wall that is 75% glass (heat absorbing). On a November day, the heat gain due to solar radiation is four times that lost by conduction to the outside; but, if the sun were suddenly hidden by clouds, this heat gain would plunge almost instantly from 107 Btu/ft^2 (1,215,149 $^J/m^2$) to a 13-Btu/ft^2 (147,635 $^J/m^2$) loss.

Thermal transmission through glass due to the temperature difference between inside and outside of the glass is also a problem for energy-conscious design. To meet the ASHRAE recommendation for maximum overall U value for new buildings--0.2 to 0.28 Btu/h/ft^2 (.63 to .88 $^W/m^2$)--the window area typically would have to be minimized.

Environmental control solutions that evolved before energy efficiency was a concern, and which are still widely used, are flexible but costly and space-consuming HVAC systems. More recent solutions have concentrated, for the most part, on passive design including window area reduction and shading and on component-based design such as altering the characteristics of glass. There is a continuing need for hybrid solutions that integrate architecture and HVAC based on the thermodynamic efficiency of system-wide energy flows.

SOLUTION

The thermal window louver system handles solar loads and their fluctuations immediately and automatically without burdening the air-conditioning system. It acts as an interior solar collector whenever the envelope temperature exceeds the internal ambient temperature. The system circulates nonrefrigerated water (77-85^{o}F [25-29.4^{o}C]), which is thermodynamically suited to removal of the higher-temperature solar radiation. The water absorbs and diverts to other use 60% of the radiant heat while 28% is reflected back through the window. Only 12% enters the occupied space (Fig. 2). These percentages are maintained at water temperatures as high as 95°F (35°C). The impact of rapid load reversal is absorbed by the system.

In winter the louver water temperature is maintained by building waste heat to offset heat loss, prevent draft, and maintain perimeter comfort. The louvers reduce by 75% the heat transmission through glass due to the outdoor-indoor temperature differential. In winter almost all of the louver system's heat losses are transferred to the occupied space, thus maintaining a higher overall efficiency. Excess radiant heat from the sun is absorbed and used to complement facility heat requirements by way of a thermal storage water tank. In summer excess heat collected by the circulating louver water can be used for such tasks as preheating domestic hot water, or it can be expelled through the cooling tower. Figure 3 shows the window louvers as part of the total, dynamically integrated energy system.

Louver blades are hollow, extruded, anodized aluminum connected top and bottom to concealed pipe manifolds that in turn are connected to the water-transfer system (Fig. 4). Louvers are controlled automatically by a solar cell that rotates louver blades to intercept direct sun rays, opening to admit more view as the sun recedes (Fig. 5). Louvers can also be operated manually.

The system is appropriate for atriums and other glass roofs as well as for window expanses. Figure 6 shows the effectiveness of the thermal louver as a shading device in intercepting solar radiation, in contrast with (1) exterior sun louvers, (2) reflecting glass, (3) clear glass with venetian blind, and (4) unshaded clear glass. The chart indicates the total Btu (1055 joules) input of solar radiation plus transmission loads entering the space for each shading device. The center of the radial scale represents a maximum thermal transfer through the envelope. Unshaded clear glass presents the highest load with the greatest variation with orientation. With the thermal louvers, all building orientations maintain thermal stability with very little heat gain.

By trapping solar heat before it enters the occupied space, the thermal louver system eliminates a significant portion of the chiller load. Table 1 compares two versions of a given building's summer cooling load analysis, one based on the thermal window louver system and the other on a conventional air-conditioning system. Calculations are shown to clarify differences. The table indicates a 40% savings in total air distribution with the louver system and a 52% savings in the total central plant refrigeration load. The result is significant savings in energy operating costs and also in first costs, due to the reduced size of air-handling equipment (fans, ductwork, etc.) and central plant refrigeration equipment (chiller, compressor, cooling tower, etc.).

DESIGN METHODOLOGY

The thermal louver concept stems from a design methodology that combines "systems integration" and thermodynamic principles to achieve total system energy efficiency. The approach is a largely unexplored and clearly promising frontier for energy conscious design. Before summarizing its main features, it may be helpful to clarify what is meant here by total system efficiency, the aim of the methodology.

Building energy efficiency may be divided conceptually into three types:

--component efficiency,

--subsystem efficiency, and

--total system efficiency.

Efficiency at each level is a prerequisite for efficiency at the next level but does not assure it. For purposes of this discussion the three types may be defined as follows:

1. Component efficiency relates primarily to the properties of component materials such as the U value of insulation.

2. Subsystem efficiency relates to the economy of the subsystem in using and transferring energy. It involves such items as proper sizing of equipment for the specific load as well as the thermal integrity of transfer points.

3. Total system efficiency refers to the extent to which building functions and energy flows are integrated, from a total building perspective, to meet all performance requirements with minimum purchased energy. It involves such techniques as (1) using the waste heat from one or more functions or subsystems as the energy source for another and (2) including cogeneration when the on-site generation of both electricity and waste heat, used efficiently, results in a net reduction in facility use of purchased energy.

Systems Integration

Systems integration is a practical technique for achieving total system efficiency. It requires a broad, system-wide (total building) perspective. It also requires a multidisciplinary approach. It is different from the physical coordination of separately designed subsystems, although it also requires physical coordination. Systems integration identifies the functional and energy flow interfaces of all building subsystems--architectural, structural, heating, cooling, ventilating, lighting, acoustical, fire-safety, interior design, etc. It integrates these functional interfaces to permit the direct interaction of system energies when the result is a net reduction in the total system's purchased energy use. Systems integration is thus a technique for interrelating all components and subsystems so they become functionally supportive elements of a single energy-integrated system.

This approach uses components to do as many jobs as possible. For example, one component may become a functional part of two subsystems, eliminating an unnecessary duplication of energy consumption or an unnecessary energy load penalty of one subsystem on another. In the case of the thermal window louver system, the louvers functionally are part of both the envelope subsystem and the heating/cooling subsystem. By shading and absorbing solar radiation in their envelope role, and passing it on to the cooling tower or to a heating task in their other role, they re-route the solar load to bypass and relieve the interior refrigeration process. In winter they function as a thermal barrier and as part of the perimeter heating system. Simultaneously, they function as a cooling system if solar intensity threatens the perimeter thermal balance.

In relation to the design of new building technology, the systems approach evaluates the particular component or subsystem in terms of its relation to other components and subsystems, its potential for efficient integration into the total system, and its contribution to overall energy efficiency.

Thermodynamic Evaluation

Thermodynamic evaluation is a prerequisite for efficient systems design. Both the quantity and temperature level of energy flows must be identified and evaluated. Not only is it necessary to protect against energy loss due to such causes as leakage, transmission, and improper sizing and inefficient operation of equipment; it is also essential to match the temperature levels of energy sources and energy requirements. Second Law efficiency requires that the temperature level of a cooling or heating medium be as close as possible to the final conditioned temperature; that is, heating should be done at the lowest temperature possible and cooling at the highest temperature possible. Examples include the use of building "waste" heat to preheat domestic hot water and of nonrefrigerated water to cool as is done with the thermal window louver.

Thus, thermodynamic evaluation is central to efficient systems integration. The combination of the systems approach and thermodynamic efficiency creates a rational methodology for achieving "total system efficiency."

TEST PROCEDURES AND RESULTS

Summary

A prototype of the thermal louvers was tested in the University of Florida's ASHRAE calorimeter. Table 2 summarizes the results. With thermal louvers but without water circulation, 65% of the solar energy entered the space when the outside temperature was 95°F (35°C) and approximately 28% was reflected out. With water circulating through the louvers, even at a water temperature as high as 95°F (35°C), only 12% of the solar heat entered the space, establishing a shading coefficient of 0.12 for design purposes. (Figure 7 depicts the comparative percentages, for louvers with and without water, at various outside air temperatures.) In addition, the louvers reduced by 75% the heat transmission through glass due to indoor-outdoor temperature difference. The following factors had only minor effect on the space heat gain: the altitude angle of the sun, rate of water flow between one and two gpm (.000063 and .000126 m^3/s), small increases in water entering temperature, and changes in outside air temperature in the range of the tests.

Details

Eighty-five recorded tests were conducted in the calorimeter to determine the thermal performance of the louver with both clear and heat absorbing glass. Solar intensities were measured with two pyrheliometers. Temperature measurements were made with calibrated copper-constantan thermocouples or mercury in glass thermometers. Water temperature differentials, both through the calorimeter and through the window, were made with multijunction thermopiles. For the clear glass tests, 7/32-in. (.0056m) heavy sheet glass having a transmittance of 86% was used. For the heat-absorbing glass test, 1/4-in (.0064m) grey plate having a transmittance of 46% and absorptance of 51% was used. The following tests were conducted:

1. Clear Sheet Glass (Transmittance = 0.86):

    a. Louvers at 45 deg, flow 1.2 gpm (7.6×10^{-5} m^3/s)*;

    b. Louvers at 25 deg, flow 1, 1-1/2, and 2 gpm (6.3×10^{-5}, 9.5×10^{-5}, 1.26×10^{-4} m^3/s);

    c. Louvers at 20 deg, flow 1, 1-1/2, and 2 gpm (6.3×10^{-5}, 9.5×10^{-5}, 1.26×10^{-4} m^3/s);

    d. Louvers at 20 deg, flow 1, 1-1/2, and 2 gpm (6.3×10^{-5}, 9.5×10^{-5}, 1.26×10^{-4} m^3/s), entering water temperature varied from 76.4 to 87.8°F (24.7° to 31°C);

    e. Louvers at 20 deg, flow 1, 1-1/2 gpm (6.3×10^{-5}, 9.5×10^{-5} m^3/s), temperature differential between back and louvers increased to about 12°F (-11.1°C);

    f. Window facing west, maximum louver opening without admitting direct sun, flow 1-1/2 gpm (9.5×10^{-5} m^3/s);

    g. Louvers at 20 deg, no water flowing in louvers;

    h. Window facing west, no water flowing in louvers.

2. Grey Plate Glass (Transmittance = 0.46):

    a. Louvers at 20 deg, flow 1, 1-1/2, and 2 gpm (6.3×10^{-5}, 9.5×10^{-5}, and 1.26×10^{-4} m^3/s);

*m^3/s = (meters)^3 per second.

b. Window facing west, maximum window opening and still no admittance of direct sun, flow 1, 1-1/2, and 2 gpm (6.3×10^{-5}, 9.5×10^{-5}, and 1.26×10^{-4} m^3/s);

c. Louvers at 20 deg, flow 1-1/2 gpm (9.5×10^{-5} m^3/s), temperature differential between back and louvers increased to about 13.5°F (-10.3°C);

d. Louvers at 20 deg, flow 1-1/2 gpm (9.5×10^{-5} m^3/s) back and entering water temperature lowered approximately 20°F (-6.7°C);

e. Louvers at 20 deg, no water flowing in louvers.

Unless otherwise noted, all runs were made with the window in the vertical wall facing directly toward the sun; thus, the incident angle is the same as the profile angle. In the west wall runs, the sun's rays strike the window at a diagonal. This introduces some special problems related to reflectance, especially with clear glass.

Effect of Change in Flow Rate

Changes in the flow rate in the range observed, from one to two gpm (6.3×10^{-5}, 1.26×10^{-4} m^3/s), had only minor effect upon the space heat gain. A low flow rate increases the heat gain to the space since it causes an increase in the temperature difference between the water and the louver surface. The temperature increase in the water is a function of window size, louver heat gain, and flow rate. For the window tested, the temperature increase varied from a low value of 0.59°F (-17.5°C) to a high value of 3.64°F (-15.8°C).

Effect of Change in the Altitude of the Sun

Only minor effects were noted due to changes in altitude angle of the sun from 8 to 46 degrees. The chief effect is an increase in reflectance at the higher angles, resulting in a slightly lower delivery of heat to the louver and to the space. At angles from 25 to 45 degrees, which are of principal concern, these changes had little effect.

Effect of Change in Azimuth vs. Degree of Louver Opening

Because of the relatively high reflectivity of the louver surfaces, and the shape of the louvers, the horizontal angle at which the sun's rays strike the louver has some bearing on the space heat gain. At certain combinations of angles, energy is reflected into the space, or re-reflected into it from the back of adjacent louvers. This is particularly true with clear glass in the window.

Effect of Fully Opening the Louvers with Direct Sun Excluded from the Space

With the louvers fully opened diffuse radiation is not excluded from the space so space load is increased. The effect of this was tested using the clear glass combination and the grey plate combination. As would be expected, the effect is less serious with the latter combination.

Effect of Outside Ambient Air Temperature

The principal effect of increasing outside air temperature is to increase the delivery of heat to the water circulating through the blind and to decrease the delivery of heat to the outside through convection and radiation. Some slight heat gain to the space also occurs. Theoretically, when a point is reached where the outside air temperature exceeds the glass surface temperature, there will be delivery of heat from the outside air to the interior space. With louvers interposed between the glass and the interior space and held at a constant temperature, most of this added heat will be carried out in the circulating water.

Effect of Reflective Louver Surface

Pyrheliometer measurements made with louvers at a 20-degree angle and with no glass in the window indicated a reflectance of about 42%. This high reflectance serves to reduce the delivery of solar energy into the space. With clear glass, about 33% of the energy striking the window was reflected to the outoutside. With the grey plate glass, only about 11% of the energy striking the window was reflected to the outside.

Effect of Admitting Direct Sunlight Between Louvers

When direct sunlight is admitted between louvers, the heat gain for the projected area through which the sunlight enters is approximately the same as for the glass type used without shading. The effect of this is illustrated in eleven runs made, where some sun was allowed to enter between louvers.

Effect of Increasing the Entering Water Temperature by 10°F (-12.2°C)

The effect of this was tested for the clear glass and for the grey glass. The space gain in the first case was increased to about 12%, and in the second to about 16%. While this gain is small, about 6 Btu/h/ft^2 (18.9 w/m^2), the desirability of holding the entering water temperature close to the desired space temperature is evident.

Effect of Circulating No Water through the Louvers

With no circulation of water through the louvers, the effect was the same as with the specific glass type with indoor shading. When values for the test runs are projected to an outside air temperature of 95°F (35°C), both glass and louver become very hot, particularly the grey glass combination, and the heat gain to the interior space is greatly increased.

USER EVALUATION OF APPLICATION

Several applications of the thermal window louver system have been in operation for many years with excellent results, including systems installed in the Financial Programs, Inc., building in Denver (now operated by the Board of Education) and in a Dallas Power and Light Company building.

One user evaluation is available, from the Dallas Power and Light Company, where the louver system was installed on the 3342-ft^2 (.3105 m^2) 16th floor when it was remodeled for executive use. User comments based on measured performance data, prepared by Karl Southward of DP&L after nine years of system operation, include the following:

> "The system as installed provides the highest degree of comfort with one small exception. The system provided near perfect temperature control (± 2°F) for several years. Only after some remodeling, we have a corner office that consistently runs 2 to 4 degrees warmer than other areas."

> "Even though a 12-ton compressor was called for in the original design for the floor, a 29-kW compressor rated at 25 tons was installed. The selection of this larger compressor was due to the need to supply the most reliable service and comfort possible, and due to the limited sizes of available equipment. The maximum metered input to the compressor to date on the cooling cycle has been 19 kW. The 12-ton air conditioner originally designed for the system would have been adequate."

> "Information from the summer cooling cycle tests (for one week) indicates: The nonrefrigerated water to the louvers at the windows is capable of removing 22,000 Btu/h during the peak summer load as predicted. The actual measurement with intermittent cloud cover was 20,900 Btu/h ."

"It is notable that an exterior zone may be heated by transferring heat from light fixtures to exterior louvers. It is particularly noteworthy that this may be accomplished at minimum cost using a small water pump resulting in a coefficient of performance (COP) of 20 to 1."

In Denver, bronze louvers were installed on bronze plate glass covering 50% of a seven-story building. The thermal louver system permitted a reduction in the size of the central air-conditioning plant from 330 tons to 180 tons.

CONCLUSION

The thermal performance of building envelopes cannot be fully evaluated without exploring the energy implications of integrating the envelope's functions with those of other subsystems based on "total system" thermodynamic efficiency.

Stringent performance, energy, and cost criteria for buildings of the future will require this kind of tightly rationalized, interdisciplinary, system-wide integration of subsystems. Significant savings are possible in energy use, space (due to the reduced size of air-handling equipment, ductwork, etc.), and in facility first costs as well as energy operating costs.

For example, there is a known relationship between and among the following: thermal properties of an envelope, window area, view, daylighting, glare, size of the solar load on the air-conditioning system, and size of central plant equipment and air handling/distribution equipment. Involved are multiple functions of the window/envelope subsystem as well as functions of the lighting and heating/cooling subsystems. To identify all of the mutual effects and integration opportunities and results requires (1) interdisciplinary design, (2) a "total system" perspective, and (3) thermodynamic analysis (identification of the temperature levels as well as quantities) of alternative energy flow patterns.

The thermal window louver is an example of a multipurpose component that integrates functions, subsystems, and energy flows. It is common to two subsystems, the envelope and the mechanical or heating/cooling subsystem. As an envelope component it performs two functions, thermal control and lighting/glare control. It also provides a view. If it were tied through automatic controls to the electric lighting in a daylighting system, it would also be a functional component of the electrical subsystem. It functions as part of the heating/cooling subsystem by (1) transferring radiant solar heat to the cooling tower or to heating tasks and (2) circulating waste heat in winter to maintain the perimeter thermal balance and reduce the heating load.

By integrating these energy operations at the envelope, the louver achieves a 52% savings in the total central plant refrigeration load and a 40% savings in the total air distribution. This achievement is due primarily to the thermodynamic basis for the integration, which directs the use of nonrefrigerated water to remove the higher temperature solar energy. The result is a level of "total system efficiency" that is not possible when subsystems are designed largely within separate disciplines and then attached as physically coordinated but functionally separate appendages.

TABLE 1

Thermal Louver vs. Conventional HVAC System
Summer Cooling Load Analysis Comparison

(Building design data follows table.)

			Conv. Btu/hr	Thermal Louver Btu/hr
1. Transmission				
Glass	24,600 x 1.06 x 20 x 0.25	=	~~521,000~~	130,000 *
Walls	37,000 x 0.20 x 20	=	148,000	148,000
Roof	60,000 x 0.15 x 20	=	180,000	180,000
	Total		~~849,000~~	458,000 *
2. Total of Solar Peaks for Each Orientation (Use for Air Load)				
North Glass.	4,300 x 18	=	77,000	77,000
East Glass	8,000 x 200 ~~x 0.64~~ x 0.12	=	~~1,023,000~~	192,000 *
South Glass.	4,300 x 200 ~~x 0.64~~ x 0.12	=	~~550,000~~	103,000 *
West Glass	8,000 x 200 ~~x 0.64~~ x 0.12	=	~~1,023,000~~	192,000 *
East Wall	12,000 x 0.20 x 2	=	5,000	5,000
West Wall	12,000 x 0.20 x 16	=	38,000	38,000
Roof	60,000 x 0.15 x 40	=	360,000	360,000
	Total		~~3,076,000~~	967,000 *
3. Total Solar Coincident - West, August, 4:00 P.M. (Use for Central Plant Tonnage)				
North Glass.	4,300 x 13	=	56,000	56,000
East Glass	8,000 x 13	=	104,000	104,000
South Glass	4,300 x 32 ~~x 0.64~~ x 0.12	=	~~88,000~~	16,000 *
West Glass	8,000 x 200 ~~x 0.64~~ x 0.12	=	~~1,025,000~~	192,000 *
South Wall	6,500 x 5	=	32,000	32,000
West Wall	12,000 x 16	=	192,000	192,000
Roof	60,000 x 0.15 x 35	=	315,000	315,000
	Total		~~1,812,000~~	907,000 *
4. Electric Load				
Lighting Load	230,000 x 2.0 x 3.4	=	1,564,000	1,564,000
Floor Power	230,000 x 0.5 x 3.4	=	391,000	391,000
	Total		1,955,000	1,955,000
5. Occupant Sensible.	2,300 x 250	=	575,000	575,000
6. Occupant Latent	2,300 x 200	=	460,000	460,000
7. Ventilation . .	46,000 x 4.45 x (10.2 enthalpy)	=	2,090,000	2,090,000
8. Total Air Quantity (20° Delta T)				
1. + 2. + 4. + 5.	3,955,000 ~~6,455,000~~ / 1.08 x 20	=	~~298,843~~ cfm	183,102 cfm *
9. Total Central Plant Refrigeration Load				
1. + 3. + 4. + 5. + 6. + 7.	3,710,000 ~~7,741,000~~ / 12,000	=	~~445~~ tons	309 tons *

* Asterisks indicate areas with savings due to the thermal louver.

TABLE 1
(Continued)

Building Design Data

Building Type	5 story office
Building Dimensions	300' x 180'
Building Glass Area	40%
Building Location	40 N. latitude
Lighting Load	2.0 watts/sq ft
Floor Power Load	0.5 watt/sq ft
Occupancy	1 person/100 sq ft
Ventilation Rate	0.2 cfm/sq ft
Occupied Floor Area	230,000 sq ft
Roof and Floor Area	60,000 sq ft ea.
North and South Wall Area	6,500 sq ft ea.
North and South Glass Area	4,300 sq ft ea.
East and West Wall Area	12,000 sq ft ea.
East and West Glass Area	8,000 sq ft ea.
Winter Design Temperature	0°F
Outside Summer Design Conditions	95°F DB, 75°F WB
Inside Space Conditions	75°F DB, 50% RH
Transmission Coefficients - Wall	0.20
Roof	0.15
Glass Summer	1.06
Glass Winter	1.13
Glass Solar Shading Coefficients - Conventional	0.64
Thermal Louver	0.12

No Thermal Louvers on North Exposure

TABLE 2

Thermal Louver Test Results
University of Florida-ASHRAE Calorimeter Laboratory Tests

Thermal Louver Ratings (Cooling)		Cooling Example (August, 4:00 P.M. 32° Latitude, West Exposure, 1 Sq Ft of Glass)	
Solar Load to Occupied Space (Shading Coefficient)	0.12	Solar Intensity (Btu/hr/sq ft)	202
Solar Load to Louver Water	0.60	Solar Load to Occupied Space (Btu/hr/sq ft)	24
Transmission Load to Occupied Space	0.25	Solar Load to Louver Water (Btu/Hr/sq ft)	121
Transmission Load to Louver Water	0.75	(Air Temperature °F) Outside Inside	 98 75
Supply Water Temperature Range (°F)	75-85	Transmission Load to Occupied Space (Btu/hr/sq ft)	6
Return Water Temperature Range (°F)	80-88	Transmission Load to Louver (Btu/hr/sq ft)	19
Water Temperature Difference (Delta T) (°F)	2.8	Total Load to Occupied Space* (Btu/hr/sq ft)	30
Pressure Drop (ft hd/10 sq ft)	2.0	Total Load to Louver Water** (Btu/hr/sq ft)	140
Flow Rate (gpm/10 sq ft)	1.0	Water Delta T (°F)	2.8
		Flow Rate (gpm/sq ft)	.10

* Cooling load to space = Solar intensity x 0.12+transmission load x 0.25

** Cooling load to louver water = Solar intensity x 0.60+transmission load x 0.75
Heating capacity of louver = 150 Btu/sq ft (use 3° for water Delta T)

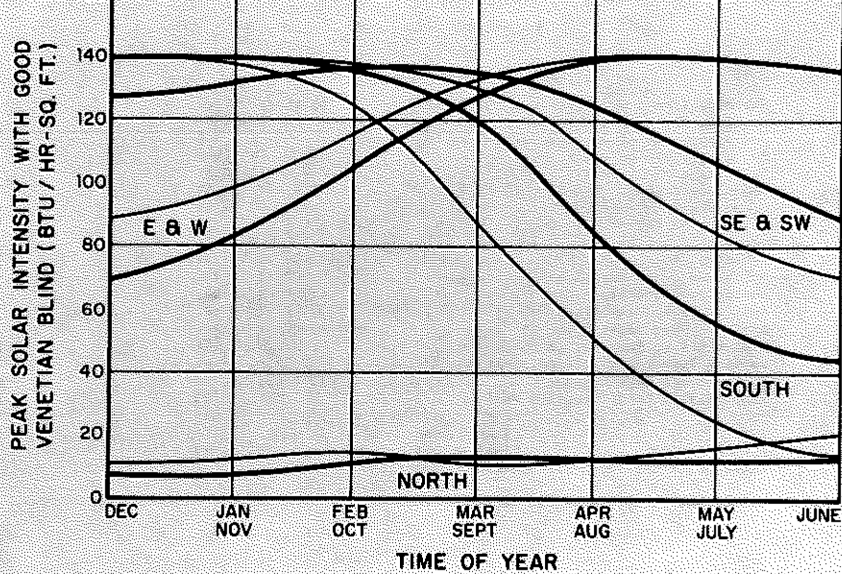

Figure 1. Variations in solar intensity throughout U.S. by month. For southern exposure, solar impact is greatest in winter.

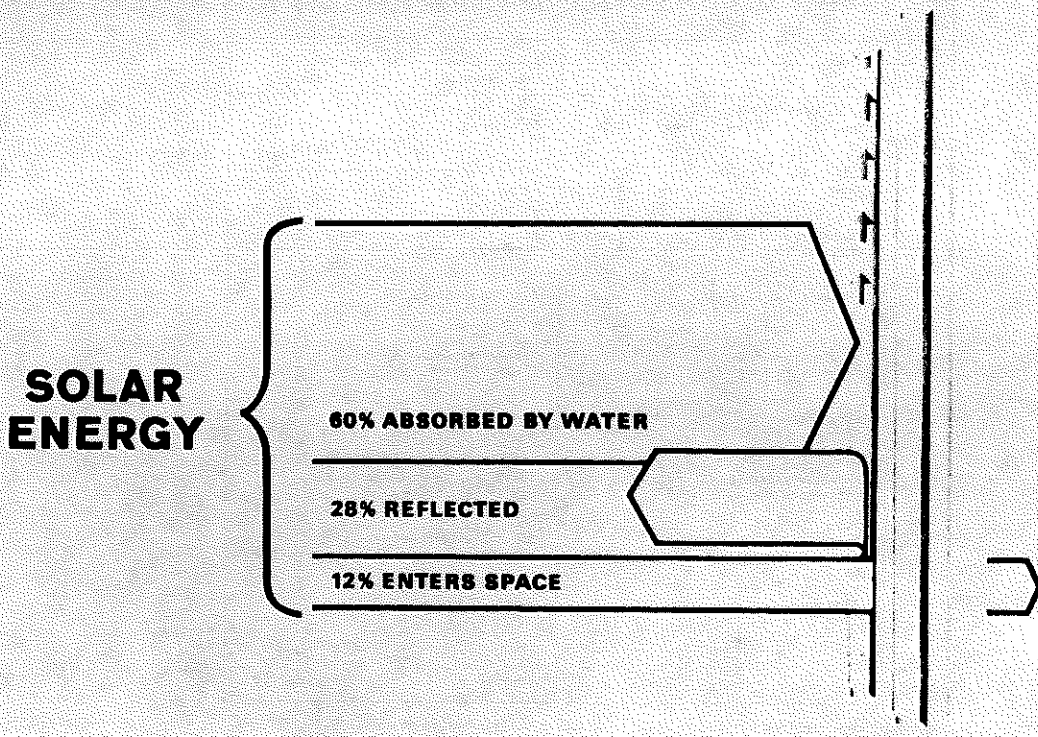

Figure 2. Distribution of radiant solar energy with water-cooled thermal window louver

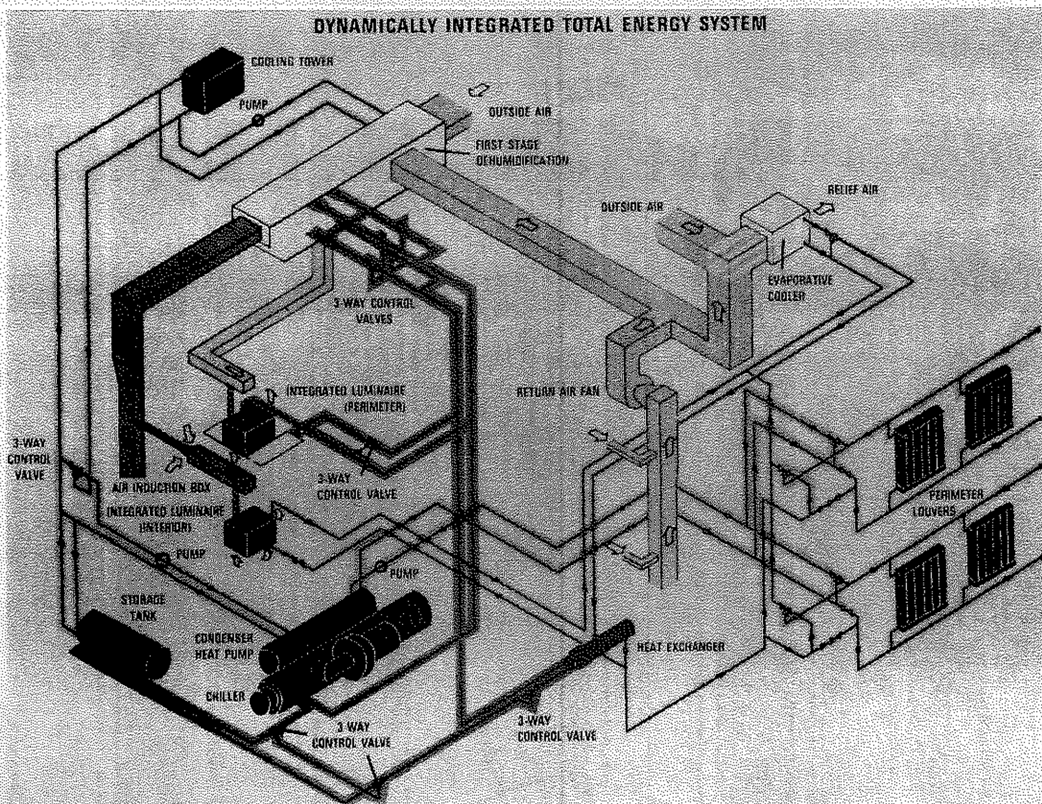

Figure 3. Thermal louvers in dynamically integrated total energy sustem

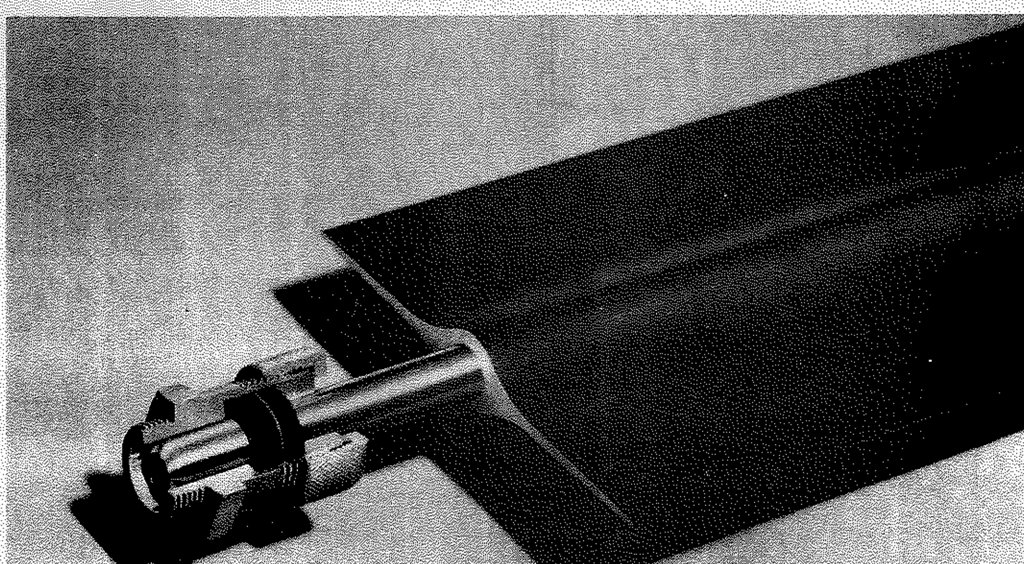

Figure 4. Extruded, anodized aluminum louver blade, with water seal assembly

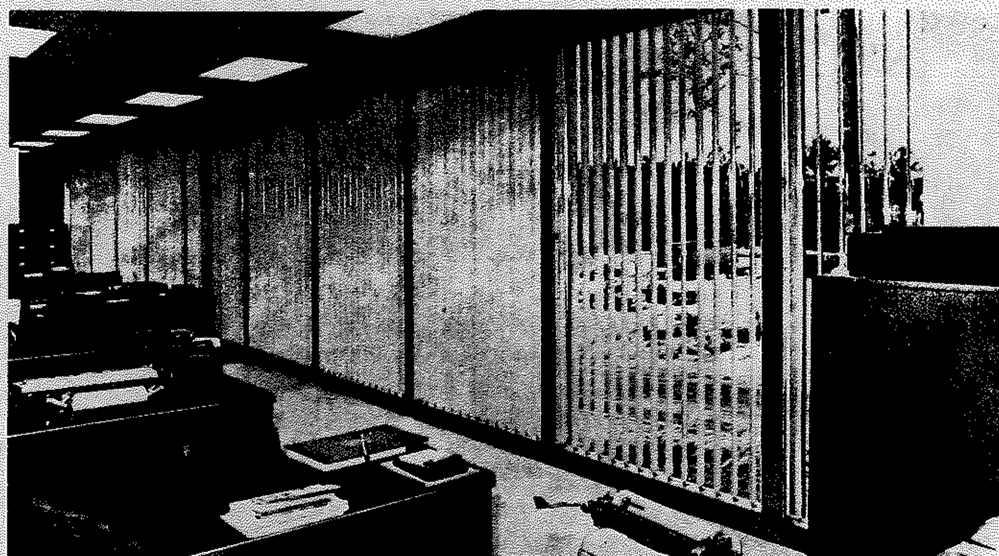

Figure 5. Thermal window louvers rotate to intercept sun and allow view to outside

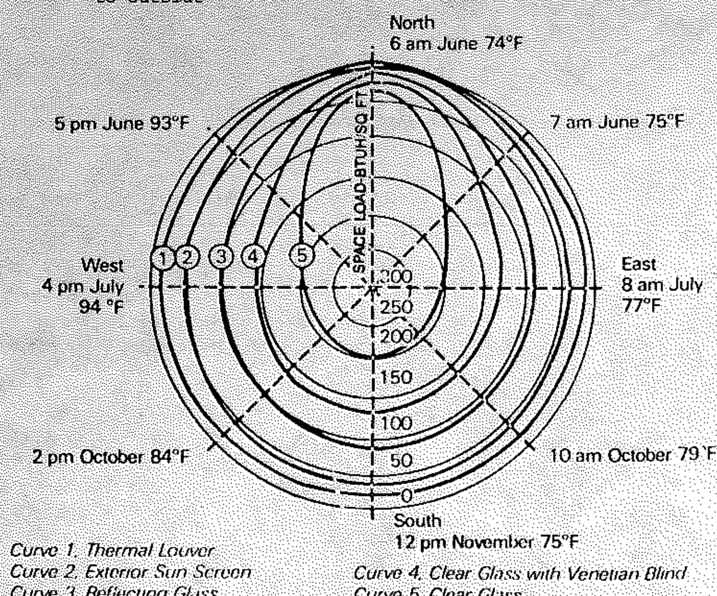

Figure 6. Effectiveness of thermal louver and other devices in intercepting solar radiation. Numbers are for all building orientations when the total load is maximum. Center represents maximum thermal transmission through envelope. With thermal louvers, all exposures remain as thermally stable as a north exposure

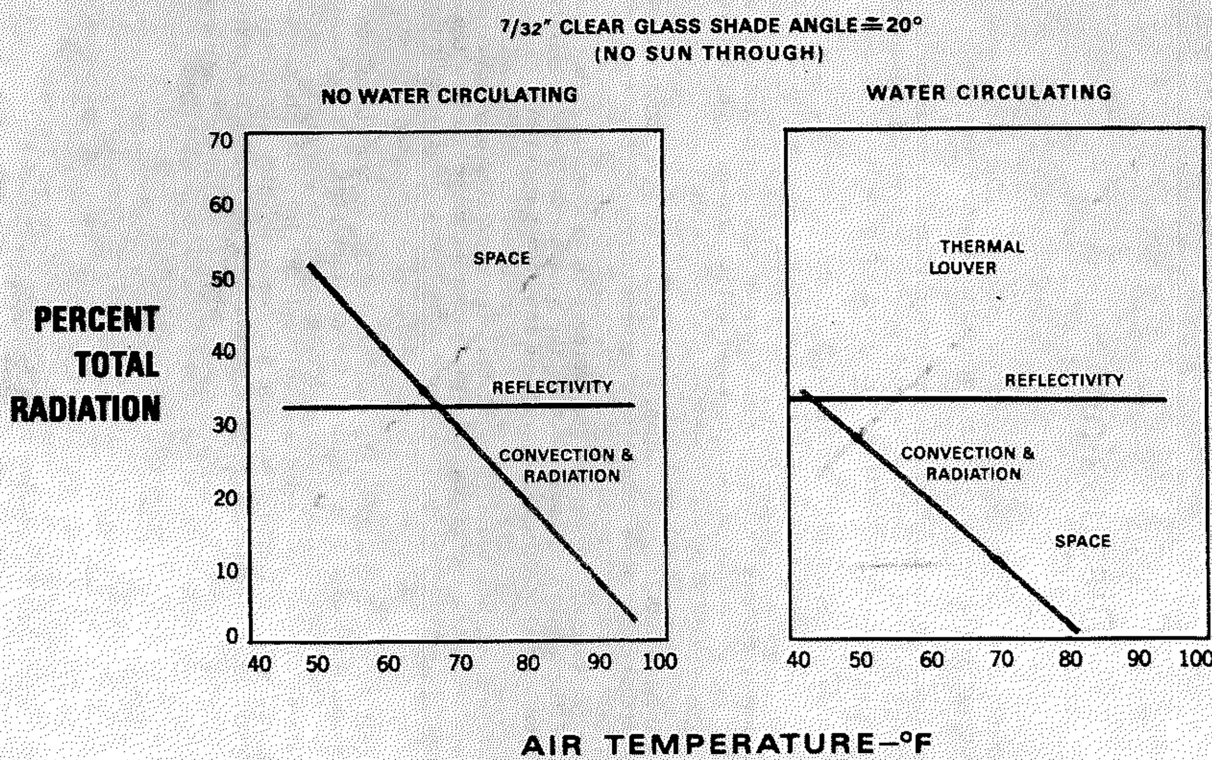

Figure 7. Thermal louver versus conventional shading performance comparison at various outside air temperatures. (Louvers without water are comparable to conventional shading)

Discussion

J. Christian, Oak Ridge Natl. Lab., Oak Ridge, TN: Please comment on the maintenance cost of this equipment. It appears to me that it is very exposed to occupant abuse.

Meckler: Maintenance problems are conceivable. But operational experience in Denver (12) years) and Dallas (15 years) indicates that the equipment is remarkably maintenance-free, more so than we anticipated. There have been no leaks, for example.

D. R. Smith, National Security Agency, Dept. of Defense, Fort Meade, MD: Is there a manufacturer of this system? Is there a noise problem associated with the flowing water?

Meckler: I designed and developed this system, and thus far we have contracted with a fabricator on a job-by-job basis. As for noise, the water velocities are such that we have not experienced a noise problem at all.

H. F. Wu, Architecture Resh. Lab., Univ. of Michigan, Ann Arbor: What is the surface temperature of louvers and their effect on mean radiant temperature?

G. Meckler: Since the temperature of the circulating water is near the room temperature, the surface temperature of the louvers is approximately the same as the room temperature, and the mean radiant temperature is within 3-5 degrees of the room temperature.

R. A. Rundquist, Ross & Baruzzini, St. Louis, MO: What is the approximate cost per square foot of the system, including the circulating water components related to the louvers? Can this approach be more cost-effective than conventional shading devices and/or glass coatings?

Meckler: Cost is difficult to pin down without looking at the specific building configuration, but it is in the order of $25 per square foot of glass area. It certainly can be more cost-effective than conventional shading devices and glass coatings based on tradeoffs such as (a) reduced size of refrigeration equipment and (b) multiple use of louvers as cooling elements, solar collectors and heating elements, which eliminates the need for local under-the-window heating/cooling elements such as fan coil units or perimeter radiators.