

(19) World Intellectual Property Organization  
International Bureau



(43) International Publication Date  
31 December 2008 (31.12.2008)

PCT

(10) International Publication Number  
**WO 2009/002350 A1**

(51) International Patent Classification:  
*F24J 2/04* (2006.01) *C02F 1/14* (2006.01)  
*F24J 2/40* (2006.01)

(21) International Application Number:  
PCT/US2007/073135

(22) International Filing Date: 10 July 2007 (10.07.2007)

(25) Filing Language: English

(26) Publication Language: English

(30) Priority Data:  
60/819,379 10 July 2006 (10.07.2006) US

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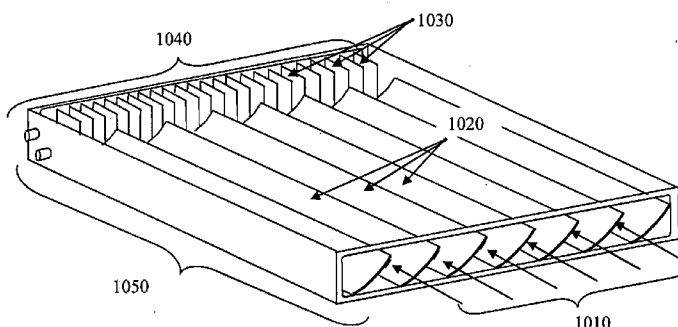
(81) Designated States (unless otherwise indicated, for every kind of national protection available): AE, AG, AL, AM, AT, AU, AZ, BA, BB, BG, BH, BR, BW, BY, BZ, CA, CH, CN, CO, CR, CU, CZ, DE, DK, DM, DO, DZ, EC, EE, EG, ES, FI, GB, GD, GE, GH, GM, GT, HN, HR, HU, ID, IL, IN, IS, JP, KE, KG, KM, KN, KP, KR, KZ, LA, LC, LK, LR, LS, LT, LU, LY, MA, MD, ME, MG, MK, MN, MW, MX, MY, MZ, NA, NG, NI, NO, NZ, OM, PG, PH, PL, PT, RO, RS, RU, SC, SD, SE, SG, SK, SL, SM, SV, SY, TJ, TM, TN, TR, TT, TZ, UA, UG, US, UZ, VC, VN, ZA, ZM, ZW.

(84) Designated States (unless otherwise indicated, for every kind of regional protection available): ARIPO (BW, GH, GM, KE, LS, MW, MZ, NA, SD, SL, SZ, TZ, UG, ZM, ZW), Eurasian (AM, AZ, BY, KG, KZ, MD, RU, TJ, TM), European (AT, BE, BG, CH, CY, CZ, DE, DK, EE, ES, FI, FR, GB, GR, HU, IE, IS, IT, LT, LU, LV, MC, MT, NL, PL, PT, RO, SE, SI, SK, TR), OAPI (BF, BJ, CF, CG, CI, CM, GA, GN, GQ, GW, ML, MR, NE, SN, TD, TG).

**Published:**  
— with international search report  
— before the expiration of the time limit for amending the claims and to be republished in the event of receipt of amendments

(54) Title: SOLAR ENERGY CONVERSION DEVICES AND SYSTEMS

Figure 1a



(57) Abstract: Methods and devices are presented that allow the harvest of electricity, heat and lighting simultaneously from a solar converter, often at less cost than conventional solar collectors. The converters use slats to intercept sunlight. Slat surfaces in the direct light path may be coated with photovoltaic (PV) material, or may be shaped to concentrate sunlight, allowing less PV material to capture reflected, concentrated light for improved economics. Forcing air flow past enclosed slats let the slats operate as PV heat sinks, heat absorbers, and heat exchangers capturing much of the solar energy that is not converted to electricity, as heat. Embodiments also allow passage of indirect light to supplement interior artificial lighting, often with positive aesthetic effects. These slatted apertures mitigate glare and overheating problems associated with typical skylights and some windows, allowing wider use as architectural elements. The devices also can be integrated into new building construction, and serve a dual purpose as building structural components.

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## Solar Energy Conversion Devices and Systems

### Field of the Invention

The invention relates to radiant energy conversion devices generally, to the capture and conversion of solar energy into heat and electricity and to building design and control of energy conversion and usage systems.

### Background of the Invention

Solar generation and cogeneration systems are becoming a logical alternative or addition to fossil fueled energy systems as fuel costs increase. The solar heat that is simultaneously collected with electricity provides a major boost to an energy system's value. Unfortunately, however "solar cogeneration" systems need to be located at the site of use, which presents challenges to most existing or previous photovoltaic concentrator methods. Since the collected heat generally is at low temperature (typically 40-80 degrees C), the heat energy cannot be transmitted far without substantial parasitic losses. Further, the capital cost of hot water and other heat transmission systems favors direct on site use. And, such low temperature heat generally cannot be converted in a heat engine to mechanical or electrical power because of the small temperature differential versus ambient temperatures. Accordingly, systems are needed that harvest light energy and transfer the harvested energy easily to the heating, lighting and electricity requirements at the site of use, such that the immediate needs of the site are factored into how the system is controlled.

Solar cogeneration technologies are held back by challenges in building optical systems that are both inexpensive and that can be mounted or integrated into a building. One problem is the practical limit for how tall a design can be to withstand forces from windy conditions on the device and building on which it may be mounted. Tying a cogeneration apparatus into the foundation or load bearing structure of a building creates expensive installations and/or mounting systems to accommodate system stresses, particularly on the roof. Many commercial sites lack sufficient ground space for a reasonably sized system and roof-mounting is the only viable option to get sufficient collector area. Thus, systems are needed that can be built into or added on to existing buildings easily and that use inexpensive materials.

Several inventions address these needs but leave many problems unsolved. For example, U.S. No. 4,690,355 teaches the use of silvered mirror slats that are coordinately controlled, but such assembly is placed on a mast and left exposed to the elements. A high cost system designed to protect solar cells from solar wind while  
5 dissipating heat only as radiant energy in space is described in U.S. No. 5,180,441. This space-based system uses thick slats and very small solar cells, while relying on a much larger surface area to dissipate heat in the absence of air (no convective cooling). The system uses a very small solar cell area with high precision reflectors that do not easily accommodate changes in radiation angle. Multiple plate designs also are presented in  
10 U.S. Nos. 4,034,736 and 4,159,707, but these require multiple reflections of light to absorb energy. U.S. No. 4,143,640 likewise teaches a Venetian blind structure, but uses thick slats with heat transfer fluid inside, which likewise is impractical.

Other problems of solar harvesting systems arise from limitations of optics used, which  
15 can be classified broadly as either reflecting or refracting optics. Refraction optics is non-linear, which limits sunlight concentration when the incidence angle of incoming light varies with respect to an optical surface. Refracting optics require focusing to track sun direction in two axes, or in one axis combined with tilt of the entire system for the second axis, with comparatively expensive structural and mechanical implications. The use of  
20 such complicated tracking systems to orient optics at the sun in 2 axes (azimuth and elevation), generally require larger apertures (collector areas) to average the cost of the complicated tracking system into a device that collects more energy. This exacerbates challenge of roof mounting such 2-axis designs. Accordingly, any technology that alleviates the need to track sunlight in a second axis would be a great improvement and  
25 can advance this industry.

#### Summary of the Invention

The problems affecting solar energy collection technology such as efficiency and cost  
30 are addressed via embodiments of a solar harvesting apparatus and methods of its use and incorporation into building structures. One embodiment provides an electromagnetic energy harvesting apparatus, comprising: a front light transmissive cover; a rear cover; a spacing between the covers that make the covers generally parallel with each other; and an array of parallel slats upon which the light impinges. Photovoltaic (PV) cells convert

photons into electricity and these are used to convert some of the light to electricity with much of the remaining incoming energy converting to heat. Air is forced through the cavity containing the warm slats and useful heat can be harvested. Apply the PV material to the sides of the slats facing the sun is straightforward and the product, with heat and electricity being generated – as well as diffuse skylight and secondarily reflected direct sunlight can provide useful light to the space behind the apparatus – makes this apparatus economically attractive vs. many other solar collection systems. A further innovation, constructing the slats with certain concave shapes facing the incoming light, with appropriate slat orientation, and a specularly reflecting concave surface can create a region of higher intensity light on the back side a nearby slat. Putting PV cells in this region allows a smaller, less expensive area of PV cells to be used to generate similar amounts of power.

Another embodiment provides a light gathering apparatus, comprising: a first light transmissive cover over a large surface of the array; a second cover over a large rear surface of the array; a spacing between the light transmissive covers, with the covers parallel to each other; an array of parallel arranged slats within the spacing and held together at least in part by two or more bars attached to slats of the array, the bars having characteristic heights measured from point of attachment outwards perpendicular to the first light transmissive cover; and one or more elongated obstructions attached to the second cover and positioned parallel to the two or more perpendicular bars at a non-occluding position, wherein the height of each one or more elongated obstructions as extending out perpendicular from the light transmissive cover is long enough to interfere with air flow near the surface(s) of the transmissive covers or to assist in directing the flow rates in different parts of the enclosure. Yet another embodiment provides an electromagnetic energy harvesting apparatus, comprising at least one: array of parallel arranged curved slats, each slat having a concave curved front side with a reflective surface, and a convex curved rear side with a photovoltaic energy converter on at least a portion of the rear side; a light transmissive cover on a large front surface of the array; a light transmissive cover on a large rear surface of the array; and a rod perpendicular to the slats as a slat positioner to coordinately open and close the slats while maintaining the slats in a parallel relationship.

Another embodiment provides a rooftop light energy harvesting apparatus, comprising: a single paned light transmissive cover facing out; a double paned light transmissive cover facing in; a spacing between the light transmissive covers, making the covers parallel with each other; and an array of parallel arranged curved slats within the spacing, each slat having a concave curved front side towards the single paned cover with a reflective surface, and a convex curved rear side with a photovoltaic energy converter on at least a portion of the rear side facing the double paned cover, and wherein the slats are of approximately equal length, so that the slat ends form an edge.

10 Yet another embodiment provides a rooftop or window system for harvesting light and heat from the sun, comprising: a first light transmissive cover facing out; a second light transmissive cover facing in; a spacing between the light transmissive covers, making the covers generally parallel with each other; an array of parallel arranged curved slats within the spacing, each slat having a concave curved surface facing the first light  
15 transmissive cover, and a convex curved rear light absorbing surface facing the second light transmissive cover, and wherein the slats are of approximately equal length, so that the slat ends form an edge; an airway on each edge of the array to allow forced air to flow along the long length of the curved slats; a pivoting mechanism to adjust the angle of the curved front side of the slats with respect to light from the first transmissive cover;  
20 a sensor that generates signals corresponding to inside light; and a controller; wherein the controller adjusts the pivoting mechanism in response to detected light to maintain a constant light level.

Yet another embodiment provides an automated system that responds to energy input or demand for a heat load, comprising a converter as described herein, and further  
25 comprising a computer, at least one sensor for detecting at least light or temperature, and at least one signal output to an actuator for adjusting slat position. In an embodiment, the automated system further comprises a light sensor located in the enclosure interior. The automated system further may comprise a feedback circuit or  
30 software that responds to output from the light sensor in the enclosure interior by adjusting slat position to maintain a constant light level within the enclosure interior. The automated system may control a building, and comprise a temperature sensor within the building, wherein a signal from the building temperature sensor is input to the computer for control of slat position to maintain a desired temperature.

The automated system further may comprise a front light transmissive cover that is integrated as part of a building's weather envelope.

Many other embodiments are presented and also will be appreciated by a skilled reader.

5

#### Description of the Drawings

Figure 1a General drawing of many embodiments, with illustration of PV material location for concentrating and non-concentrating embodiments.

Figure 1b is a non-concentrating embodiment.

10 Figure 1c utilizes a concentrating reflective lens to reduce the PV area.

Figure 2 shows a cross section of solar radiation incidence angles and slat configurations according to a concentrating embodiment. 2a is the design case sun angle at -15 degrees, Figure 2b is for the sun at +15 deg with corresponding slat angle adjustment.

Figure 2c is for 45 deg sun and Figure 2d is 55 deg sun angles.

15 Figure 3 shows embodiments of a slat movement mechanism using top linkage bars. 3a is uses a steel rule tape. 3b uses a cammed-rack & pinion. 3c uses a cable loop.

Figure 4 shows a slat movement mechanism without linkage bars on the outside of the slats. Figure 4a is a front view showing the slat flanges with pivots, support bars, actuation bar and drive motor. Figure 4b is an isometric view from below the slats

20 showing better how the features are dispersed along the slat length.

Figure 5a isometric view shows representative air dams within a converter.

Figure 5b is a partial front view showing how the linker bar extends the air dam effect when the slats are less normal to the cover.

25 Figure 6 shows two rows of converters with manifolds to share a common closed loop air circulation system.

Figure 7a shows alternative solar cell placement with a raised area on the back side of the slat.

Figure 7b shows a PV cell location on a flange off the inboard edge of the slat.

30 Figure 8 shows an alternative combination of reflecting slats with refracting lens on outboard of the reflecting slats, according to an embodiment.

Figure 9 shows solar radiation transit paths through a vertical converter utilizing planar slats at the top to reflect direct sunlight parallel to a ceiling for enhanced lighting enhancement.

Figure 10 shows desirable alternative mounting and slat positioning for different converter orientations. Figure 10a shows a horizontal converter; 10b shows a shallow converter angle, 10c a steeper inclination and 10d is a vertical installation.

Figure 11a shows converter to converter clamping mate / mount technique in a section  
5 view.

Figure 11b shows an isometric view of part of such a connection.

Figure 12 shows a portable, collapsible converter.

## 10 Detailed Description

Embodiments utilize an innovative two-dimensional radiant energy converter ("converter") that is built in a variety of configurations, incorporated into larger structures and controlled in useful ways to lower the cost and increase efficiency of electromagnetic energy (e.g. sunlight) collection and conversion. Broadly speaking, the energy converter  
15 comprises coordinately positioned slats that form a face for admitting light that is transparent to electromagnetic energy, such as sunlight. Embodiments of the converter convert radiant energy that pass through the transparent surface into electricity and/or heat in a variety of innovative conformations, based on reflection and/or absorption on slat surfaces within the converter. Energy is removed as heat from the energy converter,  
20 and optionally as electricity. The opposite face of the converter may be transparent or may be absorbent, and the converter may control the amount of radiant energy that passes through unabsorbed. In an embodiment, the slats of the converter are designed for a single reflection of radiation onto a target or for absorption.

25 Desirable packaging configurations of the radiant energy converter allow heat removal into re-circulating fluid or another gas and can be adapted for existing energy systems or incorporated into new buildings. Photovoltaic (PV) surfaces can be placed on the outward facing slats or using the slats a concentrating "lens" to create more electricity per unit area of expensive PV material. Specific designs and methods for adapting the  
30 two dimensional radiant energy converter into a building such as a roof, wall, or window are provided that limit environmental exposure compared to conventional designs. Still further, methods are presented for intelligent control and use of the converters to satisfy changing heating, lighting and electrical demands of a building.

### The Planar Radiant Energy Converter

Embodiments incorporate one or more converters, each of which comprises multiple slats arranged in Venetian blind fashion so as to form a planar structure that intercepts radiant energy such as microwave energy and light energy. A converter comprises a first  
5 front face that permits entry of radiation (e.g. transparent to sunlight) and a second rear face that may be transparent or opaque to the radiation. The faces preferably are parallel to each other but can be generally parallel (off from parallel by up to 30 degrees) or even oblique to each other.

10 The (generally) parallel faces enclose the slats and typically have closed edges to form an air tight box with flat sides, with slats of equal length lined up in a rectangular area within a box shape converter. The converter preferably is at least 5 times, 8 times, 10 times, 15 times or at least 20 times as wide and as long than it is thick. The thickness preferably is between 5 cm and 100 cm, more preferably between 7 cm and 60 cm, and  
15 yet more preferably between 9 cm and 25 cm. In this sense the converter is thought of as a planar energy converter with a defined two dimensional radiant energy input face, which typically is a glass or clear plastic transparent window. The converter may be a stand alone box with (preferably) one set of slats, with (less preferably) more than one set of slats or may be multiple boxes that work together, by sharing common edges,  
20 common airflow, and/or by sharing common conduit for transfer of heat energy via a liquid or gas.

In a desirable embodiment the light transmissive window of the converter has a means for removal to clean the cover. The means may be any of a variety of structures, as will  
25 be appreciated by an artisan in the window field. The window may have one or (preferably) two or even more pivots to allow pivoting away from a converter box. Clamps may be used to hold the window onto the converter. A pipe, or sprayer of water, air or other liquid may be positioned to wash the window. The entire converter may be tilted and water or other fluid or a gas sprayed onto the window surface, to allow particles  
30 to fall away.

In an embodiment the two dimensional converter includes one or more air dams that run parallel to the slats and that inhibit air movement perpendicular to the slat lengths.

### Slats for the Energy converters

Slats are analogous to Venetian blinds and may be of any material and size as suited for a situation. Preferably the slats are at least 10 times, more preferably at least 15 times, 20 times or at least 30 times as long as they are wide. In a desirable embodiment the  
5 slats are several centimeters wide, preferably 3 to 20 centimeters and more preferably 4-7 centimeters wide, and at least 30 centimeters, preferably at least 50 centimeters and more preferably at least 100 centimeters long. The embodiment that concentrates the sunlight has a concave "front" side of the slats preferably is reflective, and may have a  
10 white coating, a polished aluminum coating, or more preferentially, silver-based specular mirror coating or other treatment to reflect the radiation. This surface typically is oriented to catch and reflect radiation that enters the converter. The convex "rear" side of the slats preferably is opaque to the radiation and for example may be black to absorb sunlight. The rear side preferably is covered at least in part by a radiation to electricity transducer, such as a solar cell for sunlight radiation.

15

The slats may be continuously curved and also may be faceted. The slats may be parabola shaped from one side of their width to the other. In an embodiment the slats are not parabola shaped but employ a progressively curved surface where the radius of curvature continuously increases from edge to edge, for a best reflecting optical surface.  
20 Using this design, it was seen that as the sun angle changes, simply rotating the slats as in a Venetian blind by translating the relative positions of each edge with respect to each other can result in a distorted focal. The clean and sharp concentration achieved with the sun at an optimum design angle is no longer a classic focal point in this situation.

25 Figures 2a-2d show alternative solar radiation incidence angles and slat configurations according to an embodiment illustrating that as the sun direction changes in one direction (away from a vector pointing from the middle of the concave surface to the PV array on the next slat nearby), there are 2 "loss" mechanisms that arise: 1) light never intercepting the reflector and 2) focusing losses. Both of these loss mechanisms can be minimized  
30 by adjusting the length of the slat and adjusting the curvature of the slat. Figure 2d shows solar radiation incidence angles and slat configurations according to an embodiment that illustrates that designing the slat shape for a negative 15 degree sunlight angle still has very good effective capture with the sunlight 70 degrees away from that design angle (+55 degrees).

These drawings show that as sunlight angle changes, the slat angles should be altered such that sunlight hitting the outer most part of the reflector (right edge in this view) is directed at or near the right edge of the solar cell.. This design accommodates the defocused optics by using solar cells that cover an area of the rear slat that matches much of the distorted focal line.

Another optional criterion for slat shape is maximization of captured light incident to the slat and control of the amount of light to permit light to pass through the converter.

Swiveling the slats for maximum energy capture may be used in this context, as exemplified in U.S. Patent No. 4,690,335, the contents of which (particularly slat configuration and control), are incorporated by reference for what they teach in this area. In particular, the slat confocal line becomes "distorted" for radiation that is not along a designed-for-direction. Although slat swiveling is used to compensate for much of this distortion, a parabolic shape no longer has a focal line when the orientation of parallel, direct radiation is not from the design angle. Also, the focal line translates and rotates as the slats rotate. However, the combination of wide focal area, such as a solar cell reflection target of at least 10% as large as the reflecting surface, with shorter slats of less than 9 cm width is desired to provide suitable focal areas that can be captured.

Often, most distortion occurs from the reflected light off the most interior part of the slat, but one finds that this area is shaded by a nearby slat. The light reflected off of the illuminated section of the mirrored slat may remain relatively in focus

Desirable slat orientations are exemplified in Figures 2a-2d. These figures show how orientation of the concave surface of the slat can be modified for different radiation angles. Light that enters the converter more parallel to the slat at an off design value is more difficult to capture.

Slats may be formed of any material; although formed sheet metal (particularly aluminum) is preferred (roll forming appears feasible and can be very low cost in high volume). Extrusion also appears feasible. In an embodiment, slats are formed from a plastic that may be further coated with reflective and/or absorbent coating and optionally with electronic material such as a flexible photocell. A challenge with plastic slats is the poor heat conductivity of plastic will not spread the absorbed heat very well in the

embodiments with the concentrating optics. The material may be coated to become reflective or absorptive, and preferably has a specular mirror finish, coating, or film to allow reflection of radiation on a smaller, rear absorptive surface of an adjacent slat in the concentrating embodiments.

5

The slats should be mounted parallel to each other. Their parallel orientation may be maintained by a structure or mechanism as is known in the art. The use of a notched bar of polycarbonate, aluminum, and acrylic or other material that can survive high stagnation temperatures (perhaps 100 deg C if the air flow stops) particularly is preferred. Transparent materials as linkage/structural support alleviate shadows that can affect electric power generation in the PV material. So if linkage or air dams are used on the outside edge of the slats clear material is preferred, such as polycarbonate and acrylic. U.S. Patent Nos. 6,988,525; 6,561,251; 6,422,288; 5,687,785; 4,159,707; 4,155,395; 4,356,857; 4,750,539; and 4,143,640 represent some technologies in this area, and specifically are incorporated by reference with respect to structures and mechanisms for slat construction, manufacture and use.

An embodiment provides a lower cost and more convenient to manufacture converter design by virtue of the relatively short focal length from one slat to the other, and consequent relaxed focus target area requirements. The target area preferentially is close to the reflector, which is typically a distance of less than 5 slat widths, preferably less than 3 slat widths, and more preferably within about 2 slat widths. The actual curvature of the slat can vary plus or minus 2%, 5%, 10% or more and the actual distance from slat to slat (focus distance from reflector to absorbing target area) can vary plus or minus 2%, 5%, 10% 20% or more. Thus, the design according to this embodiment provides looser tolerances on the slat shape, linkage spacing, and controller precision compared to other, more expensive alternative solar concentrators. Furthermore, the spacing mechanism for holding slats apart is small enough to allow inexpensive machining, punching, and notching in a single component with conventional shop equipment, which saves costs and aids in manufacturing precision.

Slats are assembled into a two dimensional array as is known in the art for Venetian blind type of structures. Preferably however, a design is used that minimizes shadows from structures or linkages. Accordingly, slats should be coordinately linked via clear

plastic or thin metal linkages. Preferably wire is used for coordinate linkage and control, to minimize shadow interference. If a thin metal linkage is used, preferably the band has a thinness that is no more than twice the thickness of a slat, and preferably no more than the thickness of a slat. In a desirable embodiment one end of each slat is attached to a  
5 fixed immovable support. Preferably this support is on the side away from incoming radiation, and may be the rear face.

A slat support or spacing feature desirably is fixed to the collector back or the collector box walls. The outside (toward the sun) edges of the slats preferably are linked together  
10 and are translated by a top linkage, which could be implemented various ways. In selecting a linker, it is preferred to minimize the linker casting a shadow on the reflecting slat. Therefore small dimension linkers such as heavy rigid wire or the use of clear plastic such as polycarbonate are preferred.

15 The linker spacing and connection to the slat can be selected from a variety of mechanical attachments, as will be apprehended by a skilled artisan. A clear solid connector of the slats that coordinately swivels the slats can be punched or machined with precision features. A rigid wire connection between slats preferably uses notches or clips on the wire to set those positions on each slat. The motion of the top  
20 space/connector is back and forth as is apparent from the motion of the slat edges, and also changes in height in the enclosure. Thus a variety of mechanisms may be used to interconnect the top to an actuator and several are shown in Figures 3a-3c. The dashed rectangles in the figures represent the linker bar in the "up" or "in" position. As such the figures represent the linker bar in two positions for each option.

25 One interconnect method is to tie the linkage part to a shaft or cam using a curved sheet metal tape. Such curved metal tapes are known and used in tape measures. For example, a skilled artisan will appreciate the use of materials and methods for "power tape" technology that may be adapted for rolling up slats in the present embodiment.  
30 See for example U.S. Nos. 3,036,791; 6,931,734; 7,020,978; 6,223,443 and 6,470,589 the contents of which and particularly details for reversibly extensible tape structures are incorporated in their entireties. Most desirably, the material should be flexible and lightweight with high tensile strength, be flexible, but also carry a modest compression load over short distances such that shaft and tape can "push" on the linkage. A cam is

not required to allow the linkage part to rise and fall as it is translated back and forth. That is, the tape can flex a bit if necessary although with substantially reduced ability to carry compression loads.

5 Figure 3a shows an embodiment of slats 1100 with connected curved sheet metal tape 1110 tied to shaft or cam 1120, similar to that used in tape measures. This is flexible and lightweight but with high tensile strength. The tape can both pull and push on the linkages. A cam is not required to allow the linkage part to rise and fall as the linkage translates back and forth. The tape can flex some, in an embodiment.

10

A second embodiment shown in Figure 3b depicts a bar 1200 that coordinately moves the slats and is attached via a cammed rack and pinion gear. The rack 1210 and cammed-pinion 1220 and a geared pinion are on a shaft 1230 connected to motor (not shown). In a third embodiment shown in Figure 3c, flexible wire 1300 is wrapped around  
15 the assembly so the wire can pull on either end of linkage bar 1300.

A variety of interconnect methods are contemplated. Of these, a wire is preferred for having a smaller optical profile that casts a smaller shadow on the PV cells. A wire would run Venetian blind style perpendicular across the slats and can be attached by  
20 materials and methods known to the skilled artisan. Figure 4a and 4b illustrates an embodiment where the slat rotation is effected completely from the inboard edge of the slat – avoiding shadowing issues and pragmatic challenges on of bending stiffness needed from the linker bars in the embodiments in Figures 3a-3c. The slat (600) has a flange bent or extruded as part of the same piece that has the optical surface and PV  
25 mounting. The actuation bar (610) translates left and right in Figure 3a pushing on the flange.

Pivots on the end of the flange (620) translationally restrain the slat end converted the interfering motion of 610 into rotation of slat 600. The pivots are secured in a punched or  
30 machined support bar (630) that are mounted to the converter frame and/or backing. A linear actuator (640) is shown that precisely moves the actuation bar. The PV material (650) is shown on the back side of the slats. A representative contact between the slat and the actuation bar is shown as 660.

The interconnected slats acquire heat energy by, for example, direct absorption, or indirect transfer via thermal conductivity of heat from solar cells. This heat may be transferred out of the converter by convective transfer via air flow parallel to the slats. Unlike the previous techniques such as described in U.S. patent No. 4,577,619, (the contents of which and especially mechanical details for stat construction and movement, are incorporated by reference specifically) preferably air flow is not across the slat width but instead along the long axis, which provides greater heat transfer and less slat flutter.

In most embodiments this air movement is forced by a fan. Forced convection is preferred because generating flow parallel to slats is important for several reasons. This allows higher volumetric flow rates which are important to transport the heat out of the box, for air has a low density and limited specific heat. Transporting reasonable amounts of heat without the efficiency robbing high air temperatures requires flow rates that would be difficult to achieve if the flow is transverse to the slats. Also, good convective heat transfer between the flowing air and the slat requires reasonable velocities right next to the slat. That would be difficult to achieve with flow perpendicular to the slat's long axis. The flow would bypass most of the slat's surface. Analysis of the flow conditions, factoring in parasitic losses for the fan to offset the frictional losses in the flow passages and heat exchangers it appear that flow rates of 200 to 350 m<sup>3</sup>/hr per square meter of aperture between heat exchangers (which removes heat from the air) yielding temperature rise to about 4-8 deg C per collector. This results in flow velocities, when the entire area of the cavity can be used (parallel flow to the slats) of 1.5 to 3 mps. Experimental results show that for flow speeds much over 3 mps can induce undesirable flutter in inexpensive, lightweight slats.. Attempting to flow similar amounts of air transverse to the slats, as taught in some prior art would likely lower the acceptable speed that induced flutter substantially. Also, even these modest average flow speeds would be much less between the slats than the average flow that is going around the edges of the slat in the non-parallel flow approach. This could be partially mitigated with deeper cavities to let the flow go around the slats, but most importantly the low flow speed on most of the slat surface area reduces the convective heat transfer between them – substantially increasing the temperature difference between them which impacts PV performance and reduces thermal efficiency. Engineering estimates indicate that the temperature difference between the slat and the air in non-parallel flow would be 2.5-6

times higher than for parallel flow – impacting PV efficiency 10-20% loss and thermal efficiency 15-40%.

5 In an embodiment, a slat support on each edge of the slats creates an air-dam to reduce convective loss to the cover and back and also increase the flow of air along the heated slats and thereby improve heat transfer. Figure 5a depicts a representative air dam, and shows rear face 900 with fixed dams 910 attached, the linker bars or moving dams (920) to limit air flow 930 into path 940 - away from the transmissive cover to reduce heat losses and closer to the slats to improve heat transfer.

10

In an embodiment, air flow along the length of slats absorbs heat from the slats and then gives up the heat at a heat exchanger at the edges of the slats, as exemplified in Figure 1a. That shows air flow 1010 along slats 1020 that encounters fins 1030 of heat exchanger 1040 at one side of converter 1050. A heat exchanger can use a secondary fluid or gas to carry away heat and may be shared among two or more converters.

15

An array of slats can be bundled together within a converter, and heat from the converter can be removed by forced air or a secondary heat exchanger. Alternatively, two or more converters can be arranged end to end such that the ends come together as shown in Figure 6. Further, the air loop can utilize a nearby row of converters as part of the air circuit, reducing the cost and space needed for a separate parallel air duct near the row of converters. Shown are 2 rows of 6 converters (800), air manifolds at the ends of the rows (700), a fan or blower (710) and mounting frames (720). In an embodiment, a manufacturing technique provides a low cost method for quickly and effectively mating the converters to each other.

20

25

A section view of representative clamping / mating geometry is shown in Figure 11a. This shows the right end of the left box (210), the left end of the right box (220), a clamp (230) that, when restrained, couples the boxes together and secures 210 and 220 in the support bar (240). Ridged features are used on the top and bottom of the box edges to provide a surface for the clamp and support bar to grip. The versions of 210 and 220 are bent sheet metal. There are other ways to bend the sheet to get a functionally similar box end. Extrusion is another feasible option for all of all these parts. A gasket (250) between the box ends and the support bar seals the air envelope flowing in the

30

converters and provides a bit of thermal insulation between the warm boxes and the uninsulated support frames. Figure 11b is an isometric view of the "right" box, the clamp and support bar.

- 5 Although most embodiments utilize air movement along the slats to extract heat energy, direct transfer of slat heat to another material such as a solid or liquid, by thermal contact also is possible. In an embodiment air flows up through the slats instead of along the slat lengths. In yet another embodiment flow is controlled (with optional manifolds) under and over the slats and transverse to the flat surfaces. This latter embodiment may
- 10 require more height or depth to the converter. This technique also may place large flows near the cover and back surfaces that tend to increase heat losses from the collector. Optionally, a heat exchanger is located at the back side.

#### Solar Electric Conversion

- 15 An embodiment provides lower cost electrical energy conversion by focusing light from the concave curved fronts of slats onto smaller photoelectric (i.e. radiation to electricity converting) regions on the convex rear surfaces of adjacent slats such as solar cells. Desirably the focus ratio (light reflection area of concave front portion divided by the solar cell area located on the rear of the adjacent slat) is between 2 to 50, and more preferably
- 20 between 4 to 10. Figure 2a shows an optical layout of a representative concentrating slat design. Two slats are shown in each section, with sunlight and slat angles changes. In the top left side of this figure shows the design sunlight and slat angle., sunlight (in long dashed lines) shines at a negative 15 degree azimuth to the left side and reflects off concave slat surfaces (10) as dotted lines (20) into solar cells (30) according to a design
- 25 angle. Solar cells (30) are located on a rear portion of each slat onto which light is focused. Figure 2d shows that slat adjustment to accommodate sunlight shining from a 55 degree azimuth allows focus onto the same solar cell area despite changes in azimuth.
- 30 The solar cell (or other radiation to electricity conversion device) in an embodiment is placed on another part of the slat, or off the slat. See, for example, Figure 7b, which shows slat reflector surface 81 with attached solar cell 82 substantially perpendicular to the reflective surface. Other angles are intended for other embodiments, but are not shown here. As shown in Figure 7a, light rays 83 impinging on reflector 81 are directed

onto the adjacent surface of attached solar cell 82. In an embodiment, the solar cell is on a tab at the inboard end of a reflecting slat. The left side of Figure 7 shows two slats 86 with solar cells 85 on their rear surfaces but spaced off via hat structure 87.

5 Light may be concentrated by a combination of reflection and refraction, as exemplified in Figure 8. This figure shows refracting lens positioned outboard of reflecting slats 92. Direct light rays 93 impinge on the refracting lens, which refracts the light into altered paths 94 and onto reflecting surfaces 92, which then reflects into paths 95, which more effectively focuses the rays onto solar cell target 97. In an embodiment, this "hybrid  
10 optics" scheme, which uses refraction and reflection in series may employ a continuous or Fresnel lens, or even faceted refracting for each slat opening. This lens could be a top cover over the curved reflectors. The refractor can pre-bend some of the light, which changes the required shape of the reflectors and may reduce the slat rotation motion required. For example, a Fresnel cover may be added. The hybrid can alleviate the light  
15 leakage problem when the sun angle departs from the design angle. Also, not shown, the refracting aspect can have light exiting that is already starting to focus, vs. the example in the Figure 8 where it is simply deflected, but light rays remain parallel to each other after exiting. This would allow the use of flatter or more curved reflective lenses should that be beneficial.

20

Cost reduction occurs from concentrating sunlight onto smaller solar cell surface areas, and by using materials (reflective slats) that are cheaper per surface area unit than semiconductors for light scattering. In a preferred embodiment the slats are stamped sheet metal, and preferably are aluminum. By using slats, the force needed to move  
25 optical surfaces (slats) is very small compared to that needed for many previous systems of comparatively large collector areas. In a preferred embodiment, short optical paths of approximately 5 cm (i.e. 2-25 cm, preferably 3-10 cm, more preferably 4-8 cm) are used, along with moderately low concentration ratios of about 3 to 10. These dimensions provide looser manufacturing and tracking precision tolerances compared with that  
30 needed previously for systems having longer paths and higher concentration ratios. Cost savings thus exist in manufacturing the solar collector surfaces, the system to hold the surfaces at their proper spacing, and in the simpler tracking system needed to obtain good efficiencies.

Solar cells in an embodiment are attached directly to thermally conductive metal slats to facilitate heat transfer from the solar cells to the slats. Thermally conductive epoxy that includes thermally conductive filler such as boron nitride may be used. In an embodiment, electrically and thermally conductive epoxy such as silver filled, aluminum filled, or bromine intercalated graphite filled epoxy is used to both electrically and thermally connect a back surface of a solar cell onto a metal slat filler. A second connection to the solar cell may be made on a top surface or edge via wire that may connect to a metal linkage, or run along a linkage such as a mechanical linkage that holds the slats together or that pivots them together.

An embodiment provides non-symmetric curved reflectors that concentrate light efficiently at various radiant energy angles onto a target solar cell surface. For example, when the radiation vector becomes more parallel to the slats, a lower percentage of the radiation becomes captured. In some cases such radiation passes through the converter as desired illumination, potentially reducing electrical lighting needs. Such features may be exploited as a window treatment wherein direct light heat gain and glare may be controlled along with electrical power generation and even thermal power generation. Other applications include use as a skylight without the problematic heat gain and glare for occupants conventional skylights often have, while also creating an outdoor feel to a building interior when the sky can be seen undistorted by translucent coverings that otherwise may be used to correct heat gain and glare.

In an embodiment, one axis tracking is used to orient reflecting concentrators. This can create shadows and possibly radiation leakage near the ends of the photoelectric arrays, such as when the sun is substantially non-normal to the array in the non-tracked axis. These imperfections can be alleviated by omitting solar cells at slat edges and/or by the accepted practice of adding bypass diodes to one or more solar cells so that shadowing does not substantially diminish the electrical output from radiation to an electric power circuit.

#### Lengthwise Air Flow in The converter

As described, the converter has an array of slats with slats parallel to each other and coordinately controlled to swivel with a linkage. Air that circulates along the slat length may be used directly for heating by forming a circuit with air in a building. In this case a

fan may be placed anywhere in the circuit to force recirculation of air that becomes heated by contact with slat surface and then enters the building to dissipate that heat. Alternately, heated air from contact with slats may transfer heat energy to a fluid via a heat exchanger that may be packaged within the radiant energy converter, located  
5 adjacent to the converter and optionally in combination with a group of converters, or located a distance away through which the air travels.

A converter may comprise two large area faces, sides (typically 4 sides if rectangular shaped,) one (preferably) or more arrays of slats that are mechanically coupled to at  
10 least one face, and preferably air inlets and outlets for circulating air along the slat length. Air dams help ensure air flow along slat length and may be positioned within an energy converter package via attachment to either face but preferably to a face opposite the transparent radiation entry face as shown in Figure 5a. The one or more dams are oriented perpendicular to the slat lengths to keep the flow near the slats and generally  
15 less on the inside of the transmissive cover. A face should be removable to allow cleaning of the slats or other parts inside the converter. To allow easy cleaning, and associated cover removal the size of the converter area is preferably less than 2.5 square meters.

20 In one conformational embodiment, the converter is packaged within a chamber to allow heat removal from the slats via lateral air movement along the long axis of the slats. Air movement lengthwise creates less turbulence and more efficiently transfers heat from the slat to the air compared to air movement crosswise. Solar cells mounted directly onto the slats preferably are flat, or even curved and either mechanically contact a  
25 thermally conductive (e.g. metallic) slat surface or are bonded via an intermediary conductive adhesive or fastener. Photocells that cover about 8-20 percent of the rear slat surface were found to transfer adequate heat to aluminum slat surfaces and are preferred.

30 Because of the need for substantial volumes of air to carry heat away due to air's low density and lower specific heat capacity, a large "passageway" for the air is preferred. Accordingly, in an embodiment most (at least 50%, 60%, 75% or more) of the converter package depth acts as the collector, to allow large flow rates. In another embodiment the radiation is particularly at a high energy level such as direct overhead sunlight or

microwave energy that can warp or melt components of the converter in the absence of the heat transfer out of the converter. In this embodiment, a fluid may be used in place of gas to conduct heat away from the slats. The latter technique may be used, for example in microwave to electric energy conversion systems.

5

#### Powerskins: Converters Incorporated into Buildings

When incorporated into a building a converter acts as an exterior layer and provides some exterior protection. In this context, the converter may become part of the building, either added to an existing structure, or incorporated into a new structure and is termed a

10 "powerskin," A converter that is intended for installation as a powerskin may be advertised, sold and/or packaged with installation instructions, with one or more sensors and/or with one or more effectors suitable for use in an integrated building system. Such converter that is accompanied by an instruction manual or by one or more system sensors/effectors is intended for powerskin use and said to be an uninstalled powerskin.

15 A converter that has one or more electrical connections for sensory or effector signals to a controller thus is termed a "powerskin" by virtue of having one or more input/output connections that allow use of the converter as part of a larger building energy system.

As a powerskin, a converter may provide insulation and can control the amount and type

20 of energy that enters from sunlight or other radiant energy into the building. The powerskin has an exterior face or "cover" to the weather and an interior face to the building, or building interior. The cover in this embodiment acts as a weather guard for the converter and the building. The cover may minimize reflectance and absorption losses of the sunlight passing through the converter and provides an enclosure for the

25 heated air to keep the heated air separate from the external air.

A variety of characteristic features may be modified that trade off the cost of a powerskin, the powerskin's insulating performance and visible light transmission through the powerskin. The back face of the converter can be transparent (for daylighting

30 applications) or opaque which affords better insulation options and lower cost. In a preferred embodiment a multi-wall plastic/polycarbonate back wall provides a lightweight, structurally robust barrier with superior insulation than glass, although glass generally is more transparent and often less expensive. The converter back optionally supports the bottom slat spacers.

Glass glazing may be used in combination with a powerskin to form a very robust structure to resist weather. Because the powerskin optics are within a box and protected, wind loads do not affect optics actuation. Other optical concentrators are exposed to wind forces on their tracking actuators, which incurs greater installation and maintenance costs.

#### Vertical Powerskin Walls

A daylight powerskin embodiment shown in Figure 9 illustrates how high intensity sunlight may be controlled to avoid glare near the window and direct light deeper into the building. Wall unit 800 comprises upper 4 slats 810 that are controlled to allow direct daylighting (820), while the lower slats are oriented to generate electricity using PV material and also allowing diffuse light, non-direct light (220) to enter the space behind the converter as diffuse daylight (225) behind the converter.. Meanwhile, in an embodiment, occupants can see out the window as for regular Venetian blinds as shown by arrows 230. Electricity can be generated at focal point of slat reflections or by applying PV to the exterior of the slats using the direct sunlight (93).

Tracking motion required for simultaneous solar electric generation in this embodiment uses the same slat movements. The angle of such "daylighting" slats can be adjusted with respect to the angle of electric conversion concentrating slats to allow entry of direct daylight to the ceiling, or down toward the floor. The slats may have a variety of curvatures that provide a spreading pattern, as can be determined by a skilled engineer.

#### Horizontal Powerskin (Roof)

A roof powerskin offers dramatic architectural possibilities without the classic challenges of direct light on overhead apertures. A powerskin when designed into construction, or as part of a major roofing overhaul can eliminate the expense of other roofing materials. Glass used in the outside face of a powerskin is extremely long lived and water-tight, which nearly can eliminate the cost of periodic replacement of lower cost weather-proofing for the roof. The powerskin can assume the covering of a skylight or other fundamental architectural feature of a building. This provides control of light and, in some circumstances extra heat gain in the summer, and insulation loss in severe climate

conditions. Thus, a roof powerskin can convert problematic direct sunlight into useful energy forms.

#### Powerskin Slat Design and Orientation

5 Desirably, the roof powerskin is a fixed box design in a roof-top mount, and for this example assumed to be in the northern hemisphere and pointed south. The box may be installed with a tilt to fit the architecture of the building / building site and/or to optimize solar energy collection at different times of day or season. The orientation of the concave surface of the slat can vary such that when the slats are oriented most normal  
10 to the cover the concave surface can be facing the "top" or the bottom of the converter. The ideal orientation can vary depending on which values (electricity, heat, lighting) are desired at what times of day and season. The most typical orientations are shown in Figures 10a-10d where the slope of the collector is the primary variable. If the installation is more vertical, the concave surface prefers to point "up". For horizontal  
15 installations the concave surface want to point to the South (or down, if there is some slope to the converter). Converters can be installed facing in any azimuth and a skilled artisan will be able to recognize the preferential slat orientation given the site specifics.

The range of angles for incoming light rays that strike the collector varies with the installation orientation. Vertically oriented collector 910 of Figure 10d receives sun rays  
20 that vary from directly overhead to parallel to the horizon. Sun positions for this cross sectional plane vary by at most 90 degrees. The amount of radiant energy at either extreme is low because when normal to the collector the sun is nearly at the horizon, with atmospheric attenuation. In this case, the light and the duration of the sunlight in this orientation is short. If this design is used in a collector design mounted more  
25 horizontally, the sun angle can actually be in a wider range. Arrow 912 shows radiation orientation for winter morning and evening. Arrow 914 shows summer midday, and arrow 916 shows radiation orientation for summer morning and evening.

Preferably these collectors are installed in an east-west axis and have a tracking axis  
30 that follows declination of the sun. Near the summer or winter solstices this declination will vary substantially throughout the day, and the angles differ greatly in the mornings and evenings from summer to winter. Such configurations desirably can use sunlight variations of approximately 130 degrees or even more for summer mornings where the

sun rises north of east in the northern hemisphere and a horizontal east to west axis array would need to point directly north at dawn and directly south for winter dawn and dusk. The practical amount of light in these transitory periods is small. Accordingly, optimized performance for more common orientations results in more net power  
5 collected per year.

The collector optionally may be tilted towards the equator or south in the northern hemisphere, which reduces the southern most extreme because the southern horizon is no longer 90 degrees from normal. Thus leaves the northern horizon further from  
10 normal. Each of these installations can employ powerskins as described herein and, in combination with a building structure, is intended also as an installed embodiment.

Additional light reflects outside the selected focal zone. Accordingly, a more negative design sun angle is preferred for non vertical embodiments. In another embodiment, a  
15 vertical collector uses between +5 and +35 degrees, more preferably between +10 and +20 degrees, and yet more preferably approximately (i.e. plus or minus 10% of the value) +15 degrees where the sun angle cannot go below zero. A horizontal collector such as a roof top collector preferably is positioned between -5 to -35 degrees, more preferably between -10 and -20 degrees and yet more preferably approximately -15  
20 degrees. These designs were found to provide good performance for most of the year in common installation applications. Installed powerskin embodiments with these orientations are contemplated as well.

The linear nature of reflecting optics as preferred, allows a single axis design wherein  
25 light incidence variations in the non-tracked axis can vary significantly without changing the focal line in the tracked axis. That is, as radiation incidence angle moves across a non-tracked axis, the light shifts in an out of the plane in this view, but the concentrated light area remains. Advantageously, this design allows the use of a true single axis tracking system that does not require tilting. Of course, cosine losses occur with  
30 declination changes throughout the year, but the described system dramatically reduces wind loads on the system and tremendously simplifies the tracking mechanism. In an

embodiment, the system is tilted as well to change the angle of incoming sun ray hitting the aperture for a specific time of the year.

5 It was discovered that for a flat roof surface, greater efficiency of light energy capture is possible by tilting the panels modestly (typically less than 20 degrees) to improve the incidence angle to the external glazing, and thereby reduce glazing reflection losses. In this latter embodiment individual boxed units of the energy converter can be installed to allow access between the rows for installation and servicing. In embodiments the gap size may be between 6-12 inches, 12-18 inches and more preferably between 18-36  
10 inches. Minimum annual energy collection is lost because the tilted panel intercepts the light that would have otherwise fallen on the gap.

An embodiment includes at least one computer that contains stored year long sun tracking data, such as sun angle for a given time. The computer operates one or more  
15 output electromechanical devices such as a motor or piezo electric device for altering slat positioning. In a preferred embodiment the computer additionally controls the proportion of radiant energy entering the powerskin that is converted into heat versus electric energy. In another embodiment the computer additionally controls the proportion of radiant energy entering the powerskin that is converted into heat versus allowed to  
20 pass through as room or building lighting. In yet another embodiment the computer additionally controls the proportion of radiant energy that enters the powerskin that is converted into heat, into electrical energy and allowed to pass as room lighting. In another embodiment the computer additionally controls shutter closure at night as desired depending on the time of year and/or outside temperature to minimize or  
25 maximize heat loss.

#### Powerskin Control Systems

A powerskin control system, in an embodiment, comprises at least one sensory input signal, at least one powerskin effector signal, a controller computer with a controlling  
30 program that accepts sensory data and outputs control signals, and at least one powerskin (i.e. converter that is adapted to be installed into a building, or that has become installed into a building). A powerskin may be controlled to 1) generate electricity via solar voltaic cells; (2) generate heat, by circulating air through an enclosure

of the converter where most of the sunlight is absorbed directly or indirectly after reflection onto solar voltaic cells; and simultaneously (3) provide daylight out the back of the converter via scattered sunlight, and some of the diffuse sky light that comes in nearly parallel to reflecting surfaces of the slats. The control for one or more of these parameters may be automatic. For insulation, a controller can close blinds at night or when light intensity is below a specified threshold, indicates that more energy can saved by being in the maximum insulation mode instead of light collection. Closing the blinds at night automatically can enhance security by preventing views from outside in. Desirably, a control system trades off relative internal lighting versus heat collection versus electricity generation according to one or more algorithms that may be fashioned to maximize a desired condition.

In one automation embodiment, clouds passing overhead are detected, which affects electric output. In this situation, lighting can be enhanced by opening the slats to improve the "view factor" of the interior space to the sky and offsetting what might be dimmed lighting inside from the cloud effects. With this modification less lighting adjustment is needed with minimized loss of electric power for the temporary condition because the solar cell area is only illuminated by the missing direct sunlight. Somewhat simpler is the case of the sun going down or the sky becoming dark enough that the slats are oriented automatically to the night position for improved insulation and to minimize light loss through the collector aperture from interior lighting. Both operating modes are superior to conventional static skylights or window treatments.

Control systems can be connected to other building loads to minimize peak power draws from the building. Partly cloudy days can have substantially varying photoelectric output. However some loads like air conditioners, refrigeration systems, ventilation systems, or UPS charging systems can be modulated during periods of intermittent photoelectric power generation to drop the building's load when photoelectric power drops during cloudy moments. When sunlight returns or otherwise in a coordinated fashion these semi-discretionary loads can be turned back on or up. The "inertia" in the system (thermally for AC & refrigeration) allows negligible impact for such short duration modulation while potentially maximizing total electricity costs. This is because many larger buildings and power constrained areas meter power separately from energy to

account for the utility's challenge to deliver enough power (generation , transmission and distribution infrastructures are sized for worst load scenario).

5 A control system can allow a building occupant to request a temporary change in the slat orientation to see something outside, dim the room, or other purpose. After a programmed time period, the system will resume energy generation mode. Such remote controls could operate similar to that of a garage door opener with RF or IR signals to minimize the wiring needed in the building. This mode would allow individual control over the window treatments at least temporarily to view outside depending on the slat  
10 orientation.

#### POWERSKIN CONTROL SCHEME ELEMENTS (TABLE)

Each one of the listed powerskin control elements, either alone or in combination with other elements, can be used to control one or more powerskins. For example, a room  
15 temperature signal, an inside thermostat setting signal and an outside light signal may be input to a controlling computer. The computer executes software that compares the inside thermostat setting with room temperature and controls the slat setting on the powerskin to harvest more heat from sunlight, if the outside light signal exceeds a threshold. In another embodiment, the computer accepts a presence of people in  
20 building signal, an inside light signal and an outside light signal and then directs a powerskin to divert more light inside the building to increase the building light to a target value. In another embodiment, a signal that indicates presence or absence of people inside of building or room is input and the controlling computer adjusts a powerskin to permit less outside light from entering the building upon detection of people leaving. In  
25 another embodiment a powerskin is directed to allow less light in and more heat instead when an input room light signal indicates that the lights have been turned off.

Exemplary data input signals include: room temperature, outdoor temperature, Inside-  
outside temperature differential, inside light, outside light, inside-outside light differential,  
30 time of year (warm vs. cold season), time of year (stored or calculated sun elevation angle or other parameter), time of day (stored or calculated sun elevation angle, azimuth), inside thermostat setting versus other data, inside light switche(s) on, presence of people in building, room (vacation days etc), and relative or absolute need for hot

water. Exemplary output effector signals from the powerskin controller include: slat angle control, slat closure control, electrical conversion control, fan duct control (fan blows air along slats), intruder alarm based on shadows at night, substantially complete slat closure in one direction (reflective surface facing out) vs. opposite direction and non  
5 reflective or colored surface facing out.

A skilled artisan can optimize slat design for a particular installation by taking into account local weather patterns, installation orientation (tilt and azimuth), any local obstructions, the overall slat length used, and whether entry of diffuse interior daylight  
10 exit of light through the collector is desired. The representative powerskin control input elements and output elements listed above exemplify some of the parameters, but a skilled artisan readily will appreciate further useful parameters.

#### Powerskin Night Use

15 While designed primarily for radiation conversion, embodiments include useful features for night use. A powerskin can provide increased insulation compared to that of a façade when used over conventional construction surfaces, via automatic slat closure at night. Such automated movement can be used as a convective barrier. An enclosed converter with an extra layer of glass or backing adds another convection and/or conductive  
20 barrier. A powerskin can control light entry to automatically avoid bright and glare sections, which can reduce the effectiveness of interior space.

A powerskin can close reflective surface blinds at night to provide a reflective surface to the outside that minimizes nighttime lighting costs. In an embodiment the slats include  
25 one or more light emissive elements for further general external lighting or pattern creation such as advertising messages. A powerskin can provide security by automatically shielding from view the contents of a room from outside. In another embodiment, solar cell output from a converter at night is used to monitor the existence of or pattern of shadows that fall upon the side of a building and can be used for security  
30 purposes to alert the presence of unexpected or anomalous light patterns. In an embodiment, a controller compares patterns of shifting light activity to learn new patterns and also to learn patterns that indicate the approach of a person to a building.

Convex "inside" slat surfaces can be painted in a wide variety of colors or patterns to provide aesthetics or advertising that may be used in daytime or at night. The installation cost of a converter substantially may be reduced when the device does not require anchoring to a building exterior and can more easily survive wind, rain and temperature extremes that such an installation requires.

#### Portable Solar Energy System

A converter can be packaged with stacked slats, analogous to the packing of a Venetian blind when shipped from a factory as depicted in Figure 12. Preferably slats 1310 are held together flexible, tensile elements (1320) when combined with adjustable compression member 1330 will deploy the slats into a plane. Other folding frame elements (1340, 1350, and 1360) allow the slat array to be tilted to improve sunlight capture. An automated slat rotation positioner is packaged in the top housing 1370 that extends and retracts 1320 members, much like a Venetian blind.

Glass or other glazing may be included as, for example, part of a kit. However, elimination of glazing engenders a far more compact (smaller volume and or weight) design for shipping compared to a conventional solar electric array. The ability to fold up a converter provides additional cost savings because of less solar cell surface needed. Optionally the converter may be stretched out and held in a variety of orientations to the ground and sun. The collapsible features provide an easy to ship product that can be integrated with strong mounting systems and glazing materials for a permanent installation using indigenous materials at a user site without requiring such extra parts with the primary optical device. In an embodiment, such foldable converter is provided and shipped as a light weight optics assembly with solar cells, and combined with locally available glazing to form a permanent device, such as a vertical powerskin or roof powerskin.

Other combinations of the inventive features described above, of course easily can be determined by a skilled artisan after having read this specification, and are included in the spirit and scope of the claimed invention. Documents cited herein specifically are incorporated in their entireties by reference.

## We claim

1. An electromagnetic energy harvesting converter, comprising:
  - a. an enclosure having a front light transmissive cover and a rear cover;
  - b. a space between the covers;
  - 5 c. a forced air generator arranged to induce air flow within the enclosure, thereby removing solar heat from the slats; and
  - d. an array of parallel arranged slats within the spacing with one or more photovoltaic energy converters mounted on at least part of each slat, each slat having a forward face that can receive light directly, and a rear face that can receive light  
10 indirectly.
2. The converter of claim 1, wherein the forced air generator causes air near the slats to move in a direction along the length of the slats.
3. The converter of claim 2, wherein the forced air generator is a fan within the enclosure.
- 15 4. The converter of claim 2, wherein the forced air generator is an HVAC circulation fan located outside the enclosure.
5. The converter of claim 1, wherein the slats comprise at least one of: a) formed single ply of thermally conductive material; b) a sandwich of two or more materials; c) extruded material; and d) insulation on an interior side of the slats,  
20 thereby reducing heat loss at night.
6. The converter of claim 1, further comprising a fin on the slat rear face, thereby increasing slat convective surface area.
7. The converter of claim 2, wherein the slats are positioned on pivots that allow rotation along the long axes of the slats, thereby changing their orientation with  
25 respect to the plane of the front light transmissive cover.
8. The converter of claim 7, further comprising air seal surfaces near the slat edges, the air seal surfaces sized and oriented to form an air seal at one extreme of slat rotation, which at least retards or blocks air motion transverse to the slats at the extreme slat rotation position.
- 30 9. The converter of claim 7, wherein the slats comprise electrically conductive material that connects the photovoltaic energy converters to a circuit.
10. The converter of claim 7, wherein the surface of the slat rear face comprises an optical coating that absorbs scattered light.

11. The converter of claim 7, wherein at least most of the slat surface area that is not covered with photovoltaic energy converters is colored in a signage pattern
12. The converter of claim 1, wherein the photovoltaic energy converters are bonded to the slats with thermally conductive material.
- 5 13. The converter of claim 9, wherein the electrically conductive material is electrically connected to an external load by conductors that are flat to reduce the profile and flexing moments induced into the slat mechanism.
14. The converter of claim 9, wherein the electrically conductive material is electrically connected to an external load by conductors that are built into or
- 10 hidden inside one or more structural features that support or move the slats.
15. The converter of claim 1, wherein the photovoltaic energy converters are surface layers on the slats.
16. The converter of claim 1, further comprising diode shunts connected within a circuit that allows selective bypass of at least portions of a slat.
- 15 17. The converter of claim 1, further comprising a light sensitive control system that changes slat orientation with respect to intensity or orientation of light from the front light transmissive cover.
18. The converter of claim 1, wherein the slat forward faces are concave to a sufficient degree to allow concentration of light onto the rear section of a nearby
- 20 slat.
19. The converter of claim 18, wherein the slat forward faces are parabolic.
20. The converter of claim 18, wherein the slat forward faces form a constant radius curve.
21. The converter of claim 18, wherein the slat forward faces form a progressive
- 25 curve.
22. The converter of claim 18, wherein the slat forward faces form a series of short planar or curved facets that act as a concave surface to incident light.
23. The converter of claim 18, wherein the slat forward faces are polished.
24. The converter of claim 18, wherein the section of the slat rear face that receives
- 30 reflected light is near the outer edge of the slat.
25. The converter of claim 1, further comprising a linkage mechanism that rotationally engages each slat and that coordinately swivels each slat so that the slats remain parallel.

26. The converter of claim 25, wherein one long edge of each slat is pivotally attached to the front light transmissive cover.
27. The converter of claim 25, wherein the slats are positioned horizontally and parallel to each other and wherein the linkage mechanism is flexible.
- 5 28. The converter of claim 27, wherein the linkage member is a chain or string.
29. The converter of claim 25, wherein the linkage mechanism comprises at least two flexible members, each attached to one or more common slats, to allow coordinated rotation by simultaneous movement of the at least two flexible members.
- 10 30. The converter of claim 29, comprising two flexible members.
31. The converter of claim 25, wherein each slat is attached to a hinge at the slat's inboard edge.
32. The converter of claim 1, wherein the rear cover of the enclosure is transparent.
33. The converter of claim 32, wherein the rear cover of the enclosure comprises  
15 single paned glass.
34. The converter of claim 32, wherein the rear cover of the enclosure comprises double paned glass.
35. The converter of claim 32, wherein the rear cover of the enclosure comprises multi-wall transparent extruded plastic.
- 20 36. The converter of claim 32 wherein the transparent back of the enclosure is made of light selective transmissive material that changes the spectral characteristics of transmitted light.
37. The converter of claim 1, comprising an infra-red absorbing interior surface.
38. The converter of claim 36, wherein the transparent back of the enclosure  
25 preferentially passes longer optical wavelengths.
39. The converter of claim 32, wherein the transparent back of the enclosure comprises an anti-reflection coating.
40. The converter of claim 32, wherein the slat geometry allows direct passage of at least some light incident to the front light transmissive cover to the rear.
- 30 41. The converter of claim 25, further comprising planer slats that lack photovoltaic energy converters and wherein the planer slats share a common linkage mechanism with slats that contain photovoltaic energy converters.
42. The converter of claim 1, further comprising a heat exchanger at one or more lateral ends of each row of slats.

43. The converter of claim 1, further comprising one or more heat exchangers in the heated air flow path.
44. The converter of claim 42 or 43, wherein the heat exchanger comprises a chamber with moving fluid therein and wherein a chamber surface is positioned  
5 within a path of heated air that moves transverse to the slats.
45. The converter of any of claims 1 to 44, wherein solar heat removed from the slats is applied to a desiccant for a dehumidification process.
46. The converter of any of claims 1 to 44, wherein solar heat removed from the slats is applied to a heat driven cooling system.
- 10 47. The converter of any of claims 1 to 44, wherein solar heat removed from the slats is applied to a heat engine.
48. The converter of any of claims 1 to 47, wherein the solar heat removed from the slats is circulated through a building.
49. The converter of claim 1, further comprising an air flow manifold at one or more  
15 lateral ends of the slats.
50. A system comprising two or more converter as described in claim 1, and a fan that is connected to move air in the two or more converters along the long length of the slats in their respective enclosures.
51. The system of claim 50, comprising two enclosures positioned in a common  
20 plane and that share an airway, wherein the edges of a first array of slats in one enclosure are arranged adjacent to the edges of a second array of slats in the second enclosure.
52. The converter of claim 51, comprising a means for simultaneously securing the collectors together and to a mounting structure, and for providing a substantially  
25 air tight seal from a shared internal cavity to the outside.
53. The converter of claim 1, wherein air moved along the slats by the forced air generator is recirculated to the slats.
54. The converter of claim 53, further comprising air ducts at either end of the slats to conduct air flow from the outlet of one row of slats to the inlet of an adjacent row.
- 30 55. The converter of claim 54, wherein the forced air generator is positioned between the rows and forces air through air ducts at either end of the slats.
56. The converter of claim 1, wherein the spacing between the front light transmissive cover and rear cover is less than two slat widths.

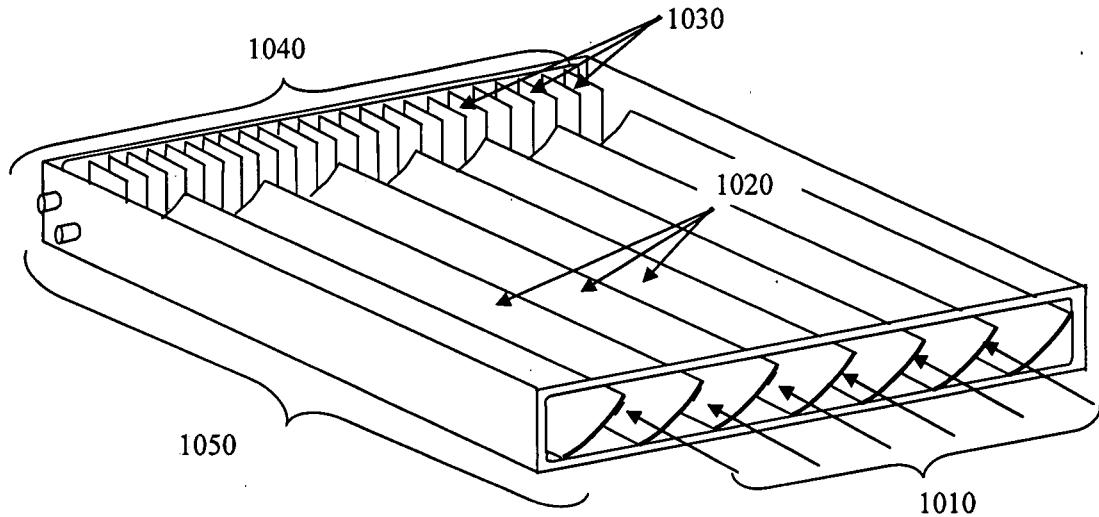
57. The converter of claim 1, further comprising protuberances on the inside surface of the front light transmissive cover that extend perpendicularly away from the front cover to obstruct air flow near the front cover surface.
58. The converter of claim 1, further comprising slat tip obstruction bars positioned operably near to the obstruction bars mounted on the transmissive cover, and oriented perpendicular to air flow.
59. The converter of claim 58, wherein the height of the cover protuberances and the height of the slat tip obstruction bars are approximately one third of the mean slat width.
60. The converter of claim 59, wherein the height of the cover protuberances and the height of the slat tip obstruction bars are between 15% to 60% of the mean slat width.
61. The converter of claim 58, wherein the cover protuberances and the slat tip obstruction bars are positioned with their inward facing surfaces within one slat width apart.
62. The converter of claim 1, wherein the shape of the air slots in the edge of the collector are adapted to facilitate air flow near the slats, by maintaining position of air flow apertures near the slats as the slat orientation angle with respect to the front light transmissive cover surface changes.
63. The converter of claim 1, wherein the front light transmissive cover is removable.
64. The converter of claim 1, wherein the front light transmissive cover comprises an anti-reflective coating.
65. The converter of claim 1, wherein the front light transmissive cover comprises low iron glass.
66. The converter of claim 1, wherein the front light transmissive cover comprises a high impact resistance material.
67. An automated system that responds to energy input or demand for a heat load, comprising the converter of claim 1, and further comprising a computer, at least one sensor for detecting at least light or temperature, and at least one signal output to an actuator for adjusting slat position.
68. The automated system of claim 67, further comprising a light sensor located in the enclosure interior.
69. The automated system of claim 67, further comprising a feedback circuit or software that responds to output from the light sensor in the enclosure interior by

adjusting slat position to maintain a constant light level within the enclosure interior.

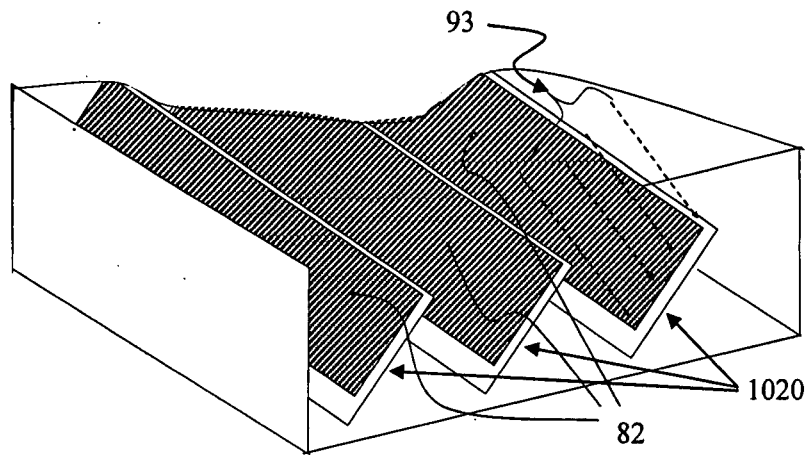
70. The automated system of claim 67, wherein the heat load is a building that comprises a temperature sensor within, and wherein a signal from the building temperature sensor is input to the computer for control of slat position to maintain a desired temperature.
71. The automated system of claim 67, wherein the heat load is a building and the front light transmissive cover is integrated as part of a building's weather envelope.
72. The automated system of claim 71, wherein the front light transmissive cover is a skylight of the building.
73. The automated system of claim 71, wherein the front light transmissive cover is a wall of the building.
74. The converter of claim 18 further comprising planer slats that lack photovoltaic energy converters and that are oriented substantially perpendicular to the front light transmissive cover, and wherein the planer slats share a common linkage mechanism with slats that contain photovoltaic energy converters.
75. The converter of claim 74 positioned as a window beneath a ceiling with horizontal slats, wherein the planer slats preferentially are located at the top of the window to guide direct sunlight near the ceiling.
76. The converter of claim 1, wherein the slat forward faces are concave to a sufficient degree to allow concentration of light onto rear sections of nearby slats and further comprising flexible linkages between the slats to allow stacking of the slats for transportation.
77. The converter of claim 1, further comprising an automated focus system comprising a flexible linkage to the slats and a sensor control wherein light intensity is used to adjust slat orientation via actuation of the flexible linkage.

30

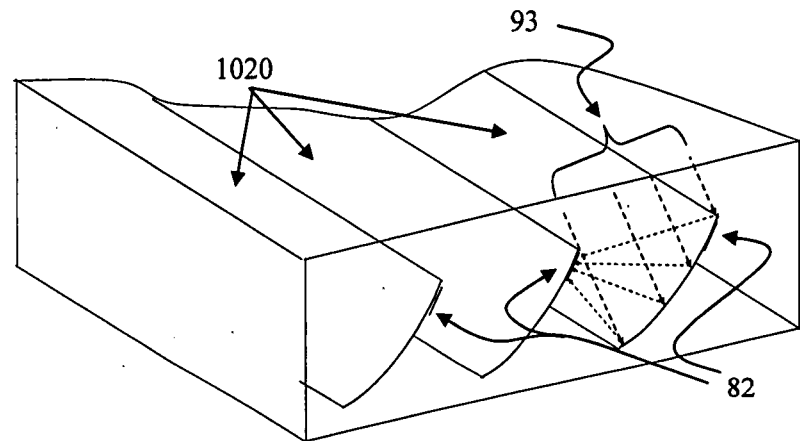
1/12  
**Figure 1a**



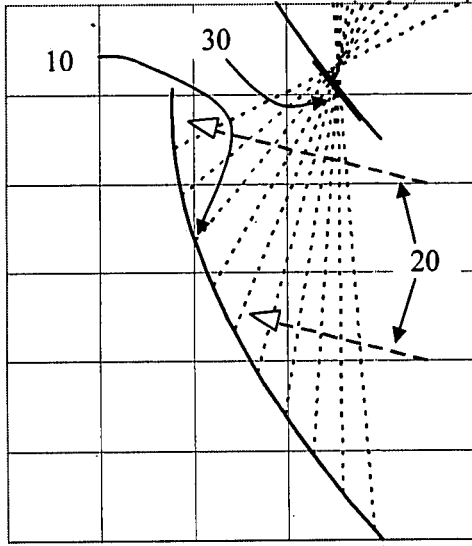
**Figure 1b**



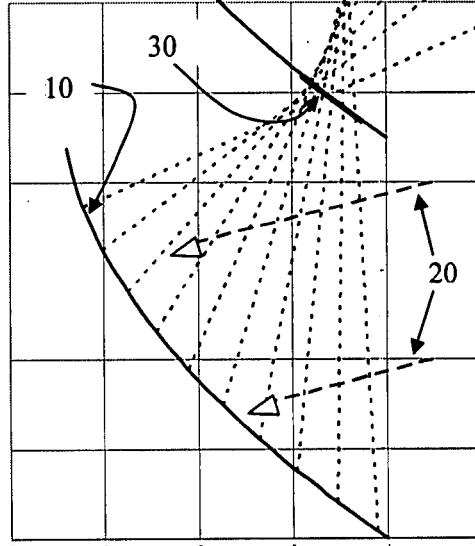
**Figure 1c**



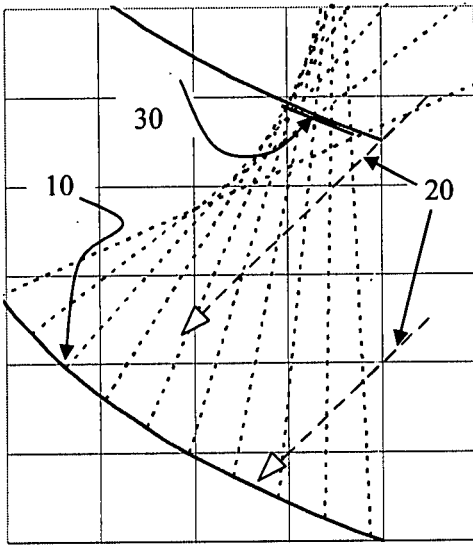
**Figure 2a**



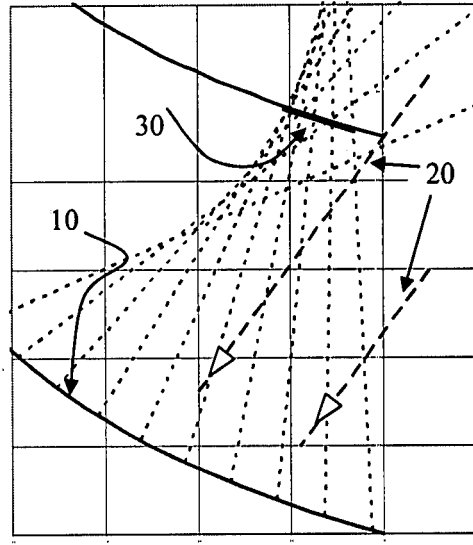
**Figure 2b**



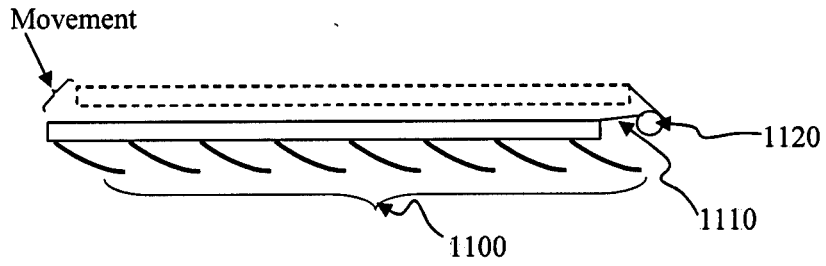
**Figure 2c**



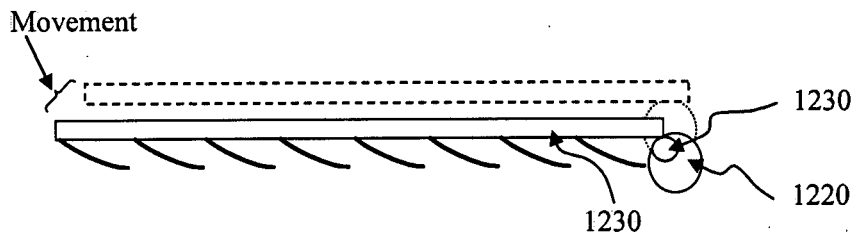
**Figure 2d**



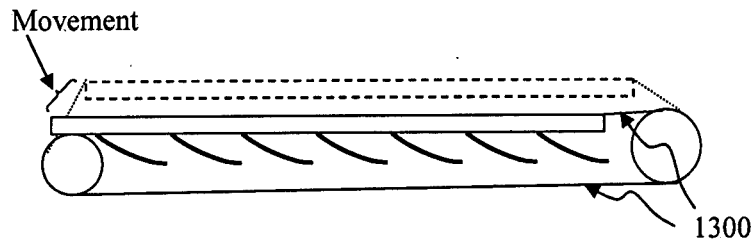
**Figure 3a**



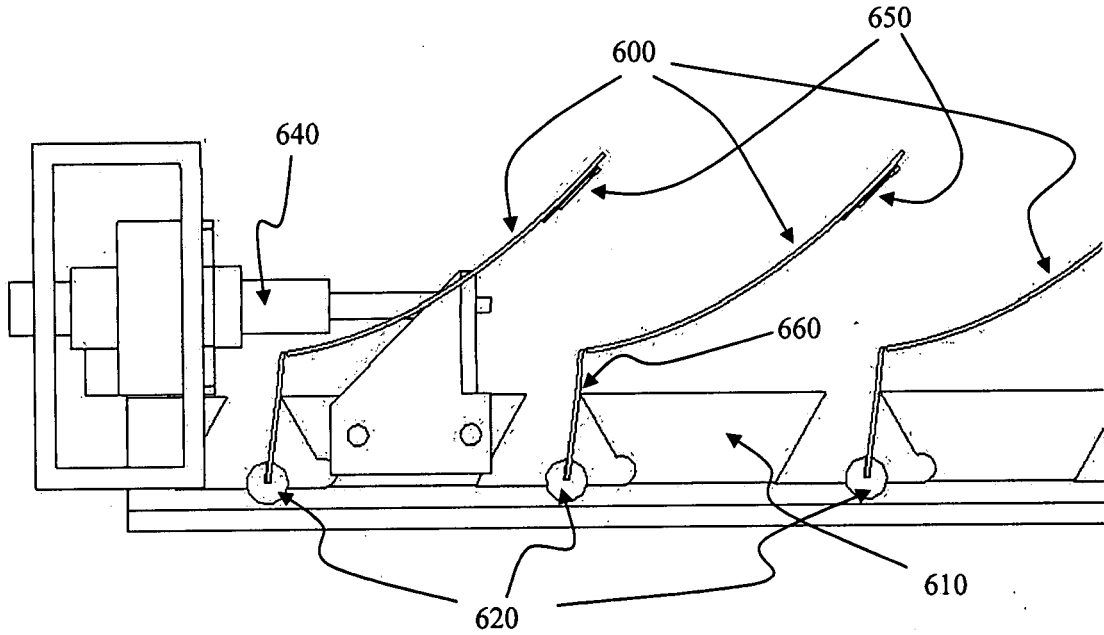
**Figure 3b**



**Figure 3c**



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**Figure 4a**



**Figure 4b – view from under slats**

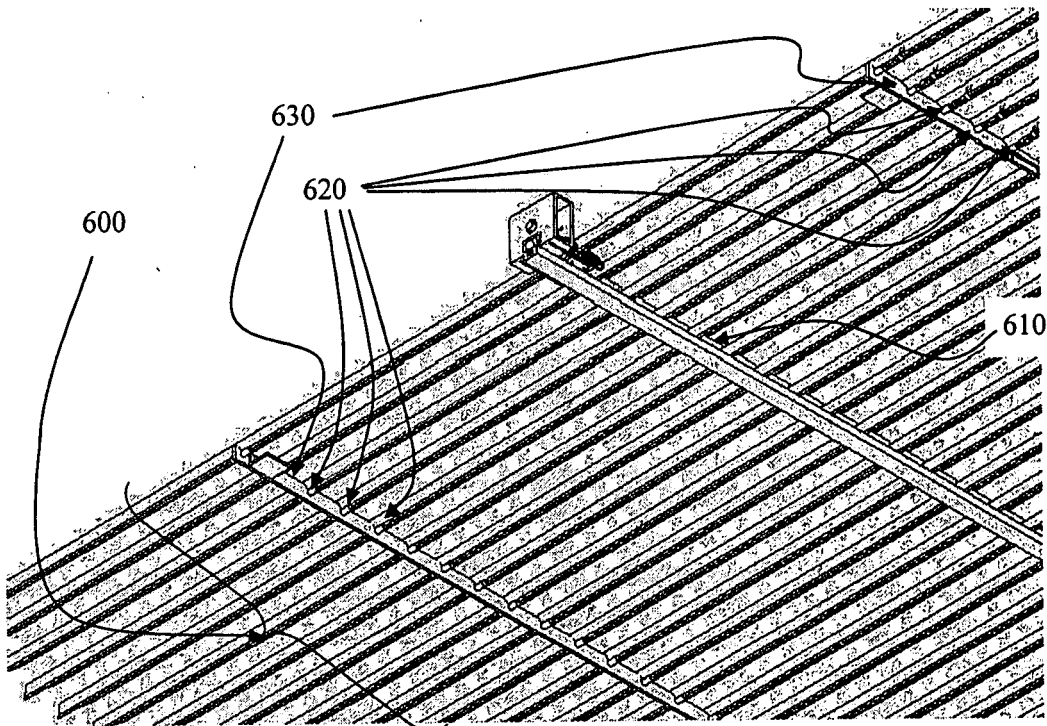


Figure 5a

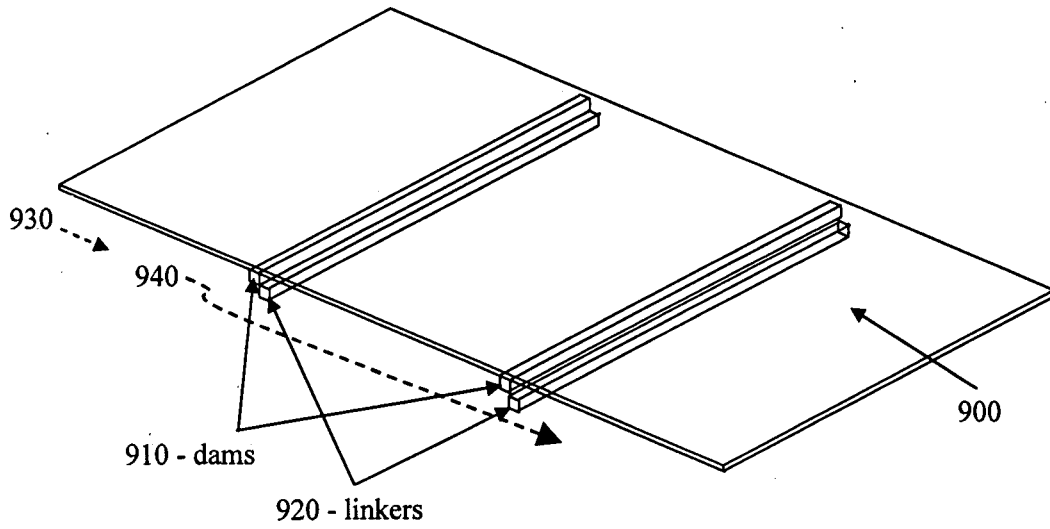
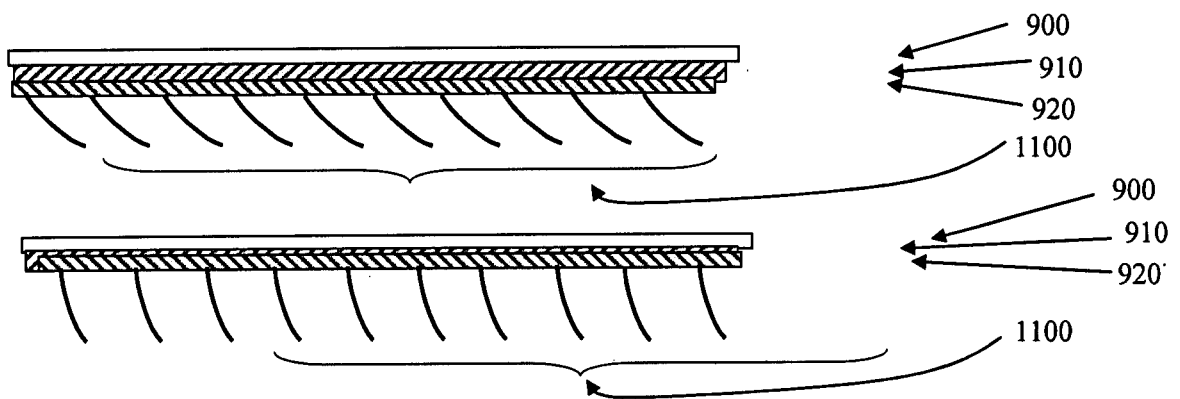
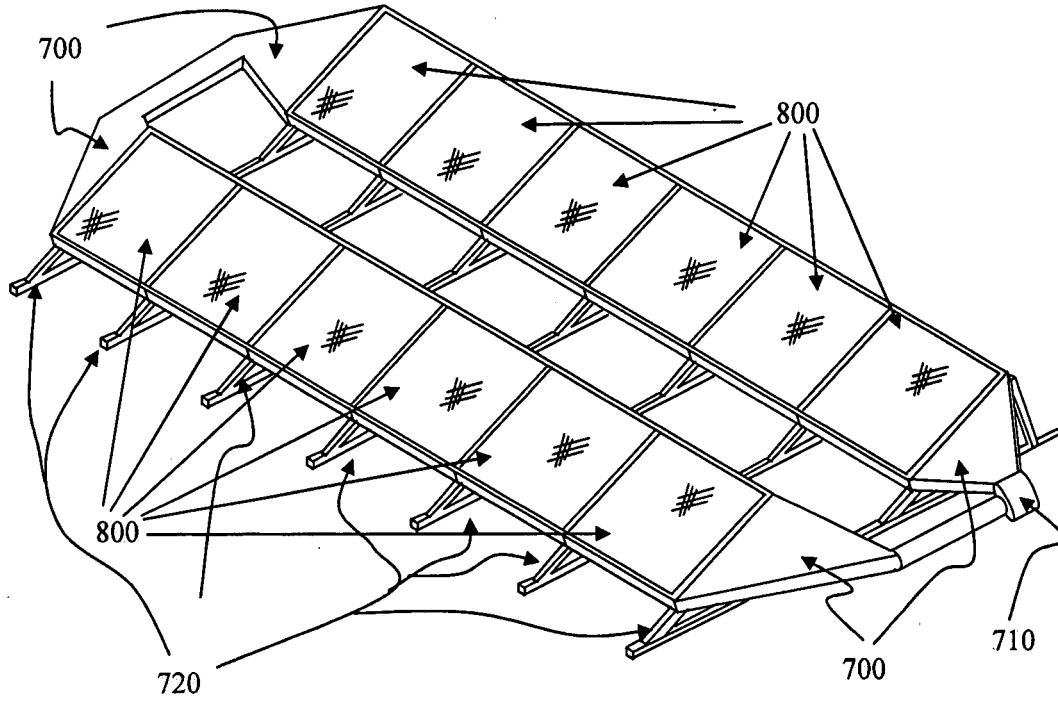


Figure 5b

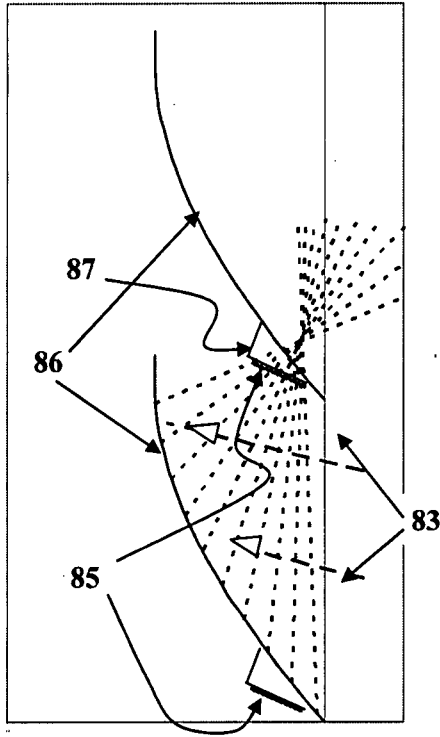


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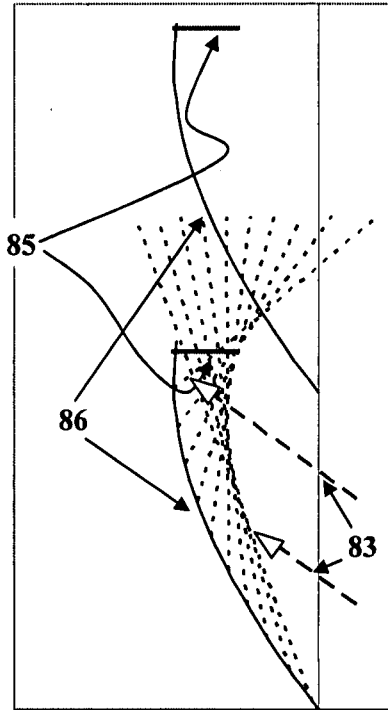
**Figure 6**



**Figure 7a**

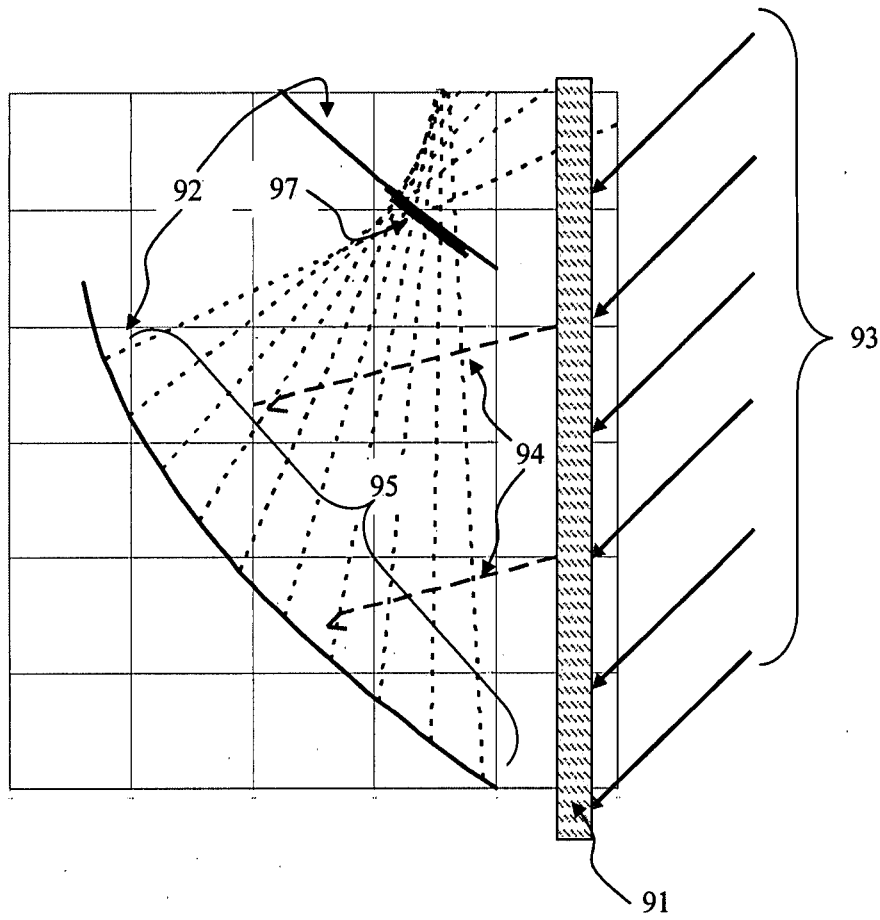


**Figure 7b**



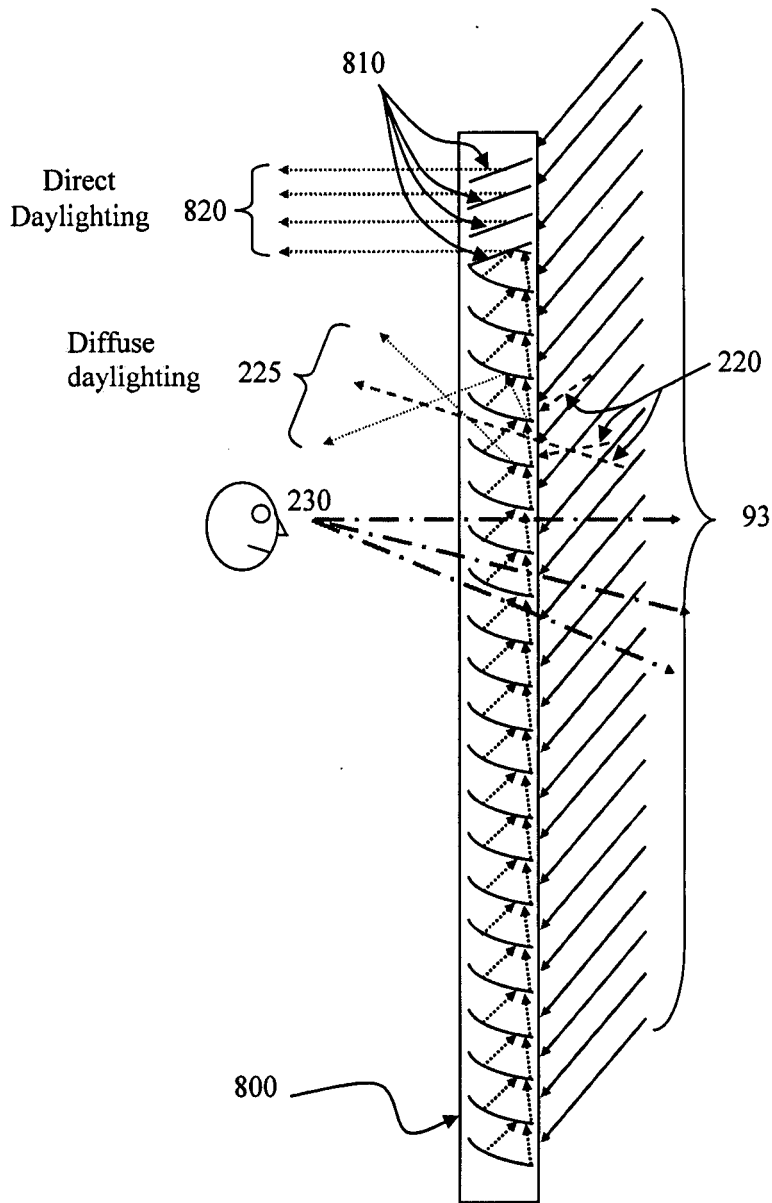
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Figure 8

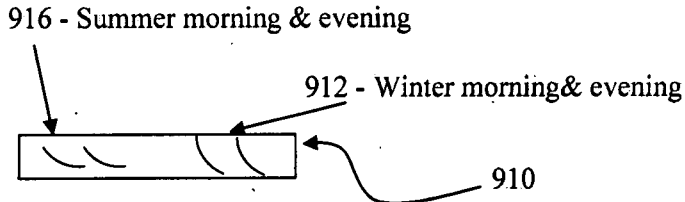


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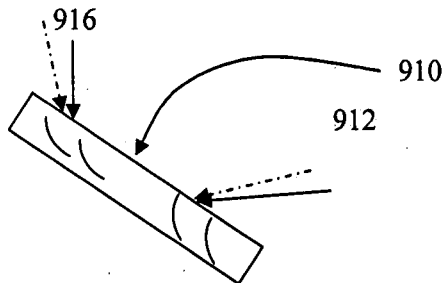
Figure 9



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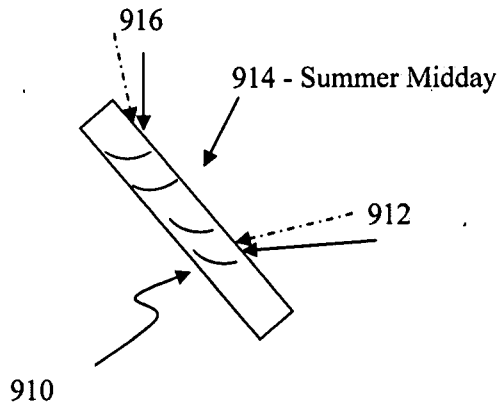


**Figure 10a**

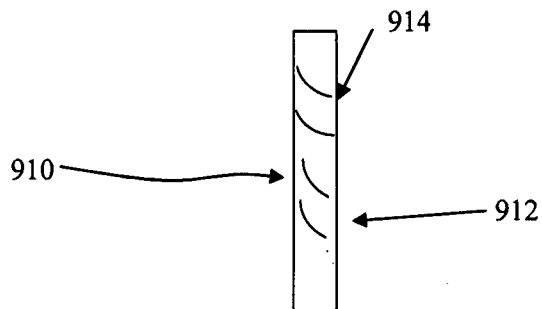


**Figure 10b**

South (Equator)



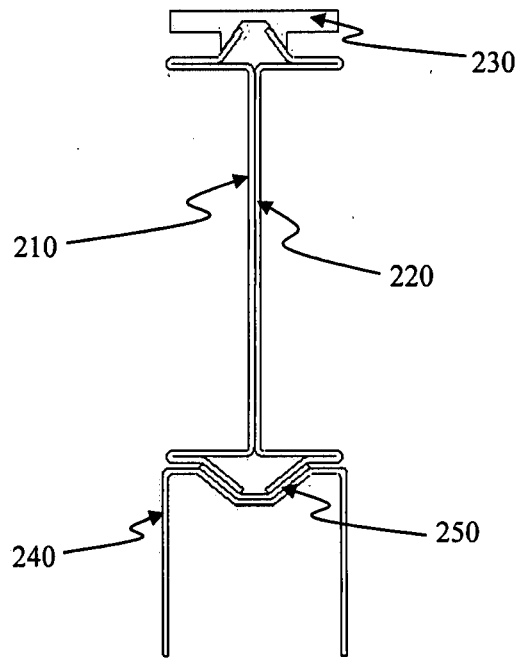
**Figure 10c**



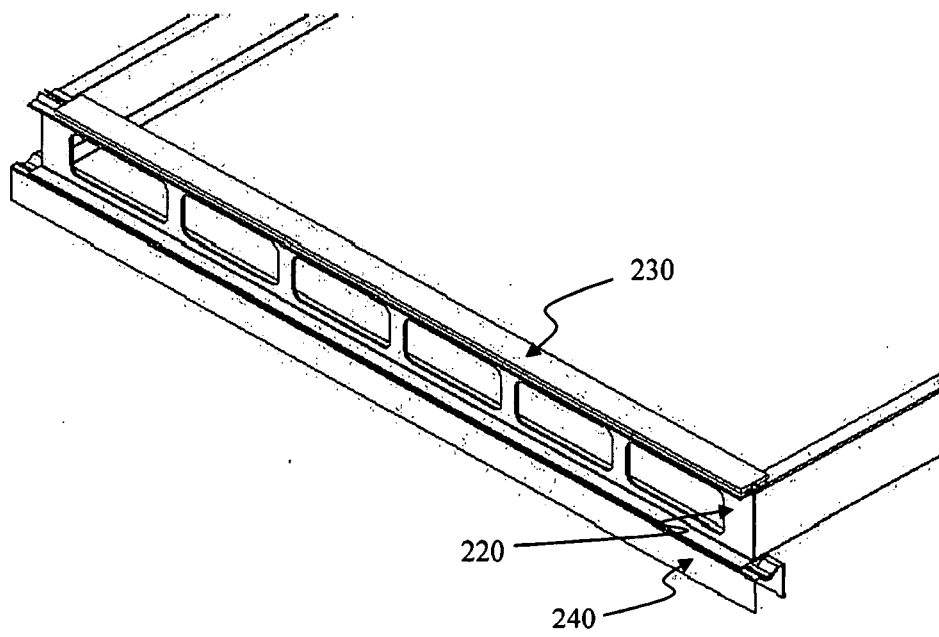
**Figure 10d**

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**Figure 11a**

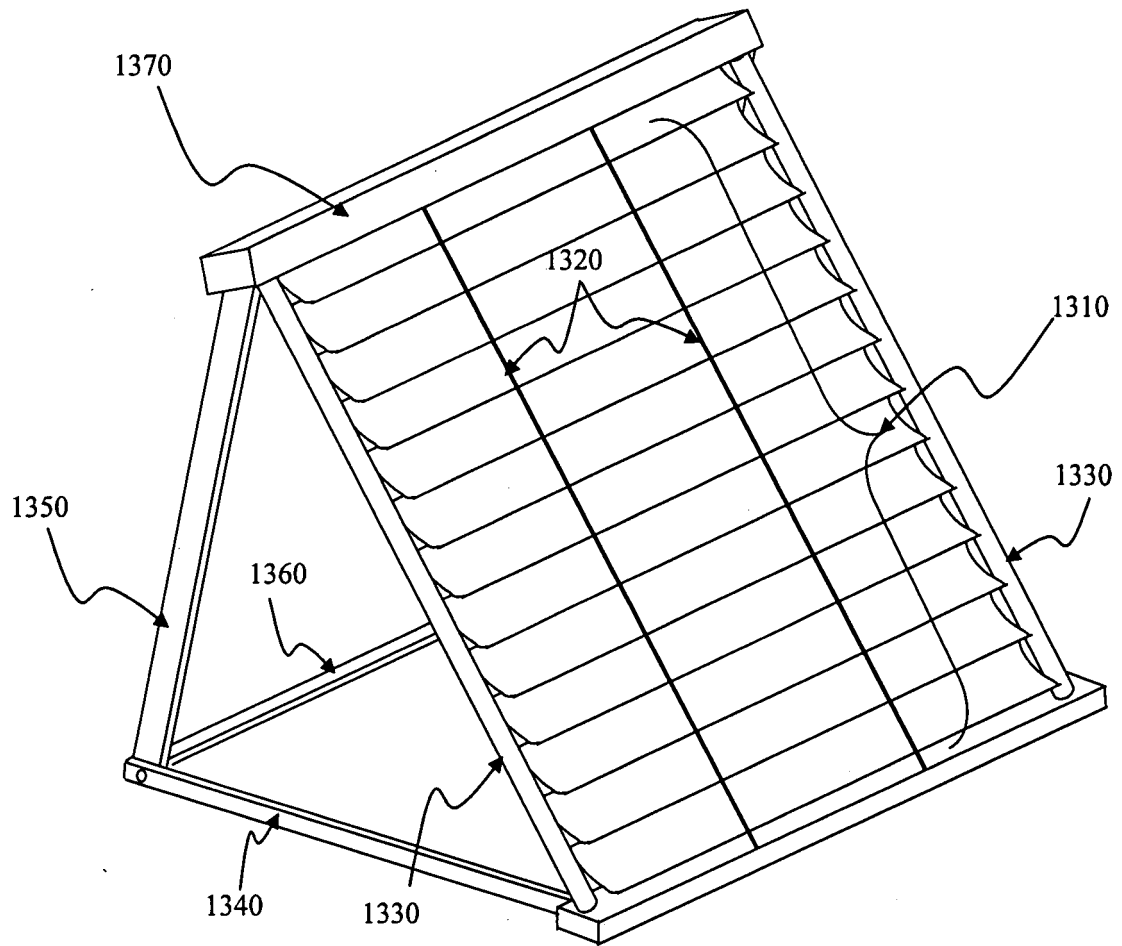


**Figure 11b**



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**Figure 12**



INTERNATIONAL SEARCH REPORT

International application No.  
PCT/US 07/73135

**A. CLASSIFICATION OF SUBJECT MATTER**  
 IPC(8) - F24J 2/04, F24J 2/40, C02F 1/14 (2008.04)  
 USPC - 126/647; 126/629, 203/11  
 According to International Patent Classification (IPC) or to both national classification and IPC

**B. FIELDS SEARCHED**

Minimum documentation searched (classification system followed by classification symbols)  
 IPC(8) - F24J 2/04, F24J 2/40, C02F 1/14 (2008.04)  
 USPC - 126/647; 126/629, 203/11

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched  
 IPC(8) - F24J 2/04, F24J 2/40, C02F 1/14 (2008.04)  
 USPC - 126/647; 126/629, 203/11

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)  
 PubWEST, Google Patents Database, Google Scholar Database (electromagnetic, energy, harvest, light, transmit, cover, front, rear, air, forced, solar, heat, slat, fan, HVAC, pivot, concave, parabolic, curve, polish, photovoltaic, parabolic, glass, pane, desiccant, dehumidify, skylight, wall, sensor, output, focus, system)

**C. DOCUMENTS CONSIDERED TO BE RELEVANT**

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
Y	US 6,372,978 B1 (Cifaldi) 16 April 2002 (16.04.2002), Fig 1, 2; col 1, ln 25-28, ln 54-56; col 3, ln 3-6, ln 20-22; col 4, ln 1-12, ln 34-39, ln 61-62; col 5, ln 1-11, ln 14-16, ln 19-24; col 6, ln 1-6, ln 8-12, ln 29-33; col 7, ln 9-15, ln 67; col 8, ln 1-2, ln 10-15	1-44, 49-77
Y	WO 2002/016707 A1 (Dinwoodie et al.) 28 February 2002 (28.02.2002), Fig 14; pg 7, ln 4-8	1-44, 49-77
Y	US 4,520,794 A (Stark et al.) 04 June 1985 (04.06.1985) Fig 1, 5, 7; col 3, ln 16-18, ln 24-26, ln 37-38; col 4, ln 3-4, ln 55-67; col 5, ln 3-4, ln 15-22, ln 31-36, ln 51-55, ln 62-63; col 6, ln 1-3, ln 6-12, ln 22-25, ln 32-45, col 7, ln 3-6, ln 9-16, ln 18-22, ln 24-39, ln 41-45, ln 51-53; col 8, ln 8-10, ln 15-21, ln 55-59	1-44, 49-77
Y	US 2003/0038610 A1 (Munshi et al.) 27 February 2003 (27.02.2003), para [0114]	16
Y	US 6,528,782 B1 (Zhang et al.) 04 March 2003 (04.03.2003); col 5, ln 37-40	38

Further documents are listed in the continuation of Box C.

* Special categories of cited documents:	"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention
"A" document defining the general state of the art which is not considered to be of particular relevance	"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone
"E" earlier application or patent but published on or after the international filing date	"Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art
"L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)	"&" document member of the same patent family
"O" document referring to an oral disclosure, use, exhibition or other means	
"P" document published prior to the international filing date but later than the priority date claimed	

Date of the actual completion of the international search 06 November 2008 (06.11.2008)	Date of mailing of the international search report <b>24 NOV 2008</b>
Name and mailing address of the ISA/US Mail Stop PCT, Attn: ISA/US, Commissioner for Patents P.O. Box 1450, Alexandria, Virginia 22313-1450 Facsimile No. 571-273-3201	Authorized officer <i>B. Young</i> Lee W. Young PCT Helpdesk: 571-272-4300 PCT OSP: 571-272-7774

INTERNATIONAL SEARCH REPORT

International application No.

PCT/US 07/73135

**Box No. II Observations where certain claims were found unsearchable (Continuation of item 2 of first sheet)**

This international search report has not been established in respect of certain claims under Article 17(2)(a) for the following reasons:

1.  Claims Nos.:  
because they relate to subject matter not required to be searched by this Authority, namely:
  
2.  Claims Nos.:  
because they relate to parts of the international application that do not comply with the prescribed requirements to such an extent that no meaningful international search can be carried out, specifically:
  
3.  Claims Nos.: 45-48  
because they are dependent claims and are not drafted in accordance with the second and third sentences of Rule 6.4(a).

**Box No. III Observations where unity of invention is lacking (Continuation of item 3 of first sheet)**

This International Searching Authority found multiple inventions in this international application, as follows:

1.  As all required additional search fees were timely paid by the applicant, this international search report covers all searchable claims.
2.  As all searchable claims could be searched without effort justifying additional fees, this Authority did not invite payment of additional fees.
3.  As only some of the required additional search fees were timely paid by the applicant, this international search report covers only those claims for which fees were paid, specifically claims Nos.:
  
4.  No required additional search fees were timely paid by the applicant. Consequently, this international search report is restricted to the invention first mentioned in the claims; it is covered by claims Nos.:

- Remark on Protest**
- The additional search fees were accompanied by the applicant's protest and, where applicable, the payment of a protest fee.
  - The additional search fees were accompanied by the applicant's protest but the applicable protest fee was not paid within the time limit specified in the invitation.
  - No protest accompanied the payment of additional search fees.