Nov. 12, 1957 R. A. BOYD 2,812,690

SKYLIGHTS

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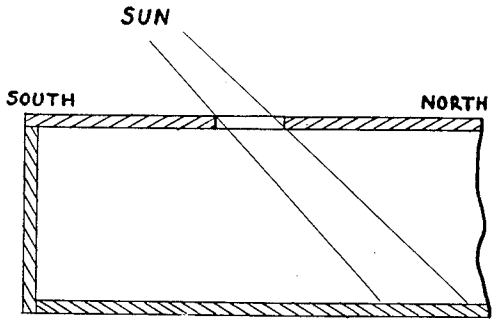


FIG-1-

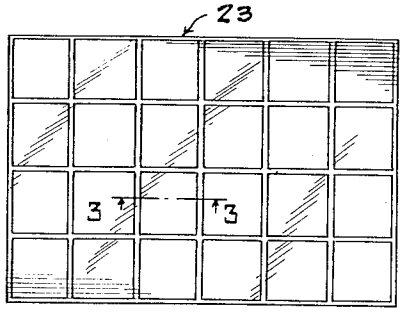


FIG-2-

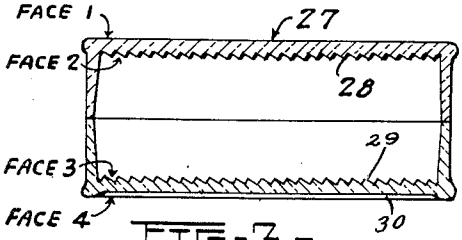


FIG-3-

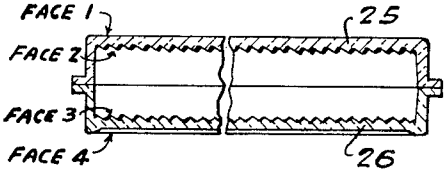


FIG-4-

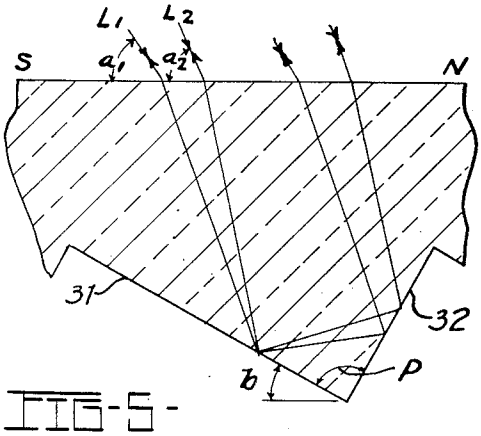


FIG-5-

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SKYLIGHTS

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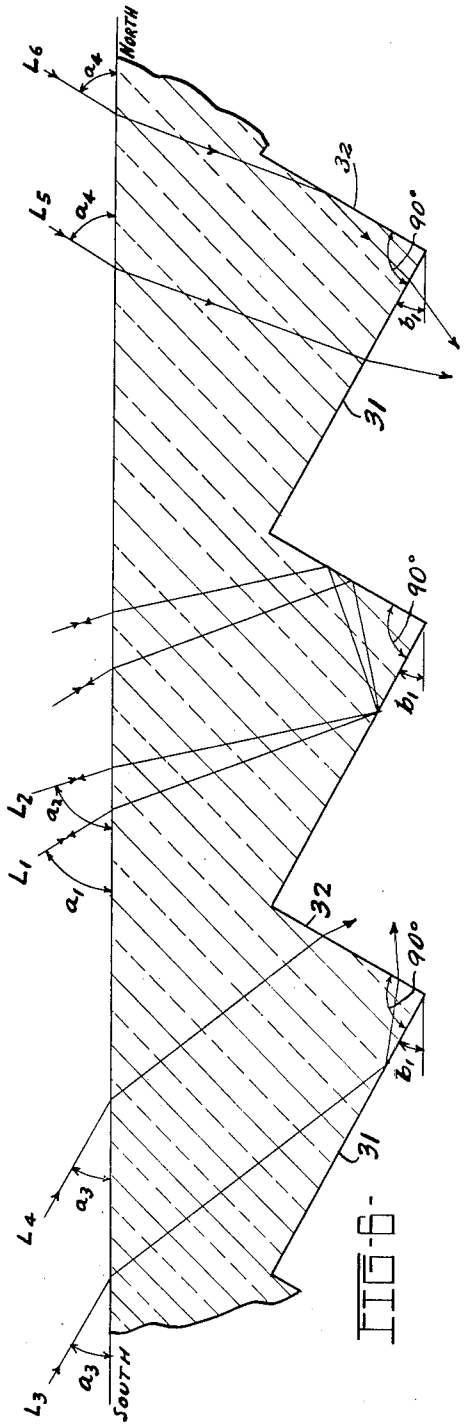


FIG-6-

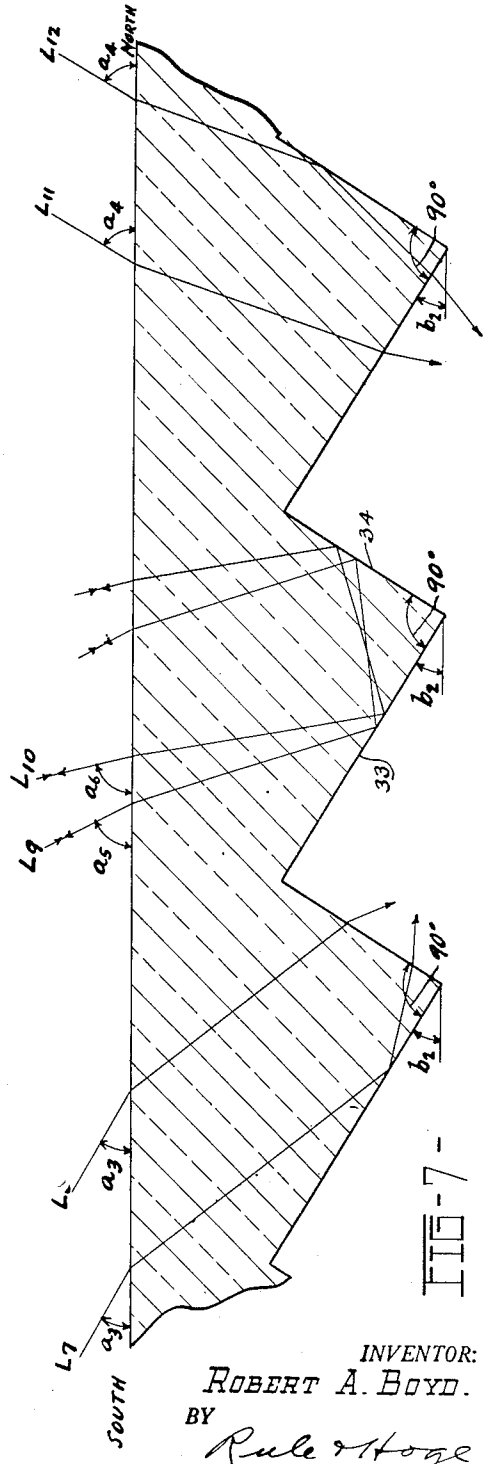


FIG-7-

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SKYLIGHTS

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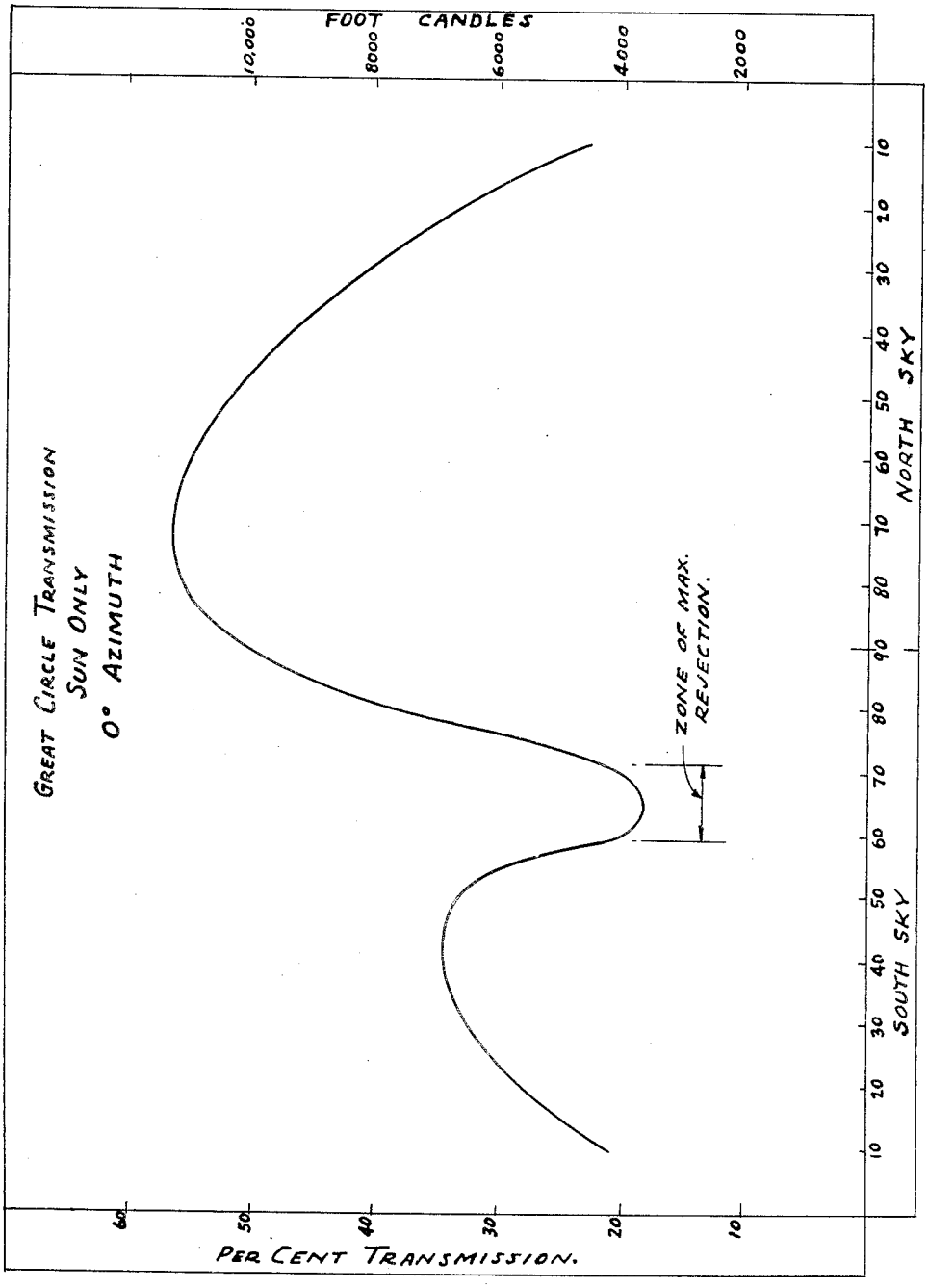


FIG-4-

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SKYLIGHTS

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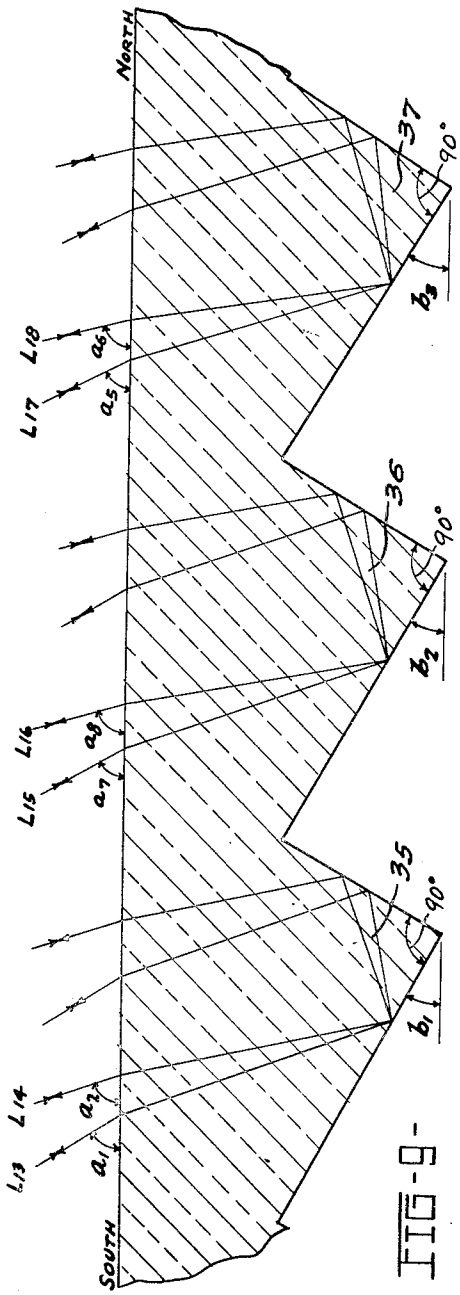


FIG-9-

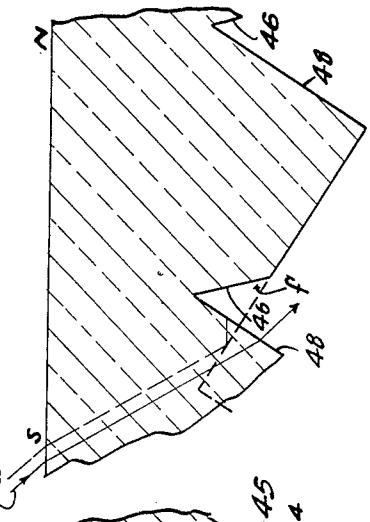


FIG-12-

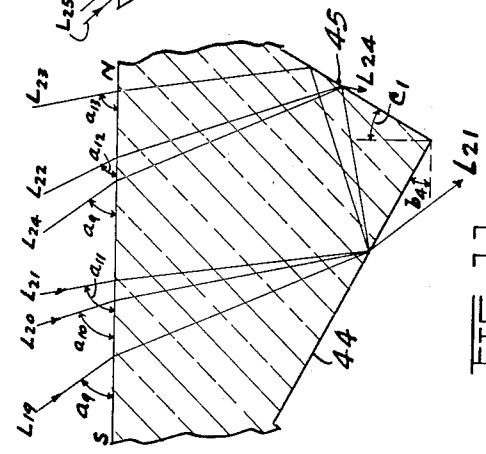


FIG-11-

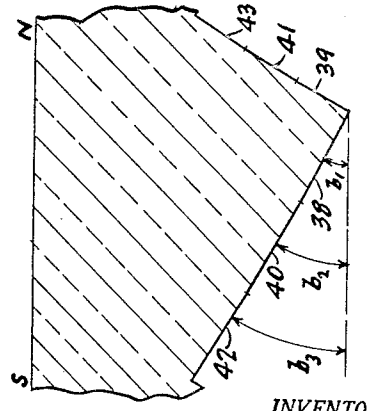


FIG-10-

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2,812,690

SKYLIGHTS

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Application June 26, 1952, Serial No. 295,730

11 Claims. (Cl. 88—59)

This invention relates to the utilization of daylight for lighting the interior of buildings through an opening in a roof or ceiling.

A major problem in utilization of daylight through an opening in a roof or ceiling is that the direct sunlight from high altitudes provides an excessive amount of light and heat. This condition is especially present during the summer months when the sun is at the higher altitudes. It is, of course, well known that the altitudes of the sun vary with the seasons of the year and also with the various latitudes.

It is therefore an object of this invention to provide a skylight which rejects direct sunlight from high altitudes and transmits light from the low altitudes and the northern sky.

Other objects of the invention will appear hereinafter.

Basically my invention comprises controlling the transmission of daylight by using four air-glass interfaces such as are present in a hollow glass block or in two spaced sheets of glass. In such a structure the interfaces are conventionally termed Faces **1**, **2**, **3**, and **4**—Face **1** being the exterior interface, Faces **2** and **3** being the interior interfaces, and Face **4** being the interface nearest the interior of the room. According to my invention, Face **1** is provided with a smooth surface or a series of longitudinal ribs extending in a generally north-south direction. Face **2** is provided with a series of parallel prisms extending in a generally east-west direction. Faces **3** and **4** are provided with ribs or are opalescent in order to diffuse the transmitted light into the interior being lighted.

The prisms on Face **2** are so constructed and arranged that direct sunlight at high altitudes from a southerly direction is rejected whereas light from the low altitudes and the northern sky is transmitted.

Referring to the accompanying drawings:

Fig. 1 is a cross sectional elevational view of a room showing the excessive sunlight from the sun at the higher altitudes;

Fig. 2 is a plan view of a skylight made of glass blocks;

Fig. 3 is a sectional view of a hollow block at the line **3**—**3** on Fig. 2;

Fig. 4 is a cross sectional view of a skylight comprising two sheets of glass and incorporating my invention;

Fig. 5 is a fragmentary cross sectional view of Faces **1** and **2** on a greatly enlarged scale, showing the path of light rays from high altitude angles;

Fig. 6 is a fragmentary cross sectional view of Faces **1** and **2** on a greatly enlarged scale, showing the path of light rays from various angles in the sky;

Fig. 7 is a cross sectional view on a greatly enlarged scale of a modified form of the prisms on Face **2**, showing the path of the light rays from various angles in the sky;

Fig. 8 is a curve of great circle transmission obtained by testing the form of the invention shown in Fig. 6;

Fig. 9 is a cross sectional view on a greatly enlarged scale of another form of the prism on Face **2**, showing the path of the light rays from various angles in the sky;

Fig. 10 is a cross sectional view on a greatly enlarged scale of another form of the prism on Face **2**;

Fig. 11 is a cross sectional view on a greatly enlarged scale of another form of the prism on Face **2**, showing the path of the light rays from various angles of the sun and;

Fig. 12 is a cross sectional view on a greatly enlarged scale of a modified form of the prisms on Face **2**, showing the path of the light rays from various angles of the sun.

The problem of illumination through an opening in a ceiling or roof may be illustrated by referring to a typical room. As shown in Fig. 1, sunlight passing through a vertical opening **20** in ceiling **21** emanates from a southerly direction (in the northern hemisphere). At high altitude angles of the sun, the amount of light and heat emanating therefrom is excessive and undesirable. This is shown more clearly by the following table of meteorological data representing conditions at 42° N. latitude.

TABLE I

Day of Year	Maximum Sun Altitude, degrees	Normal Sun Intensity (ft.-c.)	Horizontal Surface Illumination	
			Sun Only (ft.-c.)	Clear Sky
June 21	71½	9,180	8,700	1,600
May 21 and July 21	68½	9,070	8,400	1,500
Apr. 21 and Aug. 21	60	8,900	7,700	1,400
Mar. 21 and Sept. 21	48½	8,800	6,600	1,200
Feb. 21 and Oct. 21	37½	8,250	5,000	1,000
Jan. 21 and Nov. 21	28	7,500	3,500	800
Dec. 21	24½	7,000	2,900	800

As shown in Table I, the sun altitude and the normal sun intensity vary throughout the year, the maximum occuring during the months from April through August. Table I further indicates that the greater portion of the horizontal surface illumination is due to light from the sun and a small portion is due to the clear (northern) sky.

I have found that the desired control of illumination through a vertical opening may be obtained by interposing four air-glass interfaces between the light source and the interior. Referring to Fig. 2, the skylight **23** may consist of a series of blocks **24**.

As shown in Figs. 3 and 4, the four air-glass interfaces may be found in a glass block **24** or in two spaced sheets of glass **25**, **26**. In such structures the interfaces are conventionally referred to as Faces **1**, **2**, **3**, and **4**—Face **1** being the exterior interface, Faces **2** and **3** being the interior interfaces, and Face **4** being the interface nearest the interior of the room.

According to my invention as shown in Figs. 3 and 4, Face **1** is provided with a smooth surface **27** or a series of longitudinal ribs. Face **2** is provided with a series of parallel prism shaped ribs **28**, hereinafter called prisms, having particular configurations as hereinafter described and having their axes extending in a generally east-west direction. Faces **3** and **4** may be provided with a series of ribs **29** and **30** respectively at right angles to each other. The ribs **29** and **30** have a configuration such that daylight transmitted thereto is diffused into the interior of the room.

According to my invention, sunlight from high altitude angles is refracted by Face **1** and totally internally reflected at Face **2** and thereby rejected. More specifically, as shown in Fig. 5, the prisms **28** on Face **2** extend in an east-west direction and have surfaces **31**, **32** at an included angle P. I have determined the most satisfactory included angle P is 90°. As shown in Fig. 5 the surface **31** is at an angle *b* to a horizontal plane. The surface **32** faces a southerly direction.

A light ray L_1 at sun altitude angle a, is refracted at Face **1**, transmitted to and reflected at surface **31** to surface **32**, and finally reflected to Face **1** and refracted out to the atmosphere. Similarly a light ray L_2, at an angle a_2, is refracted, totally internally reflected, and finally refracted to the atmosphere. In a similar manner, light rays at angles a_1 and a_2 striking the northern slope or surface **32** are totally internally reflected. This is represented on Fig. 5 by the double arrows. Altitude angles of the sun less than a_1 or greater than a_2 are not totally internally reflected. It may be observed from Fig. 5 that the particular configuration of the prisms on Face **2** provides a range of angle, a_1 through a_2, at high altitudes from which sunlight is completely and entirely rejected.

The in corporation of the prism structure shown in Fig. 5 in a skylight construction may be more clearly represented by referring to Fig. 6. It may be observed that a ray of sunlight L_3 from a low altitude angle a_3 is refracted at Face **1**, reflected at surface **31** to surface **32**, and refracted out of surface **32**. Similarly a light ray L_4 at the same altitude angle a_3 is refracted at Face **1** and again refracted at surface **32**. A light ray L_5, representing light from the northern sky at an angle a_4 is refracted at Face **1** and at surface **31** toward the interior. A similar light ray L_6 is refracted at Face **1**, reflected at surface **32**, and refracted at surface **31** toward the interior.

As shown in Fig. 6, the construction of the prisms on Face **2** rejects the sunlight from the high altitude angles and permits sunlight from the low altitude angles and light from the northern sky to be transmitted toward the interior.

I have determined that for a latitude of 42° N. the angle b, which the surface **31** forms with a horizontal plane, is preferably 29°. After constructing a skylight in accordance with my invention, with the angle P equal to 90° and the angle b equal to 29°, and conducting illumination tests thereon the curve of great circle illumination shown in Fig. 8 is obtained. This curve represents the percent of light transmitted at various sun altitudes for the construction, measured along a great circle.

As shown in Fig. 8, there is an area or zone ranging between approximately 59° to 72° of sun altitude at which maximum rejection of the direct sunlight is obtained. This zone of rejection extends for approximately 13° when $P=90°$. It may be noted that this range of approximately 13° is slightly greater than the range of the high altitude angles of the sun which are present from April through August as shown in Table I, namely, $71\frac{1}{2}°-60°=11\frac{1}{2}°$.

The effectiveness of my invention may be more clearly shown by referring to the following table representing the results obtained by testing the construction shown in Fig. 6, the angle P being equal to 90° and the angle b equal to 29°.

TABLE II

Sun Altitude	Horizontal Surface Illumination, Sun Only	Percent Transmission	Lumens Transmitted, per sq. ft.
71½	8,700	14.0	1,220
68½	8,400	12.5	1,050
60	7,700	12.5	960
48½	6,600	22.0	1,450
37½	5,000	21.5	1,070
28	3,500	18.5	650
24½	2,900	17.5	510

This table indicates that the configuration of the ribs on Face **2** in accordance with the invention causes the rejection of the direct sunlight particularly from the sun altitudes ranging from 60 to 71½°. It may be observed that the amount of light transmitted is lowered to an amount which is less than the horizontal surface illumination from the northern sky, as shown in the right hand column in Table I.

A modified form of the prisms on Face **2** is shown in Fig. 7. In this form the surfaces of the prisms, **33**, **34**, have been changed in slope, thus in effect shifting or rotating the position of the 90° prism about its east-west axis. The surface **33** forms an angle b_2 with a horizontal plane, the angle b_2 being greater than the angle b_1 in the form of the invention shown in Fig. 6. By such a construction a light ray L_9 at an altitude angle a_5 is refracted and totally internally reflected in the prism and finally rejected to the atmosphere. In a similar manner a light ray L_{10} at an altitude angle a_6 is rejected. These light rays as in the previous form of the invention may first strike either the surface **33** or the surface **34**. This condition is indicated by the double arrows. Light rays L_7, L_8 from low altitude angles and light rays L_{11}, L_{12} from the northern sky are subjected to substantially the same action as in the form of the invention shown in Fig. 6.

Contrasting the construction in Fig. 7 with that in Fig. 6, it is found that a_5 is greater than a_1 and a_6 is greater than a_2. This indicates that by increasing the angle b, which one surface, the southern slope, of the prism makes with a horizontal plane, the area or zone of rejection of light rays from high altitude angles of the sun may be changed and shifted to include higher altitude angles. If the construction shown in Fig. 7 were made, for example, with the angle b_2 equal to 31½° it would be found that the zone of rejection of light rays would range from $a_5=62\frac{1}{2}°$ to $a_6=75\frac{1}{2}°$. If the curve of great circle illumination similar to that shown in Fig. 8 were drawn, it would be found that the zone of maximum rejection would be shifted to the right by this increase in the angle b. Moreover a reference to the standard meteorological table indicates that the maximum sun altitude of 75½°, which is rejected by the construction in Fig. 7, is comparable to the maximum sun altitude at a latitude of 37° N.

It may thus be seen that a change in the angle b will cause a shifting or change in the 13° area of rejection of high sun altitudes. In accordance with my invention a prism construction may be designed for any particular latitude; by increasing the angle b the maximum altitude of rejection may be increased, this being necessary to compensate for the lower latitudes; by decreasing the angle b the maximum altitude of rejection may be lessened, this being necessary in the higher latitudes.

The concepts of my invention may be utilized to provide a structure which is universally applicable to various latitudes. Such result may be obtained by a construction having a series of 90° prisms in which the angle b varies for each prism in a series. In Fig. 9, each series consists of three prisms, prism **35** being at the angle b_1, prism **36** at the angle b_2 and prism **37** at the angle b_3; b_3 being greater than b_2 which in turn is greater than b_1. According to my invention as heretofore discussed, the maximum altitude angle of rejection of prism **35** will be less than that of prism **36**, which in turn will be less than that of prism **37**.

More specifically, light rays L_{13} and L_{14} at altitude angles a_1, a_2 are rejected by prism **35**; light rays L_{15} and L_{16} at altitude angles a_7, a_8 are rejected by prism **36**, and light rays L_{17}, L_{18} at altitude angles a_5, a_6 are rejected by prism **37**. The relationship of the altitude angles would be as follows: a_5 greater than a_7, which in turn is greater than a_1; a_6 greater than a_8 which in turn is greater than a_2.

The prism **35** would reject sunlight from lower sun altitudes, such as are found in the higher latitudes; prism **36** would reject sunlight from intermediate sun altitudes, such as are found in intermediate latitudes; and prism **37** would reject sunlight at the highest sun altitudes such as are found in the lower latitudes. It may thus be seen that a series of prisms at varying angles may be constructed to reject the sunlight over a broad range of sun

altitudes. The following table represents the resultant areas of rejection of sun altitudes which may be obtained by a typical construction.

TABLE III

b	Sun Altitude Rejected
b_1=29°	a_1–a_2=58½°–71½°
b_2=30°	a_7–a_8=60½°–73½°
b_3=31½°	a_5–a_6=62½°–75½°

This table indicates that by specifying the angles b_1, b_2, and b_3 as indicated, the zone of rejection of sun altitudes may be in effect broadened and thereby extend from 58½° to 75½°. Table III shows that there will be total rejection of sunlight at altitude angles 62½°–71½° and partial rejection of sunlight at altitude angles 58½°–62½° and 71½°–75½°. It should be thus noted that the effect of having a series of prisms at various angles will be to diminish the amount of light rejected for any particular sun altitude. Thus, although the range of sun altitude partially rejected may increase, the range of altitude of sun totally rejected will be less than that which would be rejected if all the prisms were at the same angle. Specifically the range would be approximately 9° instead of approximately 13°.

It should be pointed out that the series as shown in Fig. 9 is only representative. It is within the scope of my invention to have a series consisting of any number of prisms having different angles b, with each arranged in accordance with my invention to reject sunlight from predetermined altitude angles.

The concepts of the invention as exemplified in Fig. 9 may be incorporated into a single prism as shown in Fig. 10. In this construction portions of the prism surfaces are at various angles. The portion **38** on the southern slope at an angle b_1 has a corresponding portion **39** on the northern slope at right angles thereto. Similarly the portion **40** at the angle b_2 has a corresponding portion **41** at right angles thereto, and the portion **42** at the angle b_3 has a corresponding portion **43** at right angles thereto. The action of the prism in Fig. 10 would be equivalent to that of the series shown in Fig. 9, namely to broaden or increase the range of angles of sun altitude at which partial rejection will take place, at the expense of lessening the range of angles which is totally rejected.

It is within the scope of my invention to have a series or multiplicity of surfaces such that the prism faces become curved surfaces. Each increment of the surface on one slope would have a complementary increment of surface on the other slope of the prism.

Fig. 11 shows another construction of the prism wherein the range or zone of rejection of sun altitudes is broadened providing the same results as shown in Figs. 9 and 10. In this construction the surfaces of the prism **44**, **45** do not form an included angle of 90°. The surface **44** forms an angle b_4 with a horizontal plane and the surface **45** forms an angle c_1 with a vertical plane. b_4 is not equal to c_1, in this case being greater than c_1.

A light ray L_{19} at an altitude angle a_9 and light ray L_{20} at angle a_{10} are totally reflected from the southern slope **44**. However, a light ray L_{21} at angle a_{11}, which is greater than a_{10} and a_9, is not totally reflected by the southern slope **44**. Thus the maximum range of rejection of sun altitudes by surface **44** is a_9 to a_{10}.

A light ray L_{22} at altitude angle a_{12} and light ray L_{23} at altitude angle a_{13} are totally reflected from the northern slope **45**. However, a light ray L_{24} at angle a_9, which is less than a_{12} and a_{13}, is not totally reflected by the northern slope **45**. Thus the maximum rejection of sun altitudes by surface **45** is a_{12} to a_{13}.

This analysis of the rays in Fig. 11 shows that total rejection of the sunlight occurs for altitudes a_{12} to a_{10}.

Thus this construction may be used to partially reject sunlight over a broad range of sun altitudes. The following table represents the resultant areas of rejection of sun altitudes which may be obtained by a typical construction.

TABLE IV

Sun altitude rejected (b_4=29°, c_1=31°)

Southern slope	a_9–a_{10}=58°–71½°
Northern slope	a_{12}–a_{13}=62°–78°
Total rejection	a_{12}–a_{10}=62°–71½°

Table IV shows that for b_4=29° and c_1=31°, total rejection of sunlight (rejection on both surfaces) occurs at altitude angles of 62°–71½°, whereas partial rejection (rejection on one surface only) occurs at altitude angles of 58°–62° and 71½°–78°.

I have determined that the inclined angle p of the prisms on Face **2** in any of the forms of my invention may range from 82° to 98°, the angle of 90° being preferred since it is the angle which produces the largest range of altitude angles wherein complete rejection of sunlight occurs.

A further modification of the prisms on Face **2** is shown in Fig. 12. In this form, a third surface **46** at angle f is placed between the surface **47** and surface **48** of the adjacent prism. Such a surface serves to shorten the length of the surface **47** from that in the other forms, and to thereby transmit the sunlight from low altitude angles, which might otherwise be reflected. For example, light ray L_{25} would normally be reflected out of the prism but by the construction shown is refracted toward the interior. Thus, the amount of light transmitted is greater than the amount transmitted in the other forms of the invention.

I have found that the angle which the surface **46** forms with a horizontal plane is preferably greater than the largest altitude angle of sunlight which is to be rejected by the prism.

It is considered to be within the scope of my invention that the axes of the prisms may extend in a generally east-west direction and not necessarily in a precise east-west direction.

In addition, it is within the scope of my invention to accomplish the equivalent of shifting or rotating the prisms about an east-west axis by changing the slope of the entire glass block panel, e. g. by varying its position slightly from the horizontal.

It is also within the scope of my invention that light transmitting materials other than glass might be used, embodying the teachings of my invention, with such modifications as might be necssary as apparent to those skilled in the art.

Modifications may be resorted to within the spirit and scope of the appended claims.

I claim:

1. The combination of a ceiling having an opening therethrough, and a skylight interposed in said opening and comprising a series of four air-glass interfaces interposed in a horizontal position between the daylight and the interior being lighted, the second interface from the light source having a series of parallel unsymmetrical prisms formed thereon extending in a generally east-west direction, each said prism having surfaces forming an included angle of approximately ninety degrees, one said surface of each prism forming an angle of approximately 30 degrees with a horizontal plane, said 30 degree surface extending upwardly in a southerly direction such that sunlight from high altitude angles is totally rejected by total internal reflection within a single prism and sunlight from low altitude angles and light from the northern sky are transmitted by refraction through the prisms toward the interior being lighted, said third and fourth interfaces having light diffusing means formed thereon for diffusing the light passing therethrough into the interior.

2. The combination of a ceiling having an opening therethrough and a skylight interposed in said opening and comprising a series of four air-glass interfaces interposed in a horizontal position between the daylight and the interior being lighted, the second interface from the light source having a series of parallel unsymmetrical prisms formed thereon extending in a generally east-west direction, each said prism having surfaces forming an included angle ranging from 82 to 98 degrees, one said surface of each prism forming an angle of approximately 30 degrees with a horizontal plane, said 30 degree surface extending upwardly in a southerly direction such that sunlight from high altitude angles is totally rejected by total internal reflection within a single prism and sunlight from low altitude angles and light from the northern sky are transmitted by refraction through the prisms toward the interior being lighted, said third and fourth interfaces having light diffusing means formed thereon for diffusing the light passing therethrough into the interior.

3. In a structure for controlling daylight, the combination comprising a ceiling having an opening therethrough and a skylight interposed in said opening and comprising at least one sheet of light-transmitting material interposed in a generally horizontal position between the daylight and the interior being lighted, said sheet having a series of unsymmetrical parallel prisms on the face thereof nearest the interior, the axes of said prisms extending in a generally east-west direction, each said prism having a first surface extending upwardly in a southerly direction and a second surface extending upwardly in a northerly direction, said second surface forming a greater angle with a horizontal plane than the angle which said first surface forms with a horizontal plane, said angles which said surfaces form with a horizontal plane, and the included angle between said surfaces ranging from 82° to 98° such that sunlight from high altiture angles is totally rejected by total internal reflection within said prisms and sunlight from low altitude angles and light from the northern sky are transmitted by refraction through the prisms toward the interior being lighted.

4. The combination set forth in claim 3 wherein the included angle between said first and second surfaces of each said prism is approximately 90°, the angle which said first surface forms with the horizontal plane being approximately 30°, and the angle which said second surface forms with a horizontal plane being approximately 60°.

5. The combination set forth in claim 3, the angle which said first surface forms with a horizontal plane being approximately 30°.

6. The combination set forth in claim 3 including a second sheet of light-transmiting material positioned between said first sheet and the interior being lighted, said second sheet being formed with light-diffusing means thereon for diffusing the light transmitted thereto to the interior being lighted.

7. The combination set forth in claim 3 wherein said sheet of light-transmitting material comprises one of the walls of a glass block.

8. The combination set forth in claim 3 wherein each said prism has a third surface between the first surface of said prism and the second surface of the adjacent prism, the angle which said third surface forms with a horizontal plane being greater than the angle which said first surface forms with the horizontal plane.

9. The combination set forth in claim 3 wherein the included angle between said first and second surfaces of each said prism is approximately 90°, the first surface of at least one of said prisms forming an angle of approximately 30° with a horizontal plane, the first surface of at least one other prism forming an angle of greater than 30° with a horizontal plane, and the first surface of at least one other prism forming an angle of less than 30° with a horizontal plane.

10. The combination set forth in claim 3 wherein the surfaces of each said prism are curved.

11. The combination set forth in claim 3 wherein the surfaces of each said prism are curved and form an included angle of approximately 90°, the first surface of each said prism having portions thereof forming angles equal to, greater than and less than 30°, respectively, with a horizontal plane, the second surface of each said prism having portions thereof forming angles of approximately 90° with corresponding portions of the first surface of said prism.

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2,665,610	Harrison	Jan. 12, 1954

FOREIGN PATENTS

16,560	Great Britain	of 1897
355,297	France	of 1905
20,046	Great Britain	of 1906