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Research Article

Solar Radiation Enhancement

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Abstract

As has been common knowledge for centuries, if limited by intensity of solar radiation the growth of plants can be improved by deflecting radiation towards the plants. An economical way of doing this is to use a convex mirror, adapted for the particular location, fixed above the target area so that no attention is required throughout the year or other period of use.

Keywords: Light; Reflect; Sun; Photosynthesis; Mirror; Convex; Balloon

Introduction

Mostly, gardens and greenhouses do not lack for light, but it can happen. This brief note is to introduce an innovative, low-cost means of increasing the intensity of solar radiation when and where it is a serious limiting factor for plant health and growth.

Obviously, reflected light can be part of the solution and it has been deliberately so used for well over two hundred years [1,2]. More recently-published means include providing surfaces that reflect light inwards from outside a greenhouse [3] or redistribute light within the structure [4], and another is an elaborate system for illuminating the space under an elevated roadway [5]. Apparently, no proposal has been made like that described here, where a convex mirror provides supplementary irradiation during all or a large part of the day, without any adjustment, controls or moving parts, and indeed can serve without attention for the whole or a large part of the horticultural year.

Using a mirror of this kind, the intensity of the irradiation that reaches the target area must necessarily be less than that of the radiation falling upon the mirror and perhaps much less: it is emphasized that the present proposal concerns circumstances where a small enhancement of intensity is beneficial. Further, no attempt is made here to review the use of either shade-tolerant plants or artificial illumination in low-light situations.

Principles and Examples

Figure 1 illustrates the main principle in the simplest possible way, for a mirror installed at 52^0N latitude, facing due south. The fixed, convex surface reflects light directly downwards at the midsummer noon solar altitude of 61.5^0; also at the midwinter noon altitude of 14.5^0 and on any day in between, provided that the sky is clear and the mirror not in shadow. It reflects a lot of light in other directions as well: that is not our prime concern though it may have to be controlled by supplementary features. In the Figure, the mirror section is drawn as being the segment of a circle - which is not an obligatory restriction though used also in the other examples described.

If this principle is generalized to all directions from which the sun might shine we will need a mirror that is convex both as viewed from above and in vertical section. Local constraints may limit the times of day when the mirror receives sunlight. Figures 2 and 3 explore in detail an installation high up on an East-facing wall, intended to reflect light downwards to a small patch of garden at the foot of the wall that otherwise may receive no direct sunlight at all. It will be obvious that many features exemplified in such an installation are applicable to other circumstances, though not examined here. Parts of a generic mirror shape may be omitted as being of no use, as illustrated in Figure 2, or if the additional radiation is not needed or is harmful at certain values of azimuth and altitude. Figure 4 is a small-scale laboratory demonstration using a mirror of the same type as in Figures 2 and 3 but shaped for and fixed to a West-facing 'brick' wall. Four laser pens are suspended around the mirror, so angled as to represent the direction of light from the sun falling upon the mirror surface at different times of the day and year. The beam is in each case re-directed downwards to fall upon the 'paved' area below.

FIGURE 1

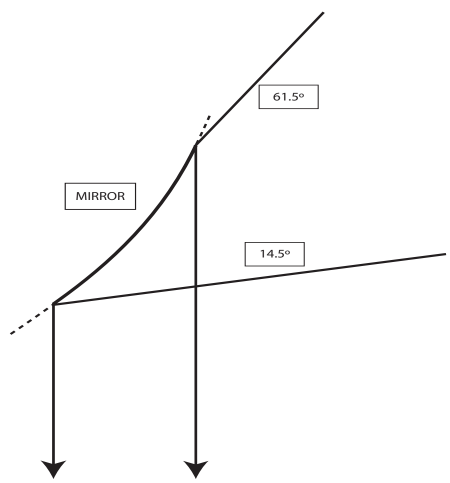

Figure 1. Vertical section through a convex mirror mounted facing due South (180^0) at 52^0N latitude. The maximum possible altitude (angular elevation) of the sun occurs at noon at the summer solstice and is then 61.5^0 above the horizontal plane. Radiation at that angle impinging on a portion of the mirror surface inclined at 75.8^0 is reflected directly downwards. The minimum noon altitude of the sun occurs at the winter solstice and is then 14.5^0. Radiation at that angle impinging on a portion of the mirror surface inclined at 52.3^0 is reflected directly downwards. For such a mirror, if it is required that the reflected light be directed vertically down, these are the maximum and minimum useful mirror inclinations but all inclinations between the extremes will be functional on other days of the year.

Designing the shape of a mirror is complex and will not be pursued in detail in this Note. However a computer application is available on request to assist by providing calculated figures for the maximum and minimum mirror inclinations that are useful for each azimuth (compass direction) of the sun available at a particular site, also the horizontal and vertical mirror dimensions at each azimuth. The present version is for the Northern hemisphere, mirrors shaped as the segment of a circle along each azimuth axis, and for radiation to be reflected vertically down. New versions or other means of calculation are being prepared to cover a wider range of locations and design requirements.

FIGURE 2

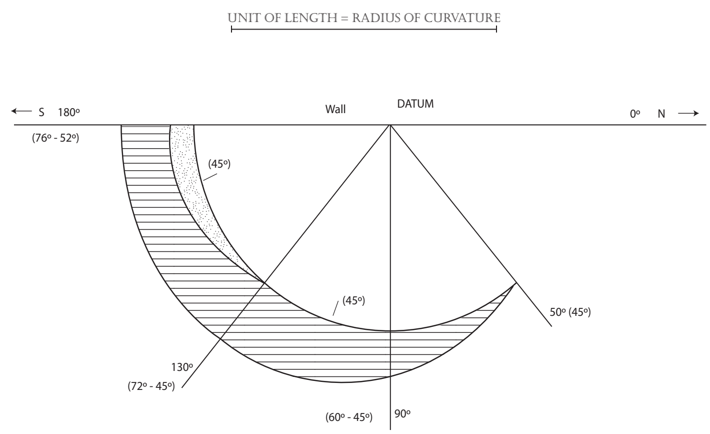

Figure 2. View from above of a mirror attached to an East-facing wall at 52^0N latitude, functional only during the hours up to solar noon: scale is shown by a marker where the unit of length is the radius of curvature of the mirror - which in this example is constant and equal in all directions. The wall surface and azimuth lines are also shown, the latter labelled with compass bearing in degrees and, shown within brackets, the maximum and minimum useful mirror inclinations at that azimuth (in degrees above horizontal). At azimuth 50^0, maximum and minimum mirror inclinations coincide at 45^0. The 'datum' is an imaginary point on the wall above the mirror and is the starting point of all measurements.

Hatching shows (the back surface of) the useful area of mirror. Stippling shows that part of the curved form which would provide a mirror surface of inclination too low to be ever useful at the azimuths concerned: this part may be omitted, or modified, or left in place for simplicity in manufacture and as contributing strength to the structure. No inclination less than 45^0 can ever be useful for deflecting sunlight directly down. The curved line corresponding to 45^0 inclination is so marked, '(45^0)', and would normally constitute the bottom edge of the mirror.

FIGURE 3

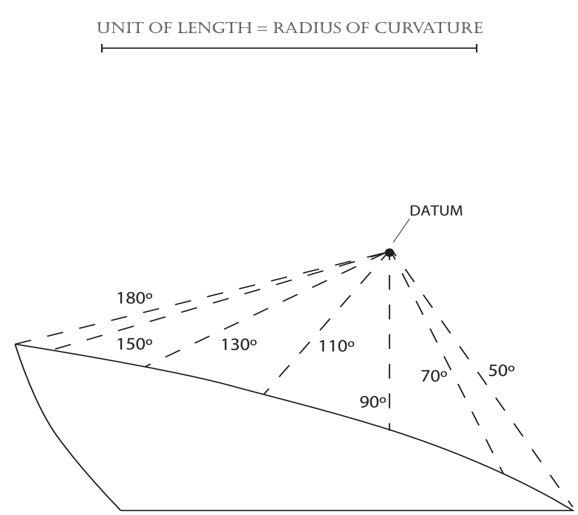

Figure 3. The same mirror as in Figure 2 though the scale may be

different, viewed from the East. Here azimuth lines are shown angled from a datum located above the mirror, downwards to the top edge of the mirror, and the points of intersection of azimuth lines with that edge crowd together at the ends of the curve because of the standpoint of the viewer. The bottom edge of the mirror is at 45^0 inclination. Only at the South end (180^0) can we see directly the curvature of a portion of mirror surface directly facing the sun. Note especially the way in which the height of the mirror changes with azimuth. In this Figure there is no indication of the non-useful part of the mirror.

FIGURE 4

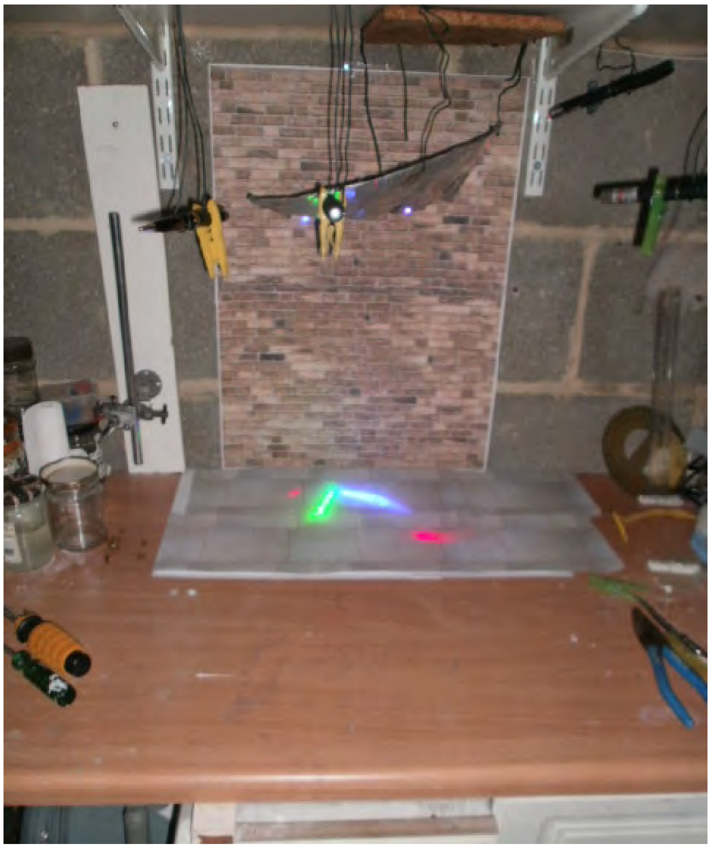

Figure 4. This photograph of a laboratory demonstration employs a mirror of the same general type as in Figures 2 and 3 but shaped for and attached at its South end to a West-facing wall as if in latitude 52°N. From the wall, the mirror curves outwards towards the viewer. Four laser pens are suspended around the mirror representing the directions of light from the sun falling upon the mirror at the following approximate times and dates; from right to left:-
13.00 early May (red),
15.00 December 21st (blue),
17.00 March 21st (green)
19.30 June 21st (red)

Points of incidence on the mirror surface are clearly visible for the first two. Some complications in interpretation are due to the high intensity of laser light, overwhelming the photodynamic range of the camera, reflection back up from the horizontal 'paved' surface to the mirror, and imperfections of the mirror. The smallest mirror envisaged for application will have a 1-metre radius of curvature. This model uses 20cm radius of curvature and is therefore of one fifth scale. Light is deflected more-or-less directly downwards from whatever direction it originates, and being from a laser yields a small bright spot; natural sunlight would be more widely scattered.

Discussion

Applications of these mirrors will be widespread, not confined to horticulture in which area of activity they will be of particular importance in the following circumstances:- small leisure gardens in urban areas, too much shadowed by surrounding buildings; where high latitude limits the available light intensity; where it is found possible to save on fuel bills by using sunlight to quickly warm up and strongly illuminate greenhouse plants for a short period each day, say the first hour or two of daylight. Other applications will be largely in provision of leisure facilities.

It may be that a mirror does not serve equally well at all azimuths on all days of the year. Some compromises are necessary and an important feature is that high optical precision is neither required nor even desirable: we wish the deflected light to be diffused and not be concentrated on spots within the target area where excessive intensity might be damaging. Advantage is seen in scattering some radiation away from the target and other radiation back in towards the target.

Other means than mirrors may be employed to direct radiation in the desired manner and the underlying mechanical construction of a mirror may be of any kind, including a balloon.
Where mirrors have been used previously to collect and deflect solar radiation, one or more of the following features is almost always found:- concentration of radiant energy (even if it is later dispersed); concave mirror; application to generate and/or store heat energy; provision for shading against excessive radiation; a complex light path within a building; mechanical means to follow the sun so that the maximum amount of solar energy can be collected. None of these is found in the present proposal, which is intended to make a modest increase of radiant energy available where it is most needed, without fear of excessive intensity, and at least possible cost.

Conclusions

An appropriately shaped, fixed, convex mirror can provide supplementary solar radiation to plants without any need for adjustment or maintenance during the period of use.

References

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