Sundownloaders: Early History, and usefulness in Vertical Farming

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Twenty years ago, we had open space in front of our house. Ten years ago they built a college opposite - we got four hours per day of sunshine, in summer. Then they started on what grew into four tower blocks, plus a huge Sports Centre with a fifty-foot-high wall across the South end of the street; soon we had less than two hours of sunshine, at street level, at the front of the house, on mid-summer's day, and none at all in winter.

This picture of our house was taken about 2 hours after daybreak in late April; a first tiny glimmer of sunlight appears right at the top. You will see later that things were better at the back where also there was little impact as yet from the tower blocks, but even so ground-level there got about 2 hours sunshine in summer, at best. There was strong motivation to act!

Mirrors offered a possible solution, lots of people have thought that way; but they move, don't they? It took a while but in the end we figured out how a stationary, convex mirror can be made such that facing any compass bearing where the sun can ever appear it reflects some sunlight straight downwards, though also dispersing light rather than focussing it. The principle is demonstrated in patent documents. These single, sweeping mirrors are called Type 1 Sundownloaders and are illustrated here (Types 1A and 1B). Another Type (2) is also described below but we did not have any workable model or unit of that kind until 2018.

Sundownloaders of Type 1A.

The next picture is the first ever, laboratory-scale, mini-model of a sundownloader, as if mounted on a West-facing wall. South is towards the right. Four lasers around the mirror represent where the sun would be at different times of day and year, as follows (the times shown being local solar time, not clock time), latitude 52◦N:-

13.00 end May (red)

15.00 December 21st (green)

17.00 21st March (blue)

19.30 21st June (red)

All the reflections are almost straight down. Obviously, this photograph is retouched, for clarity : that used in the very first scientific paper about sundownloaders (cited at the end of this text) is an original, unretouched.

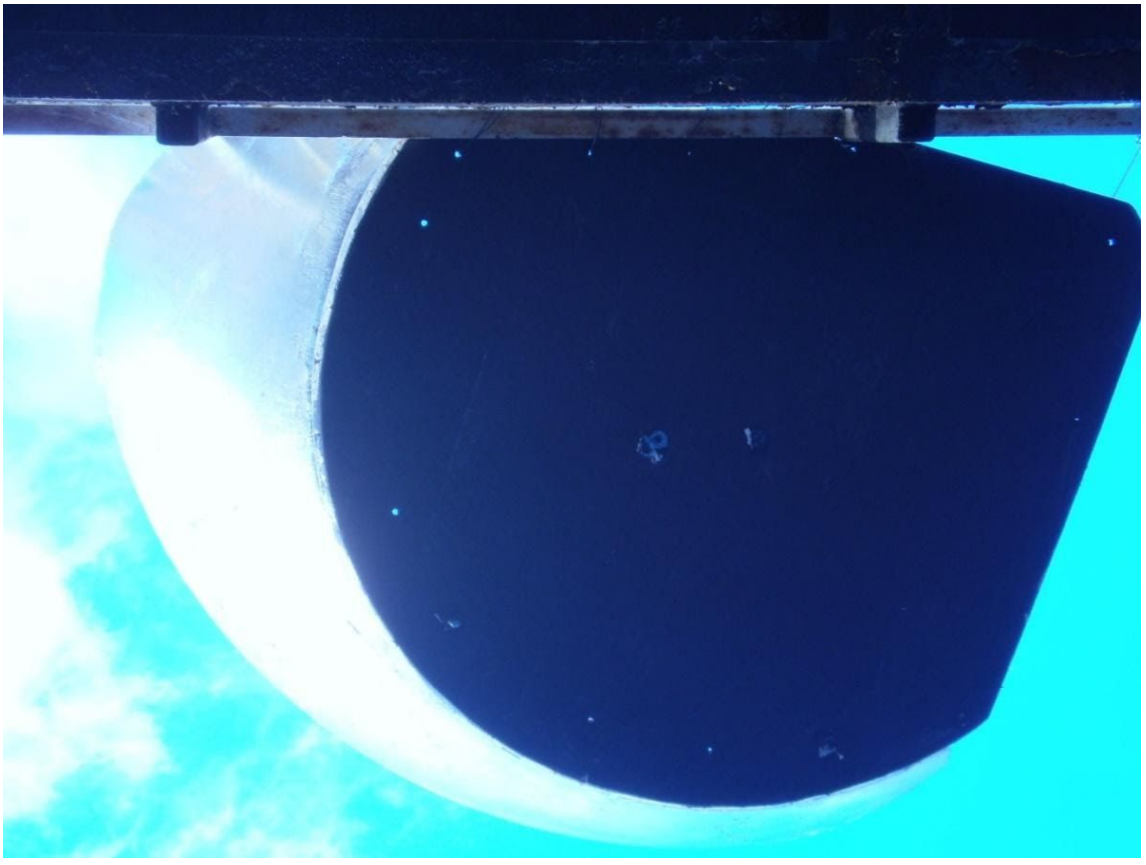
That and the next five pictures show one limitation of Type 1A. We knew already that the mirror should not be of spherical symmetry (i.e not like this one) but had not yet figured out how to make any other kind. Because curvature is the same in all directions and we omit as useless parts of the potential surface that cannot reflect light downwards to the target area, these mirrors are not of constant height. They are lower just where being taller might be most useful - to give more light reflected downwards when the sun is low in the sky - and of course that consideration is what led to the creation of Type 1B, described later.

The above is a Type 1A mirror that can work all day long at 52◦N, down-reflecting sunlight coming from North-East at dawn through to the North-West at sunset, via South at mid-day, but in this picture it is on a scaffolding tower in our dark back yard at about 3pm. The bright patch is sun reflected obliquely down into the camera lens, proof that the mirror is working, but as shown in another example later on a much-more-strongly-reflecting patch will show brighter and lower on the mirror surface if you look up from directly underneath (where the light is intended to go). The bright patch in the above picture and in another example below, also from an oblique angle, is scattered light, a tiny fraction of the total.

More impressive are the four pictures on the next two pages, taken whilst standing on our second-floor back balcony, within a minute from first to last, beginning at 3.47 pm on December 3rd 2016.

In the first of them, the sun is setting behind the buildings at the back of our house. Next, the balcony itself is demonstrated as being already in shadow but the third picture shows the sundownloader (mounted higher up, secured to a fire escape) still receiving sun (with a bright patch of light scattered back towards the camera), and the last picture shows that when the mirror is viewed from directly underneath, as intended, the intensity resembles a midsummer noon day rather than midwinter sunset - too much light for my little Olympus to deal with; it is overwhelming; the sky is bleached out.

No doubt about it, sundownloaders really do work, even Type 1A.



Sundownloaders of Type 1B.

Better mirror shapes, not of spherical curvature, can be made by 3D printing. Here is a model garden facing South; that is, towards us. Light directed in from the South-West, by reflection, illuminates the whole except a tiny corner at the South-East. The mirrors are of constant height and the curvature is not as simple as it may look at first sight. The South ends, closest to us, are curved so as to provide a range of mirror inclinations covering 23.5◦, suitable for all possible solar elevations at mid-day, throughout the year. The more Northern ends, further from us, serve respectively:-

i] (the left mirror, portion facing right, North-East) a period around summer sunrise,

ii] (that on the right, portion facing left, North-West) a period around Summer sunset.

For both the range of mirror inclinations required is much less; not far off flat.

The last three pictures are of a 1:50 model of a 10m-high greenhouse, with three Type 1B sundownloaders installed above the roof. The model is seen first as from the South. Plant racks run North-South and there are quite wide passageways between them. There is a pair of larger mirrors at the back: pairs of smaller mirrors are placed to illuminate the side aisles.

The second picture is a perspective from the South-West.

The third shows what happens if we switch off the room lights and switch on some lasers. Each of the aisles is brilliantly lit with light coming from a mirror above it - chaotic,

not well organised as yet, but you can see that with slightly better mirror placement each of the aisles could receive very well distributed radiation.

The Future, and Sundownloaders of Type 2.

Type 2 has many little mirrors (mi-lets) mounted on a frame. They are more difficult to make at model scale (and none were illustrated in this talk) though it will be much easier both to make full-size sundownloaders this way and customise them to suit installation sites. We think that some Type 1B mirrors will continue to be made for special situations, where appearance is particularly important, but that Type 2 will become commercially dominant in both horticulture (including Vertical Farming) and solar energy. They are capable of sending light obliquely, from the side, in to a growing shed or vertical farming tower - which leads me in to the last section of this presentation.

Sundownloaders in Vertical Farming.

Vertical Farming is well known to everyone else here, but I first heard the phrase at *GreenTech* last June in Amsterdam and immediately saw how sundownloaders can be a part of it, though the exhibitors in that section of that show were only interested in artificial light. After examining the science behind it all I'm now more sure than ever that Vertical Farming will only be viable in the commercial production of food, in bulk, if full use is made of the

solar radiation available on site, however much mains electric power is used also. I look forward to hearing from actual practitioners about the real cost of producing staple foods using only mains-electricity-powered artificial light. But even that is not the point. I do not question the usefulness of current Vertical Farming practice; look rather to a future when it will be routine to combine direct sun, sundownloaders, solar electricity and mains electricity.

A little more detail on the role of sundownloaders in Vertical Farming:-

Even on flat land total insolation over the whole length of a midsummer day actually increases with latitude. Then consider what happens if part of the site is a vertical surface or nearly so. Sun at a low level 'sees' more of this 'target' than when it is higher in the sky, so we have another bonus at high latitudes if we don't rely just on the downwards component of the sun's radiation. Everyone will immediately see many practical problems and there is no point belittling the objections of neighbours to being shadowed - that after all is where I started. All the same it seems clear to me that the option should always be explored, for each Vertical Farming site, not *whether* sundownloaders and local solar panels should be used, but *to what extent*, in the geographical, social and political circumstances prevailing.

Further Reading.

Solar Radiation Enhancement, T.R.C. Boyde, *Jacobs Journal of Agriculture*, 1 (2015) 1 – 4

Downloading the Sun. Optimising the use of Solar Radiation in Horticulture and otherwise, with special regard to Latitude and Cross-Section, T.R.C. Boyde, 2018
https://trcboyde.net/downloading-the-sun.html

The Concept, Definition and Economics of Vertical Farming, T.R.C. Boyde, 2020
https://trcboyde.net/vertical-farming.html

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All contacts welcome: for the present it will be best to use the email address given on the title page.