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Title: Approach to the optimization of parameters of a truncated cone solar concentrator using the Excel Solver tool

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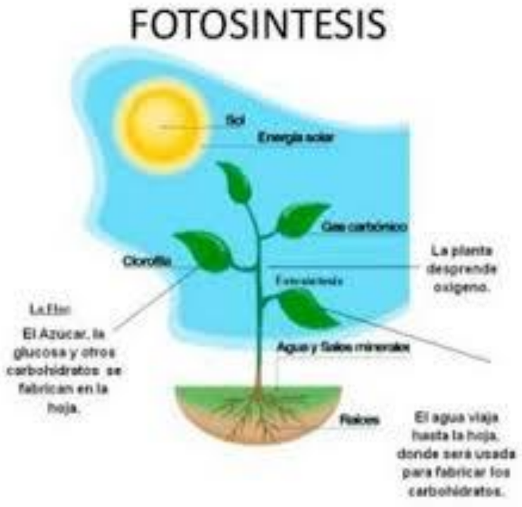
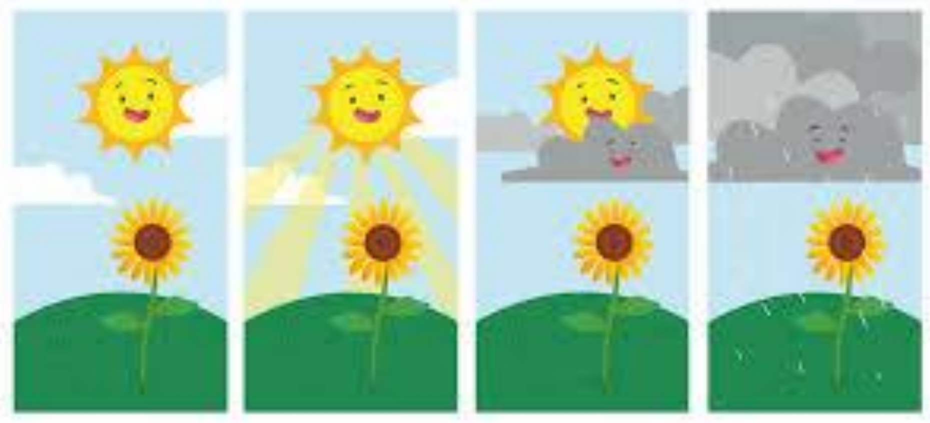
Introduction

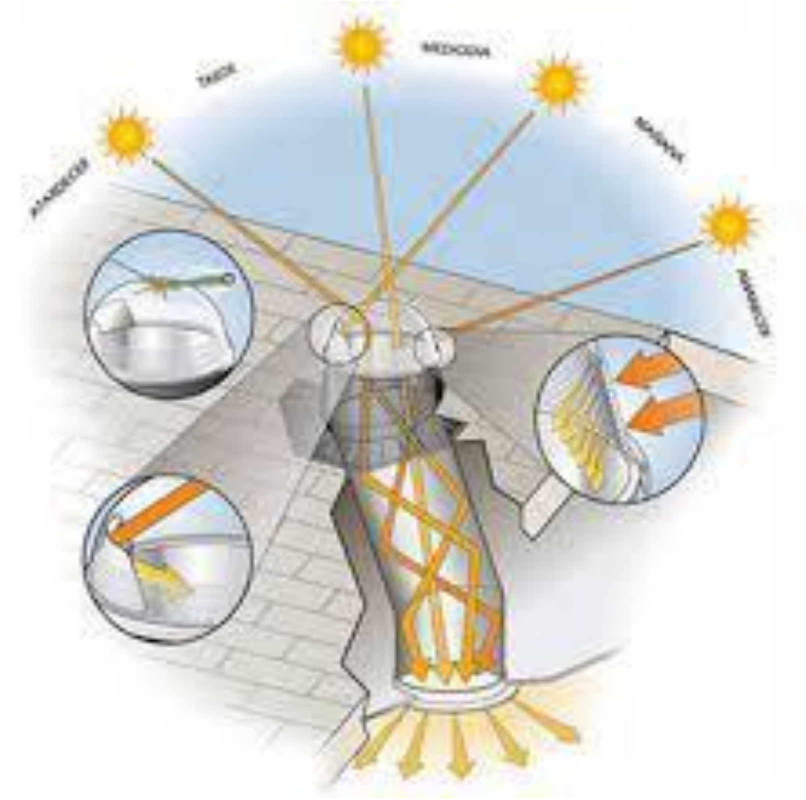
Most human and biological activities on earth are governed and powered by the sun, as the sun has been a source of illumination throughout human history. The development and use of efficient artificial lights has led humans to separate themselves from the healthiest and best source of illumination: natural light.





Studies have shown the benefits in health, safety and labor productivity when buildings are naturally illuminated (Roche, 2000). In addition to the quality of natural light, another reason to use it is its compatibility with lighting control systems to achieve a reduction in the use and cost of conventional energy, thus achieving a sustainable system.

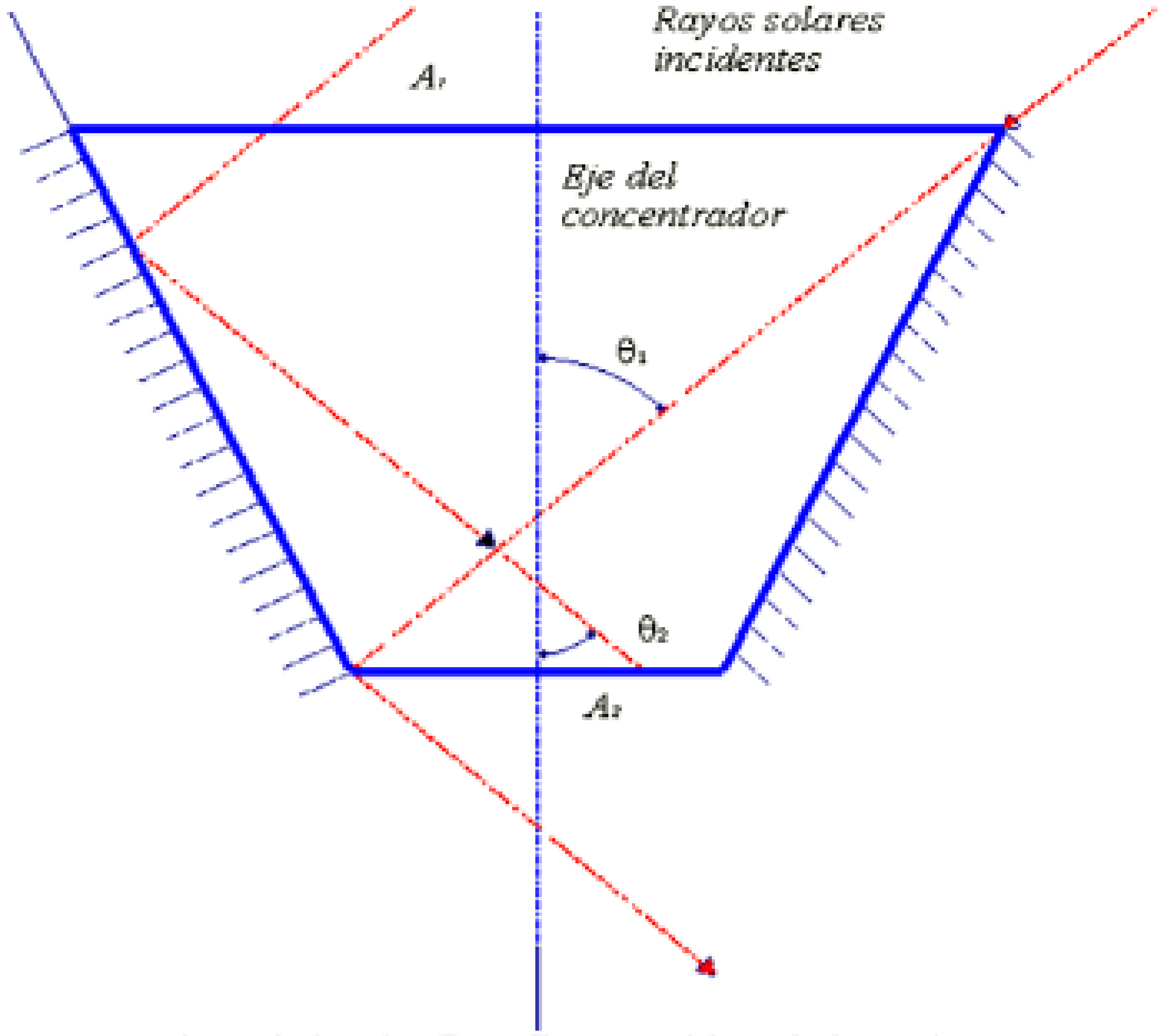
In order to transport natural light from the exterior to the interior of a physical space, lumiducts, which are simple structures that allow the transmission of natural light, are being used; there is currently a considerable increase in the use of this technology, with an estimated three million ducts installed worldwide (CIBSE, 2003). Generally, they consist of a collector (usually a hemispherical polycarbonate dome), the duct itself and an emitter.



(Ecología activa red, 20029)

Methodology

Considering a typical optical system with input aperture A_1 and output aperture A_2, light enters the system within a cone defined by $\pm\theta_1$ and output within $\pm\theta_2$ measured with respect to the optical axis (Figure 1).



First the objective function subject to be optimized (angle of the truncated cone generatrix α, see figure 9.1; which contains the parameters or variables to be determined (height of the cone ((h)) and minor diameter of the cone (a) and the constant parameter (major diameter of the cone ($b = 1181{,}1 mm$), then it is expressed by:

$$\alpha = tan - 1\ [2h/b - a]$$

Once the objective function is established, it is subject to the following restrictions:

$a > 0\, mm$;

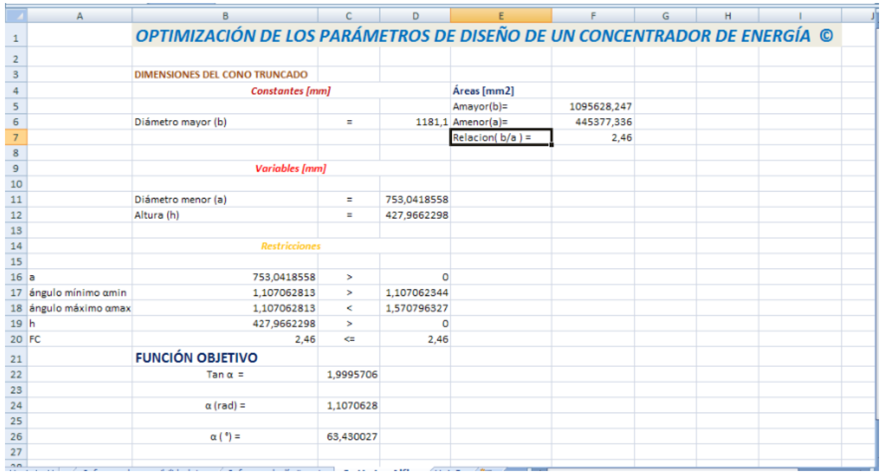
$h > 0\, mm$;

$\alpha min = 1{,}107062344\, rad$;

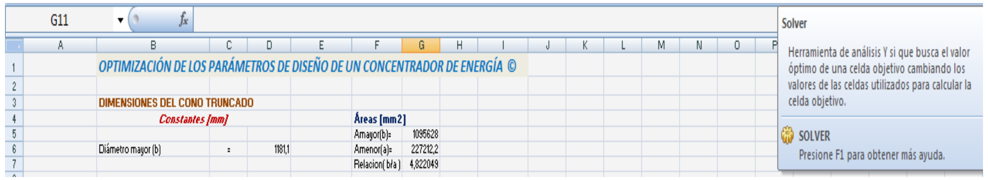
$\alpha max = 1{,}570796327\, rad\ y$

$FC = 2{,}46$

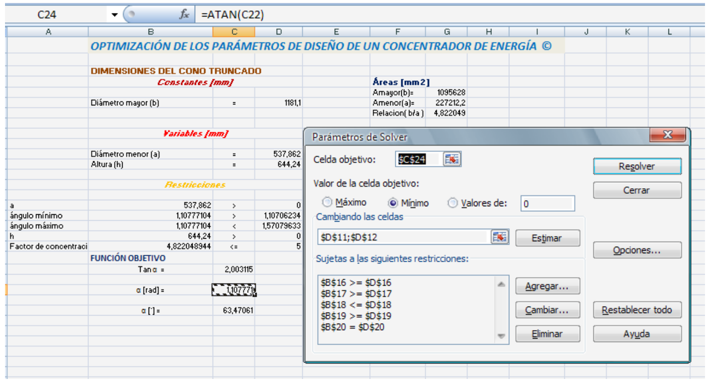
1 Definition of initial design parameters for optimization



2 Access to the Solver tool



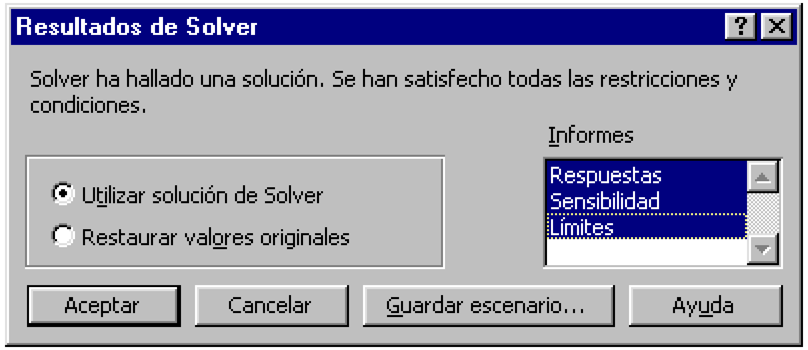
3 Definition of a and minimum h according to restrictions



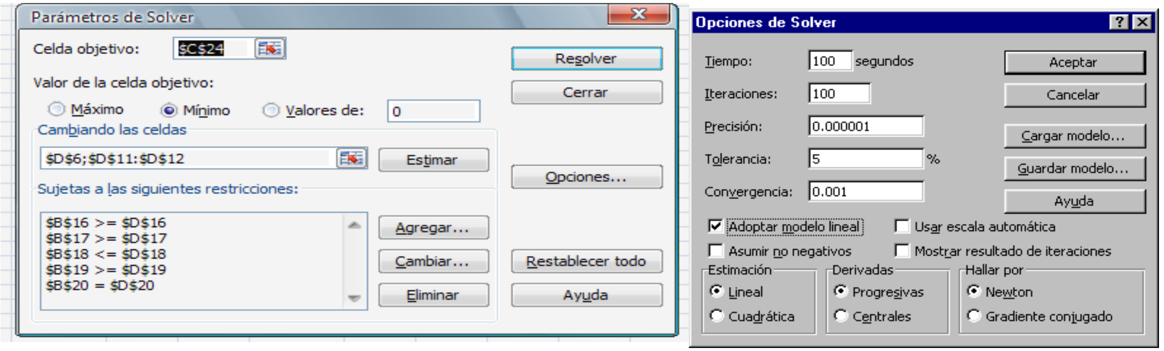
6. Then we proceeded to build a scale model to concentrate and transport light through luminous pipelines with energy concentrator, so the necessary materials are:

- Physical space.
- Portable computer equipment
- Physical components to generate prototypes: passive and active dome, tube, extractor, aluminum foil light concentrator and accessories.
- DB-526 Multilog datalogger
- Light sensors range 0-130 klx
- Temperature sensors range -25 - 110 ºC
- Software: Solver , Mechanical Desktop

5 Solver Results



4 Parameters and Solver options



Results

The results obtained in the design of the solar concentrator are shown; we take as a starting point the largest diameter (b = 1181.1 mm) of the dome to calculate the fundamental dimensions: optimum angle of the generatrix (α), cone height (h), largest diameter (b) and smallest (a), for which an optimum concentration is achieved.

Using the Solver we have:

Figure 2 Report of responses

Celda objetivo (Mínimo)

Celda	Nombre	Valor original	Valor final
$C$24	α (rad) = <=	1,107062813	1,107062813

Celdas cambiantes

Celda	Nombre	Valor original	Valor final
$D$11	=	753,0418558	753,0418558
$D$12	=	427,9662298	427,9662298

Restricciones

Celda	Nombre	Valor de la celda	Fórmula	Estado	Divergencia
$B$16	a Restricciones	753,0418558	$B$16>=$D$16	Opcional	753,0418558
$B$17	ángulo mínimo αmin Restricciones	1,107062813	$B$17>=$D$17	Obligatorio	0
$B$18	ángulo máximo αmax Restricciones	1,107062813	$B$18<=$D$18	Opcional	0,463733513
$B$19	h Restricciones	427,9662298	$B$19>=$D$19	Opcional	427,9662298
$B$20	FC Restricciones	2,46	$B$20=$D$20	Opcional	0

Constraints

Equal value: is the final value taken by the left-hand side of each constraint in the optimal solution of a (cells B16), h (cell B19), FC (cell B20), α_{min} and α_{max} (cells B17 and B18 respectively). The constraints (cells D16-D20), indicate the right-hand sides of the inequalities to which the objective function was conditioned and which are satisfied.

Figure 3 Boundaries report

Celda objetivo		
Celda	Nombre	Igual
$C$24	α (rad) = <=	1,107062813

Changng Cells

Celdas cambiantes						
Celda	Nombre	Igual	Límite inferior	Celda objetivo	Límite superior	Celda objetivo
$D$11	=	753,0418558	753,0418558	1,107062813	753,0418558	1,107062813
$D$12	=	427,9662298	427,9662298	1,107062813	#N/A	#N/A

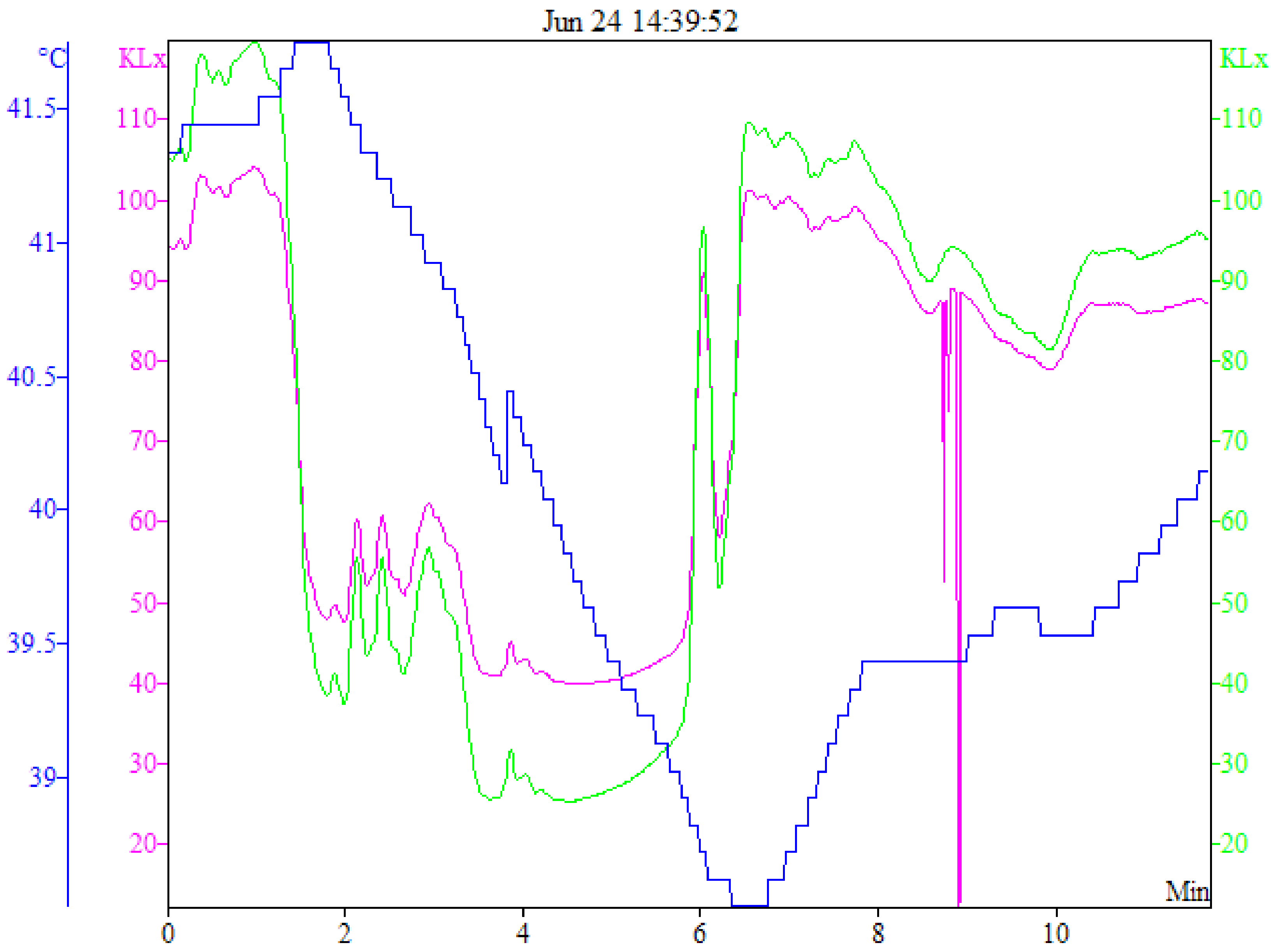
Finally, the drawing of the final plane of the truncated cone concentrator with optimal parameters was made in Mechanical Desktop (Figure 10.3). All sun rays entering at b are concentrated and finally enter at a. The parameters of the truncated cone concentrator are shown in Table 1.

Table 1 Dimensions of the solar energy concentrator

Optimum parameters of the truncated cone concentrator			
b [mm]	a [mm]	h [mm]	α [rad]
1181,1	753,0418558	427,9662298	1,107

Figure 4
Scale model, concentrator and sensors

Figure 5 *Ie*, *Ii* and *T*, under sunny - cloudy open sky conditions



Conclusions

A truncated cone solar concentrator was designed using computer tools to optimize the sizing, leaving:

$b = 1181{,}1\, mm, a = 573{,}04\, mm, h = 427{,}96, FC = 2{,}46\, y\, \alpha = 63{,}43\,°.$

A scale model was built to measure the illuminance at the entrance and exit of the truncated cone concentrator covered with aluminum reflective film, with which it was possible to capture, transfer and diffuse concentrated sunlight at average ratios of 1.78 for open sky, 1.89 with halogen lamp, which are below the FC = 2.46, which would be the ideal according to the sizing of the concentrator, This shows that it is possible to achieve higher concentrations depending on the angle of the generator, the height and diameter of the exit section of the cone according to the desired illumination levels inside a building with deficient or no natural lighting.

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