ASOCIAȚIA INGINERILOR DE INSTALAȚII DIN ROMÂNIA
Filiala Timișoara

UNIVERSITATEA "POLITEHNICA" DIN TIMIȘOARA
Departamentul de Construcții Civile și Instalații

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IMPACT OF THE LATERAL COLLECTOR EDGES ON THE IRRADIATED AREA OF THE LOWER ABSORBER SURFACE OF THE BIFACIAL SOLAR COLLECTOR

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Abstract

The bifacial flat-plate solar collector (BFPC) is a solar collector that can absorb solar irradiation from its upper as well as lower absorber surface (LAS). Absorption of a solar irradiation from its LAS is achieved using flat plate reflector placed below the collector. The reflector is parallel with collector. Compared to a conventional flat-plate solar collector, the insulation of the analyzed collector, placed in the bottom of the box, is replaced by glazing. This paper presents the mathematical model for determining the irradiated area of the LAS when the impact of the lateral collector edges on the irradiated area of the LAS of the BFPC is included.

Rezumat

Colectoarele solare plane bifacial (BFPC) sunt colectoare solare care pot absorbi radiația solară la suprafața sa superioară la fel ca şi la suprafețe de absorbție mai mici (LAS). Absorbția radiației solare de la suprafețele LAS se realizează utilizând un panou reflector amplasat sub colector. Panoul reflector este paralel cu colectorul, Comparativ cu un colector solar plat convențional placa de izolare amplasata la partea inferioară este înlocuită cu

sticlă la colectorul analizat. Această lucrare prezintă un model matematic de determinare a suprafeței radiante LAS atunci când se include impactul margini laterale a colectorului pe zona iradiată a suprafețelor inferioare ale BFPC.

Keywords: bifacial flat - plate solar collector, reflector, lateral collector edges

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1. Introduction

The most common systems used for absorbing solar energy are flat-plate (water) solar collectors (FPCs), which receive solar irradiation through the upper absorber surface. The greatest limitations to increasing the use of conventional collectors is their relatively low average efficiency and high investment cost. For this reason, significant research on improving the efficiency of FPCs has been carried out. Results from peer-reviewed studies indicate that the greatest theoretical improvements to the collector efficiency can be achieved by utilising internal fins in the collector pipes and using concentrating or reflective surfaces (reflectors) [1]. Many studies have been performed to investigate the effect of using a reflector on the FPC [2-5]. In all of these studies, the collector-reflector system (CRS) included a flat-plate reflector, which is connected to the collector. In this paper, a modified CRS, called a bifacial flat-plate solar collector (BFPC), is analysed. The term BFPC is related to the solar collector, which has the ability to receive and absorb solar irradiation from the upper and lower surfaces of the absorber. Absorption of solar irradiation from the lower absorber surface (LAS) is accomplished using a flat-plate reflector placed in parallel below the collector. The reflector is not connected with the collector. In contrast to conventional FPCs, the collector analysed here has no insulation mounted in the lower part of the collector box, and the lower box surface is replaced by a glass cover.

This paper presents an original mathematical model for determining the irradiated area of the LAS when the impact of the lateral collector edges (LCE) on the size and form of the same area is included. The collector and reflector are taken to be parallel, and the reflector, which is placed below the collector, can move in three directions: normal to the collector, east-west and north-south.

2. Mathematical model

The LCE are integral part of any solar collector. They affect the increase of the size of the shadow which a collector casts on a reflector and in the same time the reduction of the irradiated area of the LAS of the BFPC. The mathematical model for determining the irradiated area of the LAS when impact of the LCE on the same area is not included is given in [6]. That model includes the effects of shading, the distance of the reflector from the collector, the impact of an arbitrary position and the impact of the finite dimensions of reflector on the solar collector.

This paper presents the equations for calculating the "new" parameters which has to be found in order to determine the irradiated area of the LAS. The mentioned parameters are: λ_{new}, ξ_{new}, a_{pnew}, $b_{pewG\alpha new}$ and $b_{pnsG\alpha new}$. The "old" parameters are the parameters λ_{old} (λ), ξ_{old} (ξ), a_{pold} (a_p), $b_{pewG\alpha old}$ ($b_{pewG\alpha}$) and $b_{pnsG\alpha old}$ ($b_{pnsG\alpha}$). These parameters are derived when the impact of LCE is neglected. Their equations are not presented here because they are given in [6].

The impact of LCE also includes the fact that the size of the active absorber surface is not equal to the size of the collector surface. The size of the collector surface is determined as a product of external dimensions of the collector, its width and lenght. The size of the active absorber surface is less then the size of the collector surface because it is reduced by the part of the absorber with the splitter and the mixer pipes. The absorption of the solar radiation by this part of absorber is neglected in comparison to the rest of the absorber.

The parameters which present the impact of LCE are: e_{1r}, e_{2r}, e_{3r}, e_{1l}, e_{2l}, e_{3l}, f_{1r}, f_{2r}, f_{3r}, f_{1l}, f_{2l}, f_{3l}, l_{1ewr}, l_{2ewr}, l_{1ewl}, l_{2ewl}, l_{1nsr}, l_{2nsr}, l_{1nsl} и l_{2nsl}. The length of the splitter or mixer pipe in EWGα plane from right or left side of the collector is designated as e_{1r} and e_{1l}. Its lenght in NSGα plane is designated as f_{1r} and f_{1l}. The distance between the absorber and glazing in EWGα plane from right or left side of the collector is designated as e_{2r} and e_{2l} while in NSGα plane as f_{2r} and f_{2l}. The parameters e_{3r}, e_{3l}, f_{3r} and f_{3l} present

the width of the profile of the collector housing which carries the weight of the glazing. The width of this profile in EWGα plane from right or left side of the collector is designated as e_{3r} and e_{3l}, while in NSGα plane as f_{3r} and f_{3l}. In the case when the collector is placed in some supporting construction then the previously parameters are increased for the value of the width of that construction. The parameters l_{1ewr}, l_{2ewr}, l_{1ewl}, l_{2ewl}, l_{1nsr}, l_{2nsr}, l_{1nsl} and l_{2nsl} are the length parameters of the reduction of the "old" parameters of irradiation λ_{old} (λ) and ξ_{old} (ξ). The reduction of parameter λ_{old} because of inclusion of the parameters e_{1r} and e_{2r} as well as e_{1l} and e_{2l} is designated as l_{1ewr} and l_{1ewl}, respectively. On the other side, the reduction of the same parameter as a consequence of inclusion of the parameters e_{2r} and e_{3r} as well as e_{2l} and e_{3l} is presented by parameters l_{2ewr} and l_{2ewl}. The same procedure is used for designation the reduction of parameter ξ_{old} in NSGα plane as l_{1nsr}, l_{2nsr}, l_{1nsl} and l_{2nsl}. Fig. 1 graphically describes all above parameters of the impact of the LCE in EWGα plane for arbitrary reflector position. The parameters λ_{old} (λ) and ξ_{old} (ξ) present the lenght of irradiation in EWGα and NSGα plane when the impact of LCE is not inluded, while the parameters λ_{new} and ξ_{new} present parameters of irradiation when the mentioned impact is included. The solar beams which form the irradiated area when the impact of LCE is neglected are presented with blue color. The same beams are presented with red color when the mentioned impact is included.

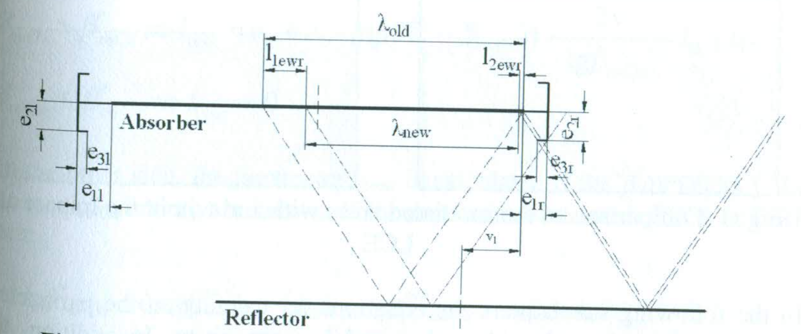

Fig. 1. The parameters of the impact of the LCE on the length of irradiation λ_{old} (λ) in EWGα plane

On Fig. 2 the procedure for determining the irradiated area of the LAS when the impact of LCE is included is presented. From the same figure it can be seen that the shadow which collector casts on the reflector is bigger when the impact of LCE is included. Because of that the irradiated area of the LAS is less then the area calculated when the impact of the LCE is neglected. Fig. 3 gives comparison of the irradiated areas with and witout the impact of LCE.

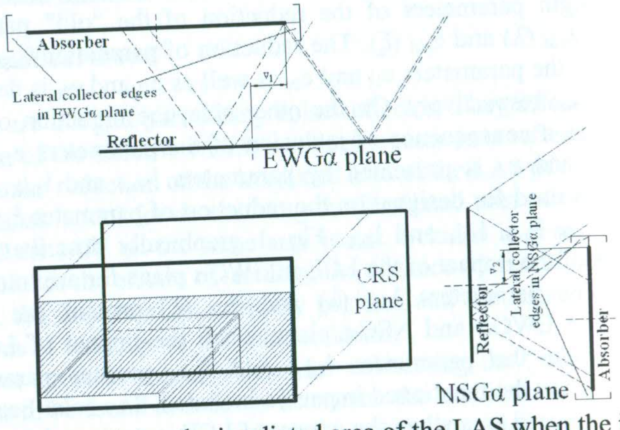

Fig. 2. The determining the irradiated area of the LAS when the impact of LCE is included

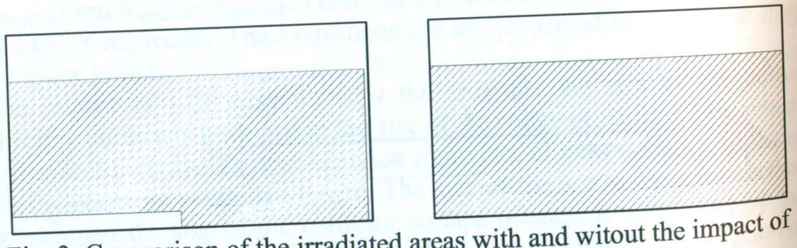

Fig. 3. Comparison of the irradiated areas with and witout the impact of LCE

In the following subchapters the equations for calculation the parameters l_{1ewr}, l_{2ewr}, l_{1ewl}, l_{2ewl}, l_{1nsr}, l_{2nsr}, l_{1nsl} and l_{2nsl} are given. In addition, the principle for calculation the "new" parameters λ, ξ, a_p, $b_{pnsG\alpha}$ and $b_{pewG\alpha}$, when the impact of the LCE is included, is presented below.

2.1. The equations for l_{1ewr}, l_{2ewr}, l_{1ewl}, l_{2ewl}, l_{1nsr}, l_{2nsr}, l_{1nsl} and l_{2nsl}

The derivation of the equations for the parameters of reduction of the lenghts of irradiation λ (ξ) is performed for arbitrary reflector position. The reflector is taken to be left in EWGα plane and right in NSGα plane relative to the collector. For other mutual positions between the reflector and the collector the equations are identical but for different intervals of $\gamma_{G\alpha}$ angle. In addition, in the following text only the equations for the parameters l_{1ewr} and l_{2ewr} will be given. The equations for l_{1ewl} and l_{2ewl} are same as the ones for l_{1ewr} and l_{2ewr} but for different intervals of $\gamma_{G\alpha}$ angle and with application of the parameters e_{1l}, e_{2l} and e_{3l} instead of parameters e_{1r}, e_{2r} and e_{3r}. In the same time, the equations for l_{1nsr}, l_{2nsr}, l_{1nsl} and l_{2nsl} are identical to ones for l_{1ewr}, l_{2ewr}, l_{1ewl} and l_{2ewl} but the intervals of $\gamma_{G\alpha}$ angle are different and the parameters f_{1r}, f_{2r}, f_{3r}, f_{1l}, f_{2l}, f_{3l} and $\beta_{nsG\alpha}$ are used instead of parameters e_{1l}, e_{2l}, e_{3l}, e_{1r}, e_{2r}, e_{3r} and $\beta_{ewG\alpha}$.

In order to determine the parameter l_{1ewr} the parameters y, L_k, e_{1r}, e_{2r} and $\beta_{ewG\alpha}$ have to be known. Depending on what the sun beam situation is active in that moment (PIRR or FIRR) the parameter l_{1ewr} is calculated as:

$PIRR_{ewG\alpha}$:

$$l_{1ewr} = e_{1r} + e_{2r} \cdot (\mathrm{tg}(90° - \beta_{ewG\alpha})) \tag{1}$$

$FIRR_{ewG\alpha}$: $\mathrm{tg}\beta^{*}_{ewG\alpha} = 2y/(L_k + e_{1r} + e_{2r} \cdot (\mathrm{tg}(90° - \beta_{ewG\alpha})))$

$$\beta_{ewG\alpha} > \beta^{*}_{ewG\alpha} \Rightarrow l_{1ewr} = e_{1r} + e_{2r} \cdot (tg(90° - \beta_{ewG\alpha})) - \frac{2y}{\mathrm{tg}\beta_{ewG\alpha}} - L_k \tag{2}$$

$$\beta_{ewG\alpha} \le \beta^{*}_{ewG\alpha} \Rightarrow l_{1ewr} = 0 \tag{3}$$

On the other side, the parameter l_{2ewr} is calculated if the parameters y, L_k, e_{1r}, e_{2r}, $\beta_{ewG\alpha}$ and e_{3r} are known. If the sun beam situation is PIRR or FIRR then:

For $\mathrm{tg}\beta^{*}_{ewG\alpha} = 0$, $\mathrm{tg}\beta^{**}_{ewG\alpha} = e_{2r}/e_{1r}$, $\mathrm{tg}\beta^{***}_{ewG\alpha} = e_{2r}/(e_{1r} - e_{3r})$

$PIRR_{ewG\alpha}$:

For $(2y/(\mathrm{tg}(\beta_{ewG\alpha})) - \lambda_{old}) < (e_{2r}/(\mathrm{tg}(\beta_{ewG\alpha})) - (e_{1r} - e_{3r}))$:

$$\left(\beta^{*}_{ewG\alpha} < \beta_{ewG\alpha} \le \beta^{**}_{ewG\alpha}\right) \Rightarrow l_{2ewr} = \frac{e_{3r}\cdot\sin(\beta_{ewG\alpha}) + \cos(\beta_{ewG\alpha})\cdot\left(e_{2r} - e_{1r}\cdot tg(\beta_{ewG\alpha})\right)}{\sin(\beta_{ewG\alpha})} \quad (4)$$

$$\left(\beta^{**}_{ewG\alpha} < \beta_{ewG\alpha} < \beta^{***}_{ewG\alpha}\right) \Rightarrow l_{2ewr} = \frac{e_{2r}}{tg(\beta_{ewG\alpha})} - \left(e_{1r} - e_{3r}\right) \quad (5)$$

For $(2y/(tg(\beta_{ewG\alpha}))-\lambda_{old}) \ge (e_{2r}/(tg(\beta_{ewG\alpha}))-(e_{1r}-e_{3r}))$:

$$l_{2ewr} = 0 \quad (6)$$

$FIRR_{ewG\alpha}$:

For $(L_k-\lambda_{old}) < (e_{2r}/(tg(\beta_{ewG\alpha}))-(e_{1r}-e_{3r}))$ and $\lambda_{old} = L_k$:

$$\left(\beta^{*}_{ewG\alpha} < \beta_{ewG\alpha} \le \beta^{**}_{ewG\alpha}\right) \Rightarrow l_{2ewr} = \frac{e_{3r}\cdot\sin(\beta_{ewG\alpha}) + \cos(\beta_{ewG\alpha})\cdot\left(e_{2r} - e_{1r}\cdot tg(\beta_{ewG\alpha})\right)}{\sin(\beta_{ewG\alpha})} \quad (7)$$

$$\left(\beta^{**}_{ewG\alpha} < \beta_{ewG\alpha} < \beta^{***}_{ewG\alpha}\right) \Rightarrow l_{2ewr} = \frac{e_{2r}}{tg(\beta_{ewG\alpha})} - \left(e_{1r} - e_{3r}\right) \quad (8)$$

For $(L_k-\lambda_{old}) < (e_{2r}/(tg(\beta_{ewG\alpha}))-(e_{1r}-e_{3r}))$ and $\lambda_{old} < L_k$:

$$\left(\beta^{*}_{ewG\alpha} < \beta_{ewG\alpha} \le \beta^{**}_{ewG\alpha}\right) \Rightarrow l_{2ewr} = \frac{e_{3r}\cdot\sin(\beta_{ewG\alpha}) + \cos(\beta_{ewG\alpha})\cdot\left(e_{2r} - e_{1r}\cdot tg(\beta_{ewG\alpha})\right)}{\sin(\beta_{ewG\alpha})} - \left(L_k - \lambda_{old}\right) \quad (9)$$

$$\left(\beta^{**}_{ewG\alpha} < \beta_{ewG\alpha} < \beta^{***}_{ewG\alpha}\right) \Rightarrow l_{2ewr} = \frac{e_{2r}}{tg(\beta_{ewG\alpha})} - \left(e_{1r} - e_{3r}\right) - \left(L_k - \lambda_{old}\right) \quad (10)$$

For $(L_k-\lambda_{old}) \ge (e_{2r}/(tg(\beta_{ewG\alpha}))-(e_{1r}-e_{3r}))$:

$$l_{2ewr} = 0 \quad (11)$$

As it was mentioned the equations for l_{1ewl} and l_{2ewl} for the interval $0^\circ < \gamma_{G\alpha} < 180^\circ$ are identical as ones for l_{1ewr} and l_{2ewr} for the interval $180^\circ < \gamma_{G\alpha} < 360^\circ$. Within them the parameters e_{1l}, e_{2l} and e_{3l} are used instead of parameters e_{1r}, e_{2r} and e_{3r}. For calculation the parameters l_{1nsr} and l_{2nsr} as well as l_{1nsl} and l_{2nsl} the above equations are used but for the interval $90^\circ < \gamma_{G\alpha} < 270^\circ$ and $270^\circ < \gamma_{G\alpha} < 90^\circ$, respectively. Instead of the parameters e_{1l}, e_{2l}, e_{3l}, e_{1r}, e_{2r}, e_{3r} and $\beta_{ewG\alpha}$ the parameters f_{1l}, f_{2l}, f_{3l}, f_{1r}, f_{2r}, f_{3r} and $\beta_{nsG\alpha}$ are valid now.

2.2. The equations for λ_{new} (ξ_{new})

After calculation of the parameters l_{1ewr}, l_{2ewr}, l_{1ewl}, l_{2ewl}, l_{1nsr}, l_{2nsr}, l_{1nsl} and l_{2nsl} the parameters λ_{new} (ξ_{new}) are calculated. Before their calculation the parameters λ (ξ) has to be found. The parameters λ (ξ) present the lenght of irradiation in EWGα (NSGα) plane when the impact of LCE is neglected. That is why these parameters are designated as λ_{old} (ξ_{old}). The procedure for calculation the parameters λ_{old} (ξ_{old}) is explained in detail in [6]. When the parameters l_{1ewr}, l_{2ewr}, l_{1ewl}, l_{2ewl}, l_{1nsr}, l_{2nsr}, l_{1nsl}, l_{2nsl}, λ_{old} (ξ_{old}) and active sun beam situation (PIRR, FIRR and FSH) are known the "new" parameters λ_{new} (ξ_{new}) can be found as:

For $0^\circ < \gamma_{G\alpha} < 180^\circ$ and $180^\circ < \gamma_{G\alpha} < 360^\circ$ and FSH
$\lambda_{new} = \lambda_{old} \rightarrow$ FSH (12)

For $0^\circ < \gamma_{G\alpha} < 180^\circ$ and PIRR
$\lambda_{new} = \lambda_{old} - l_{1ewr} - l_{2ewr} \rightarrow$ PIRR (13)

For $180^\circ < \gamma_{G\alpha} < 360^\circ$ and PIRR
$\lambda_{new} = \lambda_{old} - l_{1ewl} - l_{2ewl} \rightarrow$ PIRR (14)

For $0^\circ < \gamma_{G\alpha} < 180^\circ$, FIRR and $l_{1ewr} = 0$, $l_{2ewr} = 0$
$\lambda_{new} = \lambda_{old} \rightarrow$ FIRR (15)

For $180^\circ < \gamma_{G\alpha} < 360^\circ$, FIRR and $l_{1ewl} = 0$, $l_{2ewl} = 0$
$\lambda_{new} = \lambda_{old} \rightarrow$ FIRR (16)

For $0^\circ < \gamma_{G\alpha} < 180^\circ$, FIRR and $l_{1ewr} = 0$, $l_{2ewr} > 0$
$\lambda_{new} = \lambda_{old} - l_{2ewr} \rightarrow$ FIRR (17)

For $180^\circ < \gamma_{G\alpha} < 360^\circ$, FIRR and $l_{1ewl} = 0$, $l_{2ewl} > 0$
$\lambda_{new} = \lambda_{old} - l_{2ewl} \rightarrow$ FIRR (18)

For $0^\circ < \gamma_{G\alpha} < 180^\circ$, FIRR and $l_{1ewr} > 0$, $l_{2ewr} > 0$
$\lambda_{new} = \lambda_{old} - l_{1ewr} - l_{2ewr} \rightarrow$ PIRR (19)

For $180^\circ < \gamma_{G\alpha} < 360^\circ$, FIRR and $l_{1ewl} > 0$, $l_{2ewl} > 0$
$\lambda_{new} = \lambda_{old} - l_{1ewl} - l_{2ewl} \rightarrow$ PIRR (20)

If obtained value of parameter λ_{new} is negative that means that in some of planes (EWGα or NSGα) the sun beam situation FSH is active instead of the situation PIRR. The equations which are valid now are split into ones that are used for a combination of cases **E-F** and ones for a combination of cases **A-B**. The mentioned equations are given below:

For cases (subcases) **A-B**

If $(L_k+w_1) > (L_r/2)$ then:
For $0° < \gamma_{G\alpha} < 180°$

$$\lambda_{new} = \frac{L_r - 2w_1}{2} - \frac{y}{tg\beta_{ewG\alpha}} \quad (21)$$

For $180° < \gamma_{G\alpha} < 360°$, $tg\beta^*_{ewG\alpha} = y/(L_k+w_1-(L_r/2))$

$$\beta_{ewG\alpha} \geq \beta^*_{ewG\alpha} \Rightarrow \lambda_{new} = \frac{L_r - 2w_1}{2} + \frac{y}{tg\beta_{ewG\alpha}} \quad (22)$$

$$\beta_{ewG\alpha} < \beta^*_{ewG\alpha} \Rightarrow \lambda_{new} = L_k \quad (23)$$

If $(L_k+w_1) = (L_r/2)$ then:
For $0° < \gamma_{G\alpha} < 180°$

$$\lambda_{new} = L_k - \frac{y}{tg\beta_{ewG\alpha}} \quad (24)$$

For $180° < \gamma_{G\alpha} < 360°$

$$\lambda_{new} = L_k \quad (25)$$

If $(L_k+w_1) < (L_r/2)$ then:
For $0° < \gamma_{G\alpha} < 180°$, $tg\beta^*_{ewG\alpha} = y/((L_r/2)-(L_k+w_1))$

$$\beta_{ewG\alpha} \geq \beta^*_{ewG\alpha} \Rightarrow \lambda_{new} = L_k \quad (26)$$

$$\beta_{ewG\alpha} < \beta^*_{ewG\alpha} \Rightarrow \lambda_{new} = \frac{L_r - 2w_1}{2} - \frac{y}{tg\beta_{ewG\alpha}} \quad (27)$$

For $180° < \gamma_{G\alpha} < 360°$

$$\lambda_{new} = L_k \quad (28)$$

For cases (subcases) **E-F**

If $(L_r/2=v_1)$ and $(L_k/2=v_1)$ then:
For $0° < \gamma_{G\alpha} < 180°$ and $180° < \gamma_{G\alpha} < 360°$

$$\lambda_{new} = L_k - \frac{y}{tg\beta_{ewG\alpha}} \quad (29)$$

If $(L_r/2>v_1)$ and $(L_r/2<(L_k-v_1))$ then:
For $0° < \gamma_{G\alpha} < 180°$

$$\lambda_{new} = \frac{L_r + 2v_1}{2} - \frac{y}{tg\beta_{ewG\alpha}} \quad (30)$$

For $180° < \gamma_{G\alpha} < 360°$, $tg\beta^*_{ewG\alpha} = y/((L_r/2)-v_1)$, $tg\beta^{**}_{ewG\alpha} = y/(L_k-v_1-(L_r/2))$

$$\beta^*_{ewG\alpha} \leq \beta_{ewG\alpha} \leq \beta^{**}_{ewG\alpha} \Rightarrow \lambda_{new} = \frac{L_r + 2v_1}{2} + \frac{y}{tg(\beta_{ewG\alpha})} \quad (31)$$

$$\beta^*_{ewG\alpha} \leq \beta_{ewG\alpha} < \beta^{**}_{ewG\alpha} \Rightarrow \lambda_{new} = L_k \quad (32)$$

$$\beta^*_{ewG\alpha} > \beta_{ewG\alpha} \geq \beta^{**}_{ewG\alpha} \Rightarrow \lambda_{new} = L_r \quad (33)$$

$$\beta^*_{ewG\alpha} > \beta_{ewG\alpha} < \beta^{**}_{ewG\alpha} \Rightarrow \lambda_{new} = \frac{L_r - 2v_1}{2} - \frac{y}{tg(\beta_{ewG\alpha})} + L_k \quad (34)$$

If $(L_r/2>v_1)$ and $(L_r/2=(L_k-v_1))$ then:
For $0° < \gamma_{G\alpha} < 180°$

$$\lambda_{new} = L_k - \frac{y}{tg\beta_{ewG\alpha}} \quad (35)$$

For $180° < \gamma_{G\alpha} < 360°$, $tg\beta^*_{ewG\alpha} = y/((L_r/2)-v_1)$

$$\beta_{ewG\alpha} \geq \beta^*_{ewG\alpha} \Rightarrow \lambda_{new} = L_k \quad (36)$$

$$\beta_{ewG\alpha} < \beta^*_{ewG\alpha} \Rightarrow \lambda_{new} = \frac{L_r - 2v_1}{2} - \frac{y}{tg(\beta_{ewG\alpha})} + L_k \quad (37)$$

If $(L_r/2>v_1)$ and $(L_r/2>(L_k-v_1))$ then:
For $0° < \gamma_{G\alpha} < 180°$, $tg\beta^*_{ewG\alpha} = y/((L_r/2)-v_1)$

$$\beta_{ewG\alpha} \geq \beta^*_{ewG\alpha} \Rightarrow \lambda_{new} = L_k \quad (38)$$

$$\beta_{ewG\alpha} < \beta^{*}_{ewG\alpha} \Rightarrow \lambda_{new} = \frac{L_r - 2v_1}{2} - \frac{y}{tg(\beta_{ewG\alpha})} + L_k \quad (39)$$

For $180^\circ < \gamma_{G\alpha} < 360^\circ$, $tg\beta^{*}_{ewG\alpha} = y/((L_r/2)-v_1)$

$$\beta_{ewG\alpha} \geq \beta^{*}_{ewG\alpha} \Rightarrow \lambda_{new} = L_k \quad (40)$$

$$\beta_{ewG\alpha} < \beta^{*}_{ewG\alpha} \Rightarrow \lambda_{new} = \frac{L_r - 2v_1}{2} - \frac{y}{tg(\beta_{ewG\alpha})} + L_k \quad (41)$$

The equations for ξ_{new} are same as the equations for λ_{new} with difference that now the parameters W_k, W_r, v_2, w_2, $\beta_{nsG\alpha}$, l_{1nsr}, l_{2nsr}, l_{1nsl} and l_{2nsl} are used instead of the parameters L_k, L_r, v_1, w_1, $\beta_{ewG\alpha}$, l_{1ewr}, l_{2ewr}, l_{1ewl} and l_{2ewl}.

2.3. The equations for a_p, $b_{pewG\alpha}$, $b_{pnsG\alpha}$

In order to determine the irradiated area of the LAS (A_{irr}) when the impact of LCE is included it is necessary to determine the parameters a_{pnew} ($DO_{ewG\alpha}$-$DO_{nsG\alpha}$), a_{pnew} ($DO_{ewG\alpha}$-$POZ_{nsG\alpha}$) and $b_{pewG\alpha new}$ ($b_{pnsG\alpha new}$), too. The equations for calculation of these parameters are presented below. As it was mentioned those equations are defined only for EWGα plane. Because of the similarity between the equations for the interval $0^\circ < \gamma_{G\alpha} < 180^\circ$ and the interval $180^\circ < \gamma_{G\alpha} < 360^\circ$, only the equations for the interval $0^\circ < \gamma_{G\alpha} < 180^\circ$ are presented below. Before the calculation of above parameters the "old" parameters a_{pold} (a_p), $b_{pewG\alpha old}$ ($b_{pewG\alpha}$) and $b_{pnsG\alpha old}$ ($b_{pnsG\alpha}$) have to be known. The equations for their calculation are given in [6].

For $0^\circ < \gamma_{G\alpha} < 180^\circ$, a_{pnew} ($DO_{ewG\alpha}$-$DO_{nsG\alpha}$), $b_{pewG\alpha new}$, a_{pnew} ($DO_{ewG\alpha}$-$POZ_{nsG\alpha}$)

$DO_{ewG\alpha}$-$DO_{nsG\alpha}$: $a_{pnew} = a_{pold} - l_{2ewr}$ (42)

$$b_{pewG\alpha new} = b_{pewG\alpha old} + e_{1r} + e_{2r} \cdot tg(90^\circ - \beta_{ewG\alpha}) \quad (43)$$

If $b_{pewG\alpha new} + 2p_{ewG\alpha old} \geq L_k + e_{1r} + e_{2r} \cdot tg(90^\circ - \beta_{ewG\alpha})$ then

$$b_{pewG\alpha new} = L_k + e_{1r} + e_{2r} \cdot tg(90^\circ - \beta_{ewG\alpha}) - 2p_{ewG\alpha old} \quad (44)$$

$DO_{ewG\alpha}$-$POZ_{nsG\alpha}$: $a_{pnew} = b_{pewG\alpha new} + \lambda_{new}$ (45)

If $b_{pewG\alpha new} + 2p_{ewG\alpha old} \geq L_k + e_{1r} + e_{2r} \cdot tg(90^\circ - \beta_{ewG\alpha})$ then

$$a_{pnew} = L_k + e_{1r} + e_{2r} \cdot tg(90^\circ - \beta_{ewG\alpha}) - 2p_{ewG\alpha old} + \lambda_{new} \quad (46)$$

The equations for the interval $180^\circ < \gamma_{G\alpha} < 360^\circ$ are same as above equations for the interval $0^\circ < \gamma_{G\alpha} < 180^\circ$ except that the parameters l_{2ewl},

e_{1l} and e_{2l} are used instead of the parameteres l_{2ewr}, e_{1r} and e_{2r}. As it was mentioned at the beginning of this chapter, the above equations are valid only when the reflector is left in EWGα plane and right in NSGα plane relative to the collector. For other reflector-collector positions the rules from Table 3 given in [6].

3. Conclusion

In this paper the mathematical model for determining the irradiated area of the LAS of the BFPC, when the impact of the LCE is included, is presented. The LCE are the integral part of every flat-plate solar collector. It means that they will always affect the formation of the irradiated area of the LAS. Because of that, the size of the irradiated area is always less then the size of the same area when the impact of the LCE is neglected. It should be noted that the impact of the LCE increases when the dimensions of the collector decrease if the dimensions of the LCE do not change.

4. References

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