**solar radiation**

* direct normal irradiance (DNI): part of NEN, plane perpendicular to solar beam (ideal tracking)
* direct horizontal irradiance: irradiance on a horizontal plane , with

h = solar altitude (with correction for parallax and refraction)

* diffuse horizontal irradiance: diffuse light on horizontal plane (diffuse by atmosphere, measured at ground level)
* global horizontal irradiance: direct horizontal + diffuse horizontal
* ground reflected irradiance: diffuse radiation reflected from the ground surface, fraction of the global horizontal irradiance
* global irradiance on surface: sum of direct, diffuse and reflected diffuse

What is measured by the weather stations? direct horizontal

**In NEN:**

globale zonnestraling: gemeten? Ja, de Bilt globale zoninstraling (op horizontaal vlak?)

diffuse zonnestraling: afgeleid? (diffuus + direct = globaal)

directe zonnestraling: afgeleid? (diffuus + direct = globaal)

directe normale zonnestraling: gemeten/theoretisch/afgeleid? niet gemeten

NEN 5060 pag 10 noemt methode om maandoverrgangen glad te trekken: NEN-EN-ISO 15927-4

In appendix D.1.9, the NEN gives a method for deriving the direct and diffuse components of the measured global irradiation on a horizontal surface. No reference for the presented equations has been given, which makes the foundation for this approach weak.

<https://reader.elsevier.com/reader/sd/pii/S0038092X12001132?token=188766777AF37A2C47E4B7165B67F0C210B301B071447FDF8125CF423F363618CE2F487EB111A92BEFDB4F9268C85DDA&originRegion=eu-west-1&originCreation=20220322105943>

The paper above presents a comparison on of different models for estimating the diffuse fraction of the irradiance. One of the methods is the Erbs model (by Erbs, Klein and Duffie, 1982). This model shows great resemblance to the equations in the NEN, although there seem to be several typos. [investigating the original paper of Erbs et al. shows that the typos are mainly in the NEN]. In the conclusion the authors mention that the Erbs model is one of the more accurate models, together with the model from Reindl et al. and the model from Orgiil and Hollands. The paper presents a further comparison with a model with “adapted coefficients” based on a polynomial fitting of irradiance measurements performed in Vienna. Unfortunately, the adapted coefficients are not presented in the paper, only the results that claim the improved performance.

**direct insolation on an inclined surface**

I\_direct\_surface = cos(theta) \* I\_direct\_normal

I\_direct\_surface = cos(theta)/sin(h) \* I\_horizontal

cos(theta) = max(0, sin(h)\*cos(beta)+cos(h)\*sin(beta)\*cos(A-gamma)

h: solar altitude

A: solar azimuth (what definition north= 0 or south = 0)

beta: inclination of surface (zero = horizontal)

gamma: azimuth surface (south = 0, east -90, west = 90)

theta= angle between surface normal and direction of sun

<https://github.com/pvedu/photovoltaic> contains a library of python functions used in photovoltaics

**PV-panel**

**temp pv:** vgl. 3.5.1 (Dictaat Marc) dependent windspeed and global insolation on panel = direct +diffuse + reflected

A linear dependency of the efficiency on the cell temperature may be assumed:

parameters: some reference value at reference temp, and a shift in efficiency per degree

Joao Gomes et al, Minimizing the impact of shading at oblique solar angles in ... , 2014: assumes a constant efficiency for a insolation levels of 0 to 1000 W/m2

chengquan Xiao et al., Impact of solar irradiance intensity and temperature on the performance ..., 2014, shows a near constant efficiency over the range 400 – 1000 W/m2, for lower insolation levels the efficiency drops, in a nonlinear fashion. this trend can be found in other articles as well

(<https://www.semanticscholar.org/paper/Efficiency-VS.-irradiance-characterization-of-PV-Donovan-Bourne/f3f6bd7c8379ee52da7435d7aa6f2d1404772ca9/figure/0>)

<https://www.researchgate.net/publication/263243375_Improvement_in_Perturb_and_Observe_Method_for_Maximum_Power_Point_Tracking_of_PV_Panel>

Improvement in Perturb and Observe Method for Maximum Power Point Tracking of PV Panel

(<https://www.researchgate.net/publication/263243375_Improvement_in_Perturb_and_Observe_Method_for_Maximum_Power_Point_Tracking_of_PV_Panel>)

gives a set of equations for the load current as a function of the temp, reverse saturation current, and voltage based on a basic circuit model of the PV panel. They show computed efficiency curves as function of the insolation for different temps

What do we want?

## PV-panel

Is a surface with orientation

* **area**: surface area in square meters
* **inclination**: angle with the horizontal plane (0 to 90 degrees)
* **azimuth**: angle with due south direction -180 to 180 degrees
* **get insolation level at a given time** (global insolation based on orientation and surface area + time + weather)
  + global insolation = direct + diffuse + reflected
    - direct depends on orientation, time of day (sun location), NEN-direct insolation on horizontal plane?
    - diffuse (directly from NEN)
    - reflected

NEN provides global on horizontal plane. diffuse is orientation independent, direct is orientation dependent.

PV-specific properties

* **nominal\_operation\_temp:** spec from data sheet
* **nominal\_efficiency:** efficiency at nominal operation temp, spec from data sheet
* **efficiecy\_loss\_parameter**
* **temperature computation** vgl 3.5.1 dictaat marc (input windspeed, amb temp, insolation)

More detailed model in app B1.



T\_a --> amb. temp from the NEN

v\_w --> wind\_speed from NEN

I\_g,s --> global insolation from NEN

* **efficiency factor**, function of temp and insolation level **+ panel parameters** (first implementation only temp)



T\_cell --> from computation above

eta\_cell,N: nominal efficiency --> parameter from panel specs (example value from lecture notes **fig 3.5.4** module efficiency: 0.183 / 18.3 %)

T\_cell,N: nominal operation temp --> parameter from panel specs, (example value from lecture notes **fig 3.5.4** nominal operating temp: 45 degrees Celsius)

gamma\_T: efficiency\_loss\_parameter --> parameter from panel specs, (example value from lecture notes **fig 3.5.4** P\_mpp: -0.41 %/degree --> gamma\_T -0.0041

* **output power** ( efficiency factor, insolation level)

output\_power = eta\_cell \* global\_insolation

eta\_cell --> temperature fependent efficiency from computation above

global\_insolation --> from get insolation level at given time on oriented surface.

At this moment the electrical output is disconnected from the rest of the house, when the model is extended to electrical energy we can hook this up. (of course a output of the electrical output can be generated and plotted when desired.)

# Thermal collector

heat balance eq. 4.2.1 dictaat: useful energy yield based on (surface area, heat removal factor, absorbed solar radiation, heat loss coeff, inlet temp – amb temp)

efficiency factor = useful energy/(global insolation\*surface area)

appendix C. gives an detailed model description of a flat plate collector.

Do we want to implement this? Is there an implementation available?

I guess we need to do this as it is all about the heat transfer to the fluids.

Large set of parameters, is this practically available?

What is the interface?

-------------------------------------------------------------------------------------------------------------

# collector

**Surface with orientation:**

* **area**: surface area in square meters (user input)
* **inclination**: angle with the horizontal plane (0 to 90 degrees) (user input)
* **azimuth**: angle with due south direction -180 to 180 degrees (user input)
* **get insolation level at a given time time** (global insolation based on orientation and surface area + time + weather)
  + global insolation = direct + diffuse + reflected
    - direct depends on orientation, time of day (sun location), NEN-direct insolation on horizontal plane?
    - diffuse (directly from NEN)
    - reflected

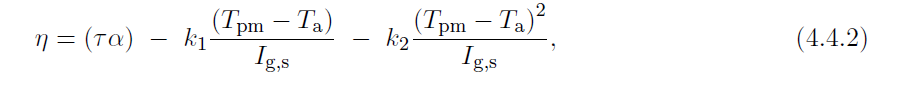
NEN provides global on horizontal plane. diffuse is orientation independent, direct is orientation dependent.

collector specific:

* **C\_p**: specific heat collector fluid [J/(kg\*K)
* **density\_fluid**: density fluid [kg/m^3]
* **flow\_rate:** flow rate of the collector fluid (m^3/sec)
* **tau\_alpha:** collector property for transmittance/absorbance in simplified equations (example value 0.8 [page 84, exc. 3])
* **k\_1:** model parameter in simplified model (example value 3.58 W/(m2\*K) [page 84, exc. 3]))
* **k\_1:** model parameter in simplified model (example value 0.018 W/(m2\*K2) [page 84, exc. 3]))

lets start with the simplified equations as mentioned in 4.4.1 of Marc

**efficiency**:



tau\_alpha: collector property should be handed as input

k\_1 = measured parameter should be handed as input

k\_2 = measured parameter should be handed as input

T\_a : ambient temp from NEN

I\_g,s: global insolation on the collector from get insolation at a given time [W/m2]

Tpm: mean absorber plate temp (How do we obtain this?)

energy balance



from this we can get the outflow temp:

* Q\_u = eta \* Ig,s \* A\_c
* Tfo = Tfi + Q\_u/(Phi\_m\*C\_p)

Phi\_m is the fluid mass flow ion kg/s, depending on the fluid and flow rate

**fluid\_mass\_flow = flow\_rate \* density**

C\_p is the specific heat, depends on the fluid (input by user?)

* useful energy yield collector:



A\_c --> **area** collector (input property)

F\_R --> heat removal factor, how do we get this? (section 4.2.4)

S --> absorbed solar irradiation, how do we get this (section 4.2.2)

U\_L --> heat loss coeff, how do we get this (section 4.2.5)

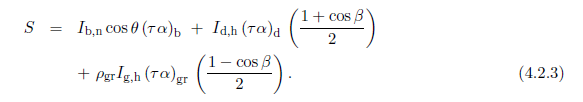
T\_fi --> inlet temp collector fluid, This should come from the heat exchange with buffer vessel (how will the interface be?)

T\_a --> ambient temp, from NEN

Is this what we need? Or do we need something that computes the Temp of the returning collector fluid. How to use the solar collector in the house model?

What will be the interface with the heatpump??

* Insolation absorbed by collector:



# PVT

combination of PV and Thermal collector

<https://www.researchgate.net/publication/291338864_Analysis_of_Flat_Plate_Photovoltaic-Thermal_PVT_Models>

<https://www.sciencedirect.com/science/article/pii/S0038092X19309223>

gives two models for the thermal performance, using the electrical circuit equivalent like the house.

first model with one capacitor, the second with two thermal capacitors.