Introduction and objectives
We are developing a concentrated photo-voltaic system for the built environment. Apart from generating electrical energy using small and efficient triple-junction PV cells, we aim at preventing direct sunlight from entering the building, while diffuse daylight can still provide sufficient ambient lighting. Thus, additional energy is saved because the building needs less cooling. Our target market consists of greenhouses and other buildings with glass roofs or skylights, like shipping containers. In this poster, we present a lightweight and accurate routine to compute the position of the Sun, and a model that predicts the energy yield, mutual shading and the energy flux that passes between the units and falls on the ground, for a field of CPV modules.

An accurate position for the Sun
We present a C routine called SolTrack [1] that can compute the position of the Sun in topocentric coordinates, both in a horizontal and in an equatorial system. The code is based on the Fortran library libTheSky [2] and includes corrections for aberration and parallax, and a simple routine to correct for atmospheric refraction [3]. We compared the performance of our code to detailed calculations using VSOP87 [4] and an accurate model for atmospheric refraction [5]. This was carried out for 100,000 random moments in the next 100 years (between 2014 and 2113) when the Sun is above the horizon in the Netherlands. We find that the error in position is $0.0036 \pm 0.0038^\circ$, which is sufficient for solar tracking of CPV systems under all conditions. The achieved accuracy would result in 0.095% of loss of power if the circular solar image would fall outside a PV chip by that amount. The code can compute a million positions in 2.28 $\pm$ 0.04 s on a single 2.67 GHz CPU core when only horizontal coordinates (azimuth and altitude) are computed, and takes 2.80 $\pm$ 0.05 s if refraction-corrected parallactic coordinates are also calculated.

Comparison to PSA and SPA
When compared to the PSA SunPos routine [6], which is also lightweight and freely available, our code is 20 times more accurate and 10% faster (see Table 1). When correcting equatorial coordinates for refraction, our code is 11% slower than SunPos. We also compared the performance of the code to the NREL SPA routine [7], which is more elaborate and has a more restricted licence. SPA is 37% more accurate than SolTrack, but also seven times slower. Here, we computed only the Sun’s position in SPA (no rise and set times or incident radiation) and corrected equatorial coordinates for refraction in our code, which is not available in SPA.

The high accuracy and low computational cost allow a flexible use of SolTrack, ensuring that the code can run on inexpensive, low-spec embedded systems like the STM32F4 DISCOVERY boards, on simple systems with lightweight operating systems like the Raspberry Pi, on PLCs and on standard PCs or servers. In addition to SolTrack, we are developing a closed-loop system that allows feedback from sensors near the PV cell in order to correct for discrepancies that arise due to e.g. an imperfect installation of the system, or mechanical deformations. In addition, we have designed an algorithm that takes into account non-perfect alignment, for example because the system is aligned with the main axes of the building, rather than the north-south axis.

Modelling a field of CPV units
We developed a code to model a field of CPV units (Fig. 3), in order to determine the influence of their mutual distance on the energy yield, and the amount of sunlight that reaches the ground. In particular, we simulate the mutual shading between the CPV units. In addition, we can visualise what happens if e.g. we do not track the Sun all the way to the horizon, in favour of a tighter grid of CPV modules, or how the yield changes as a function of geographical location. Figure 4 shows that a tighter grid not only allows less direct sunlight to fall on the ground, but also has a decreased electrical yield, due to increased shading.

Conclusions and future work
► Using a simple prescription for atmospheric refraction significantly improves the accuracy of the Sun’s computed position, and hence the yield of solar energy for CPV, without additional computational cost;
► We are developing a closed-loop system to correct for an imperfect orientation of the units and mechanical inaccuracies;
► A detailed model of a field of CPV units allows us to determine the optimal constellation for a specific purpose, and find an acceptable consensus between the electrical yield and the flux of sunlight that falls on the ground.

References