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ON THE SUN-EARTH ANGLES USED IN THE SOLAR TRACKERS' DESIGN. PART 2: SIMULATIONS

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Abstract: Based on the formulas established in the first part, the second part of the paper presents simulations for certain representative latitudes from the northern hemisphere. There are also presented the interpretation of the obtained results. The obtained data play an important role in the solar trackers' design.

1. Introduction

Based on the formulas established in the first part of the paper, the second part presents simulations for certain representative latitudes, between 0° and 90°N, and their interpretation with explanations of the curves' meanings. The obtained data play an important role in the choice of the solar trackers' type and in their design also.

2. The declination angle variation

The declination angle depends only on *n* (the day number of the year); this means that the declination angle remains the same at any latitude (see Fig. 1.).

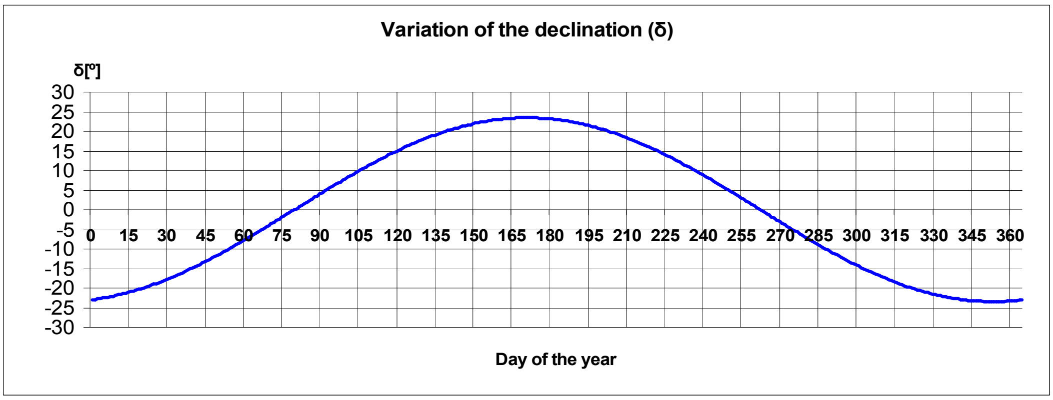

Fig. 1. *The variation of the declination during the year*

3. The hour angle variation when the latitude varies from 0° (Equator) to 90° N

In Fig. 2, …, 7 there are represented the diagrams obtained from the hour angle simulations corresponding to 0°, 23,45°; 45°; 66,55°; 75° and 89,99° latitude N. These diagrams allow the analysis of the hour angle variation, when the latitude varies between 0° (Equator) and 90° N.

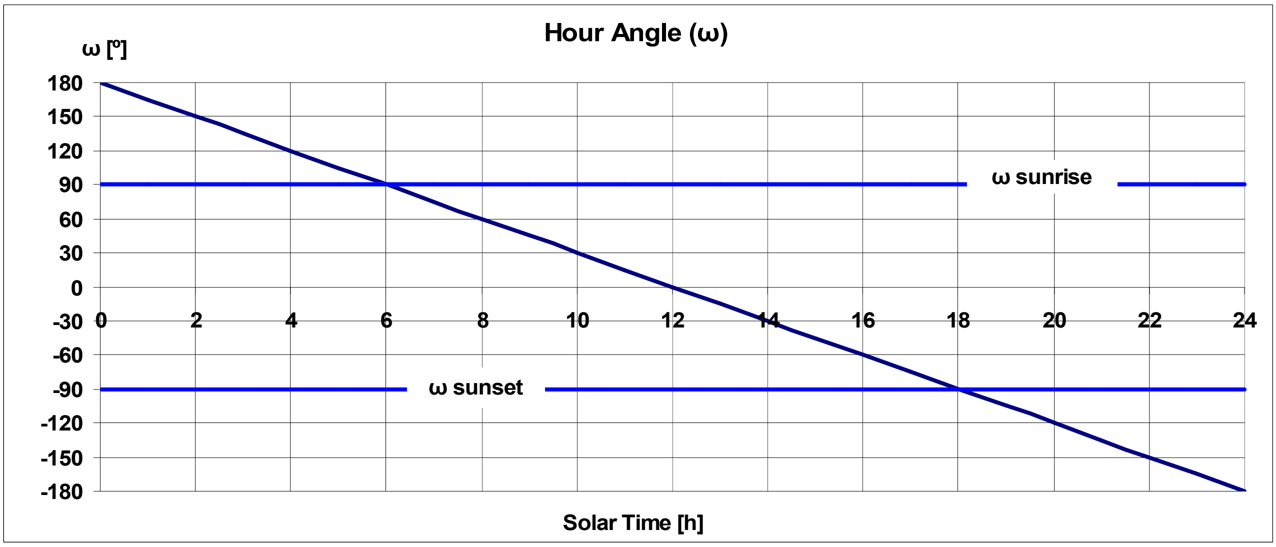

Fig. 2. *The variation of the hour angle at 0° latitude*

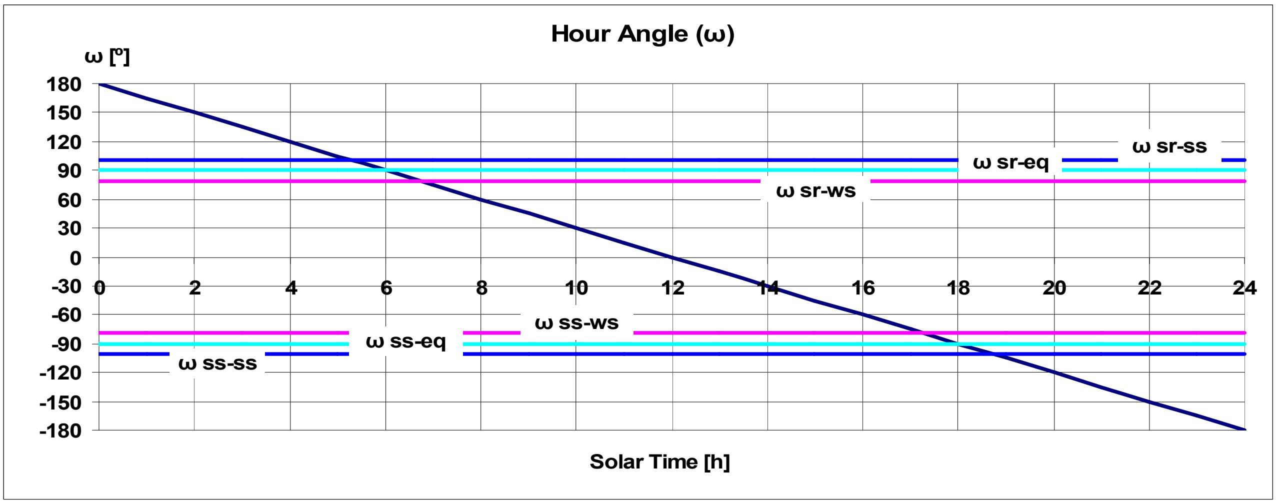

Fig. 3. *The variation of the hour angle at 23,45° latitude N*

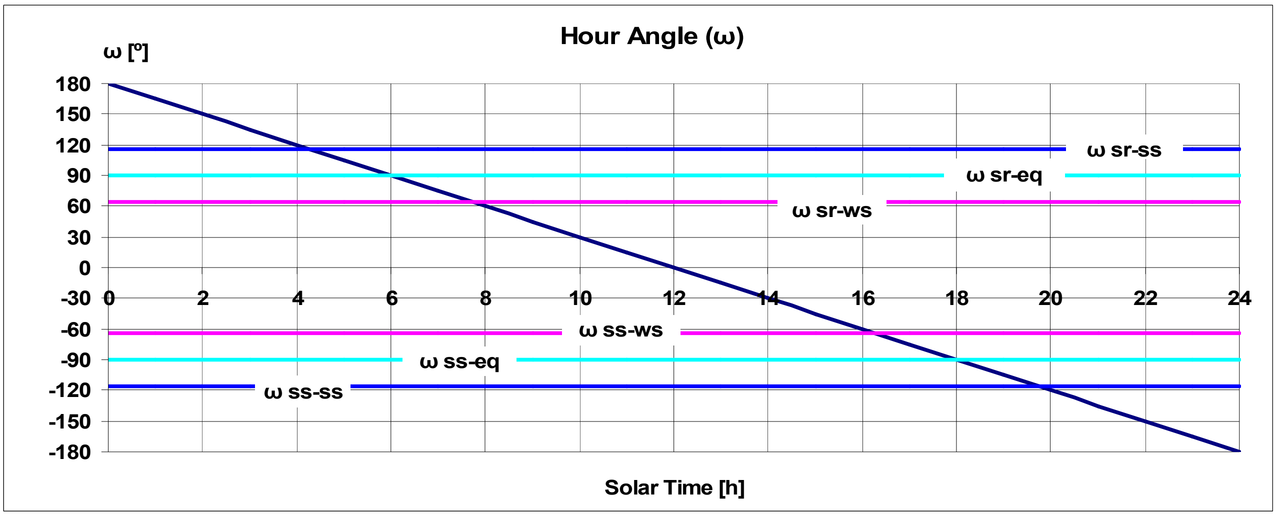

Fig. 4. *The variation of the hour angle at 45° latitude N*

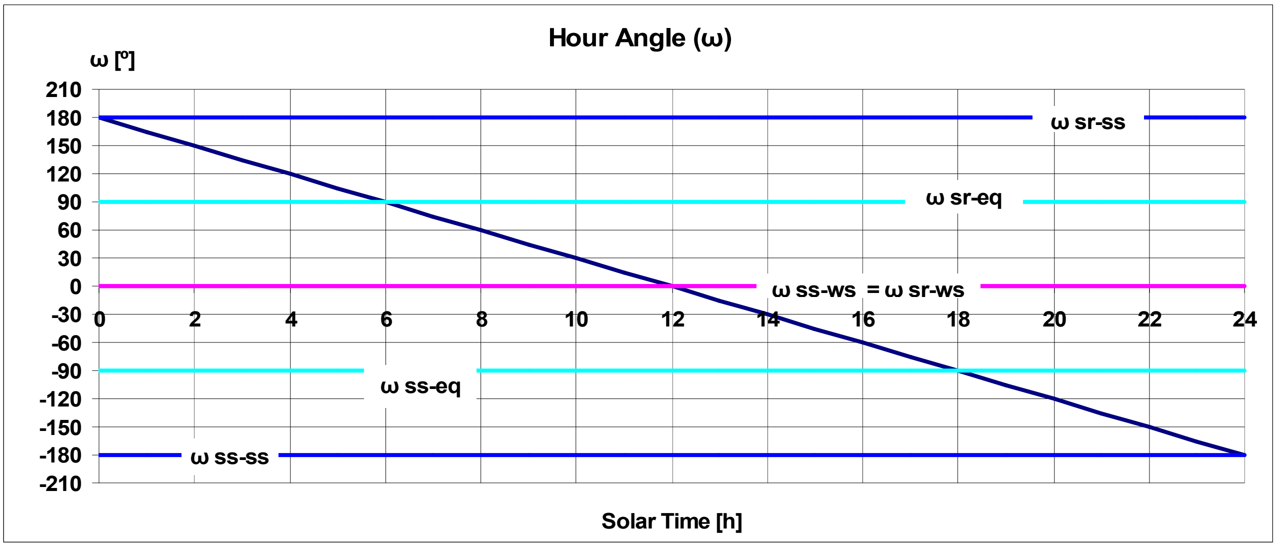

Fig. 5. *The variation of the hour angle at 66,55° latitude N*

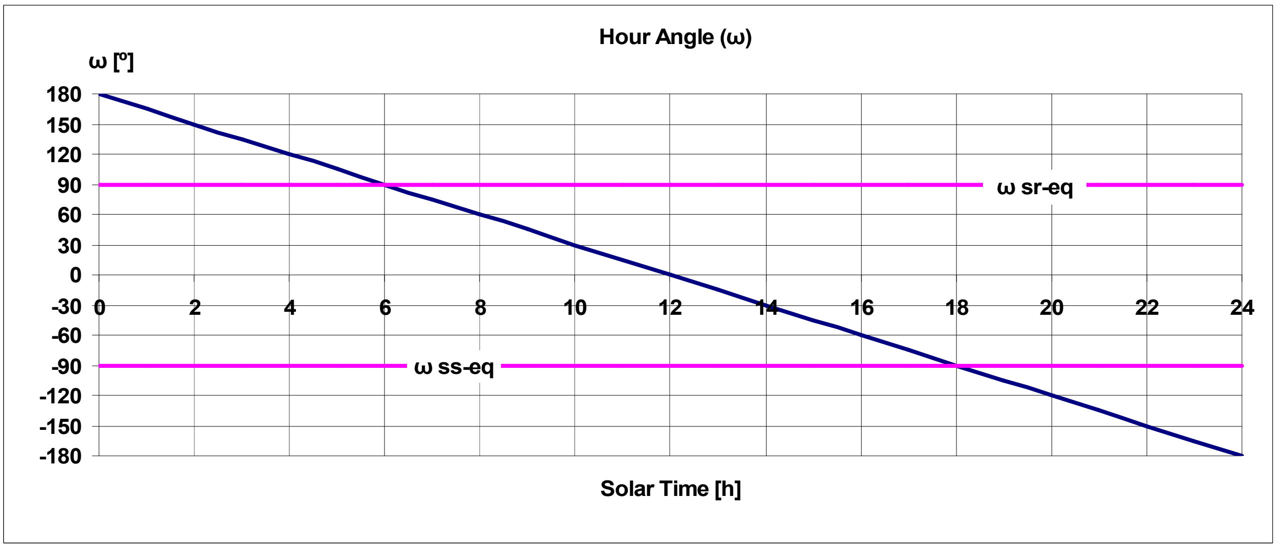

Fig. 6. *The variation of the hour angle at 75° latitude N*

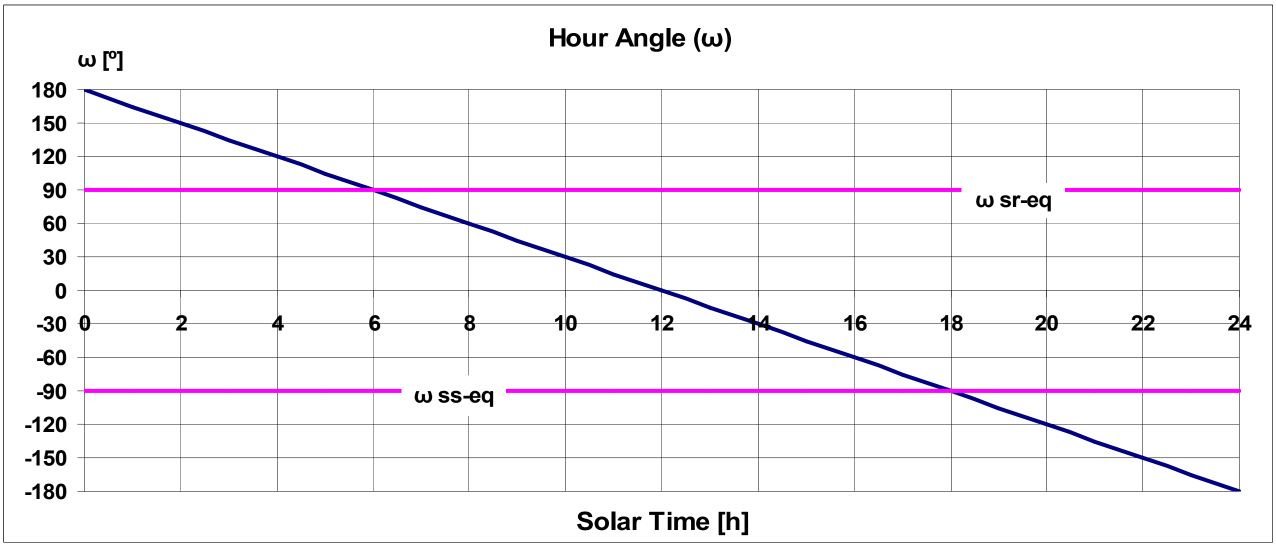

Fig. 7. *The variation of the hour angle at 89,99° latitude N*

The analysis of the Fig. 2, …, 6 leads to the following conclusions:

a) The variation of the hour angle is linear and remains always the same; this means that, relative to the Earth, the Sun has always a constant angular velocity equal to 15°/h;

b) In accordance with the diagram from Fig. 2, at the equator (0° latitude) the Sun rises at the same hour a.m. and sets at the same hour p.m., in all the four representative days of the year (summer and winter solstices, vernal and autumnal equinoxes) and implicitly in every day of the year;

c) In contrast to 0° latitude, when the latitude increases, the sunrises and the sunsets corresponding to the four representative days (summer and winter solstices, vernal and autumnal equinoxes) become different: at summer solstice the sunrise angle increases, at equinoxes it remains always 90° and at winter solstice it decreases;

d) The day duration has the following behavior when the latitude increases (see Fig. 2,…, 7): it increases at summer solstice, it remains the same at equinoxes (because in these cases: $\omega_{SR} = -\omega_{SS} = 90°$) and it decreases at winter solstice;

e) For latitudes between 66,55° N and 90° N, the sunrise and the sunset don't exist at solstices; this means that at summer solstice it is only day and at winter solstice it is only night.

4. The azimuth and altitude variations when the latitude varies from 0° to 90° N

In Fig. 8, …, 14 there are represented the diagrams obtained from the azimuth and altitude simulations corresponding to 0°, 15°; 23,45°; 45°; 66,55°; 75° and 89,99° latitude N. These diagrams allow the analysis of the azimuth and altitude variations, when the latitude varies between 0° (Equator) and 90° N.

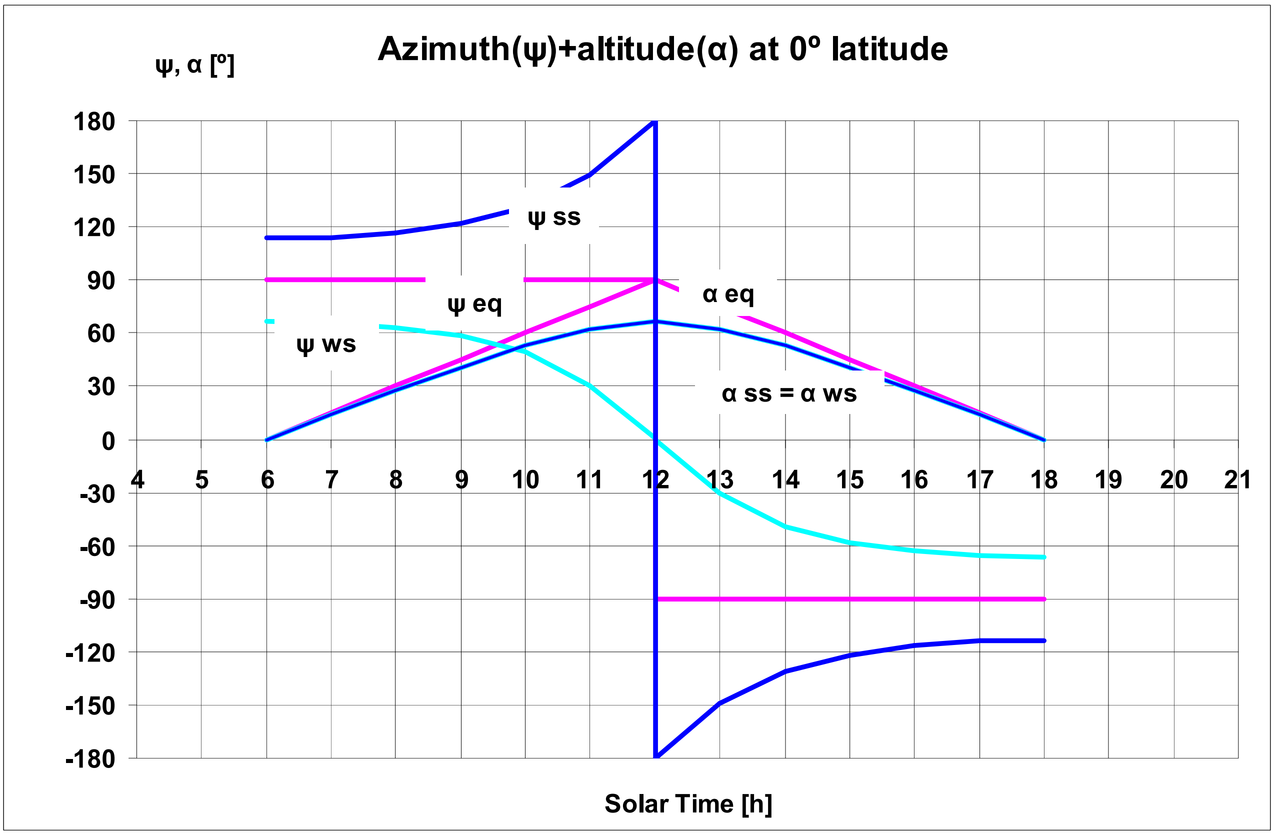

Fig. 8. *The variation of the azimuth and altitude at 0° latitude*

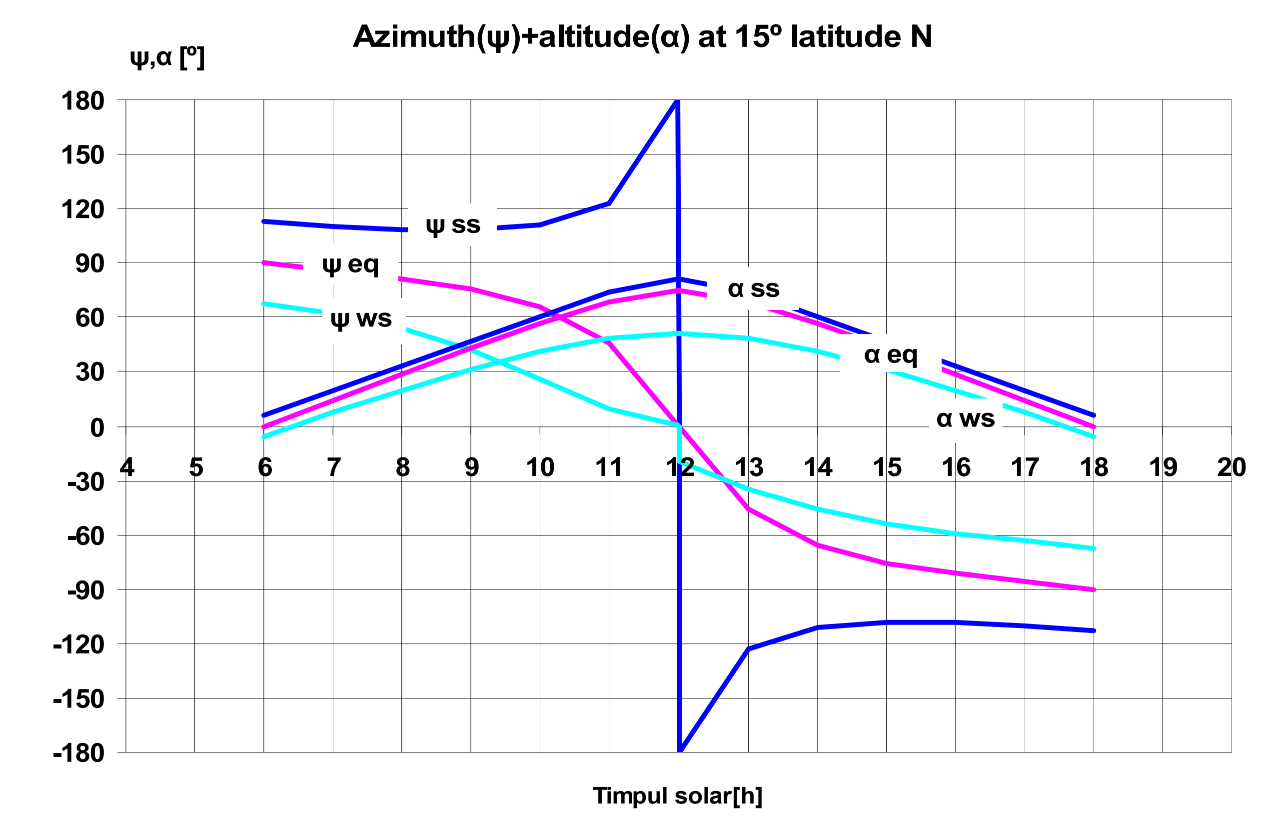

Fig. 9. The variation of the azimuth and altitude at 15° latitude N

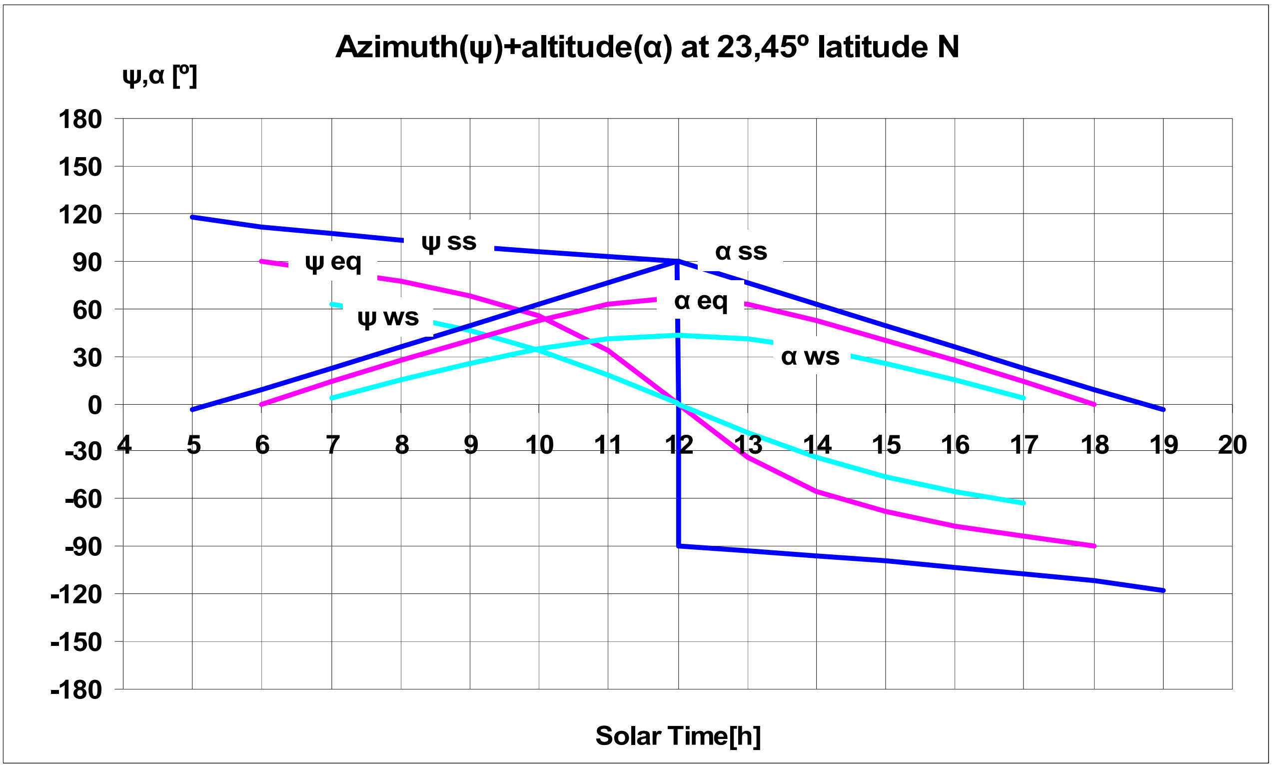

Fig. 10. The variation of the azimuth and altitude at 23,45° latitude N

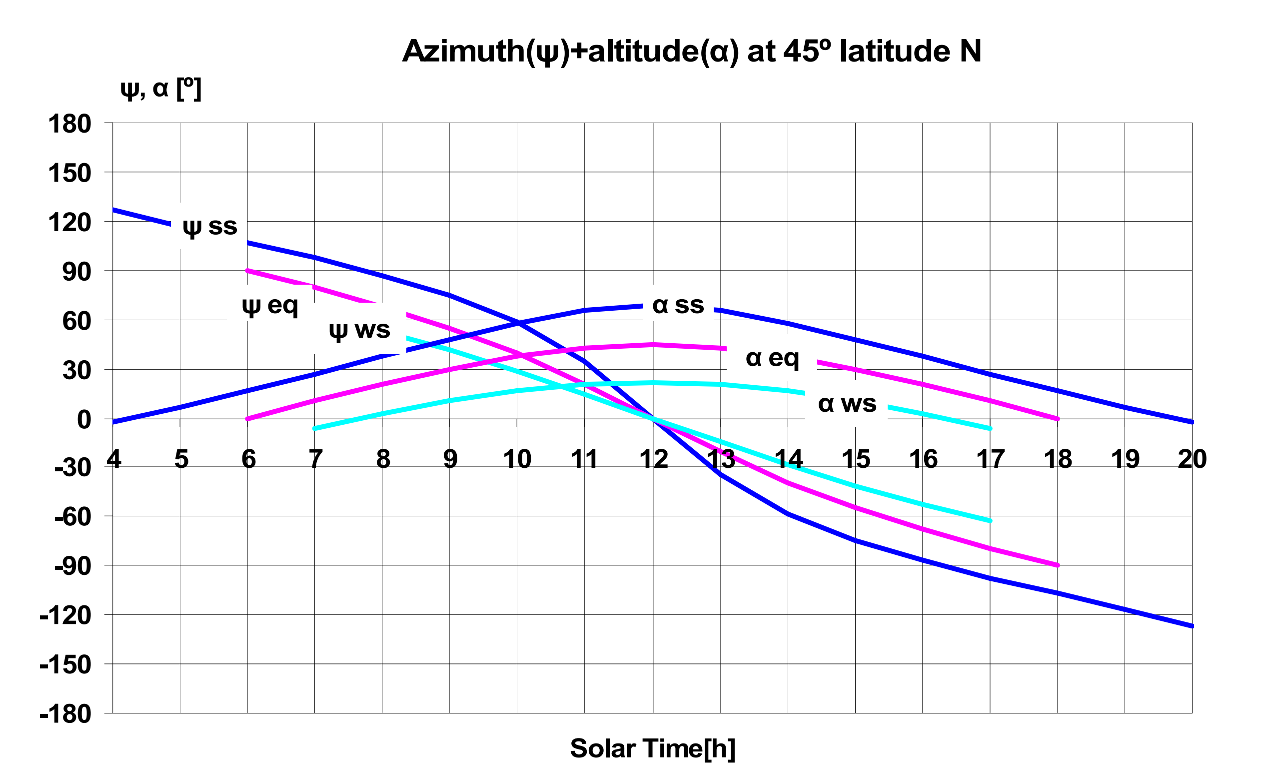

Fig. 11. *The variation of the azimuth and altitude at 45° latitude N*

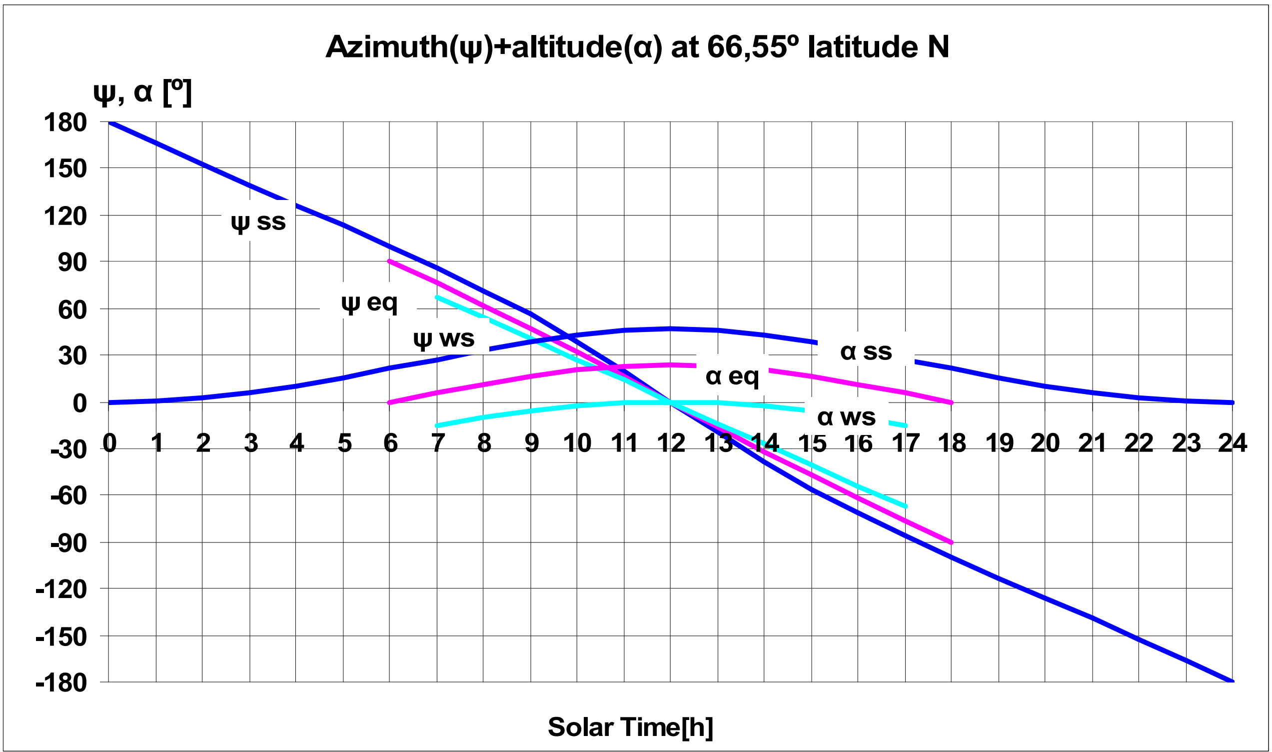

Fig. 12. *The variation of the azimuth and altitude at 66,55° latitude N*

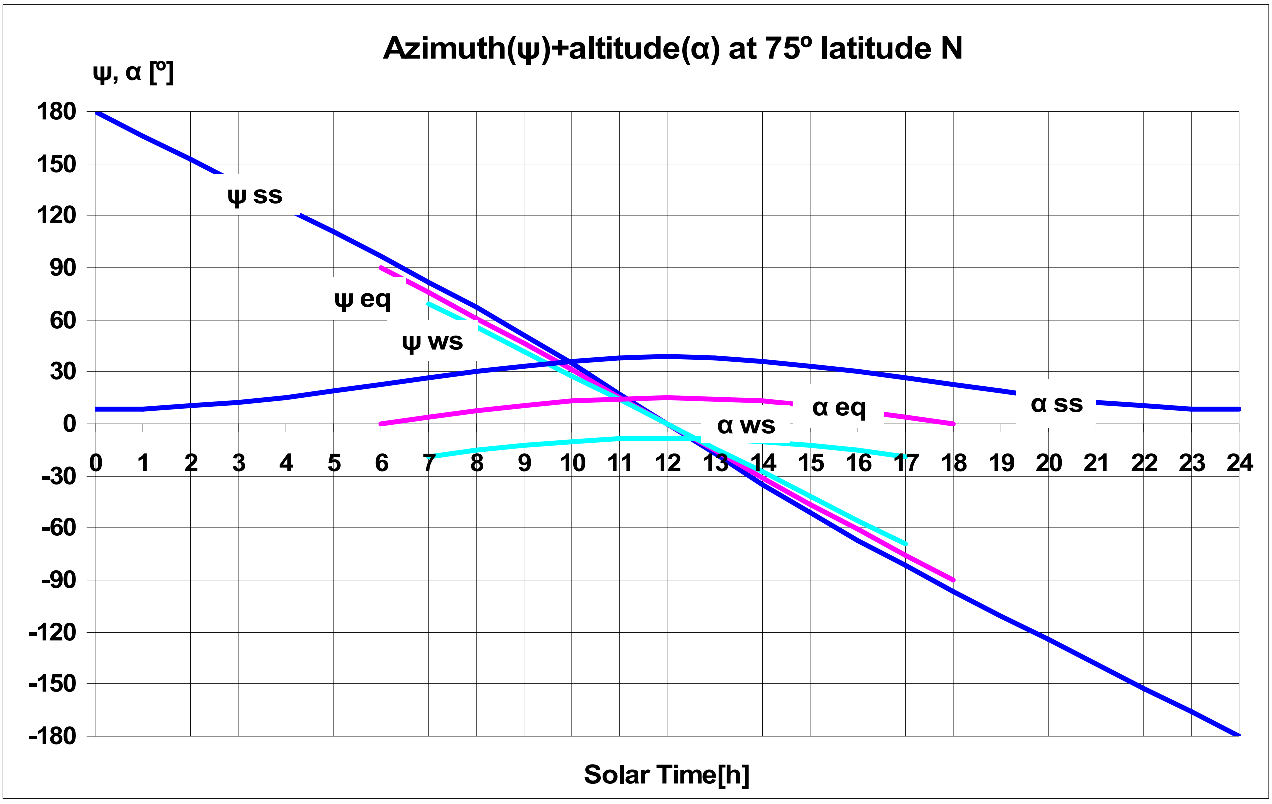

Fig. 13. *The variation of the azimuth and altitude at 75° latitude N*

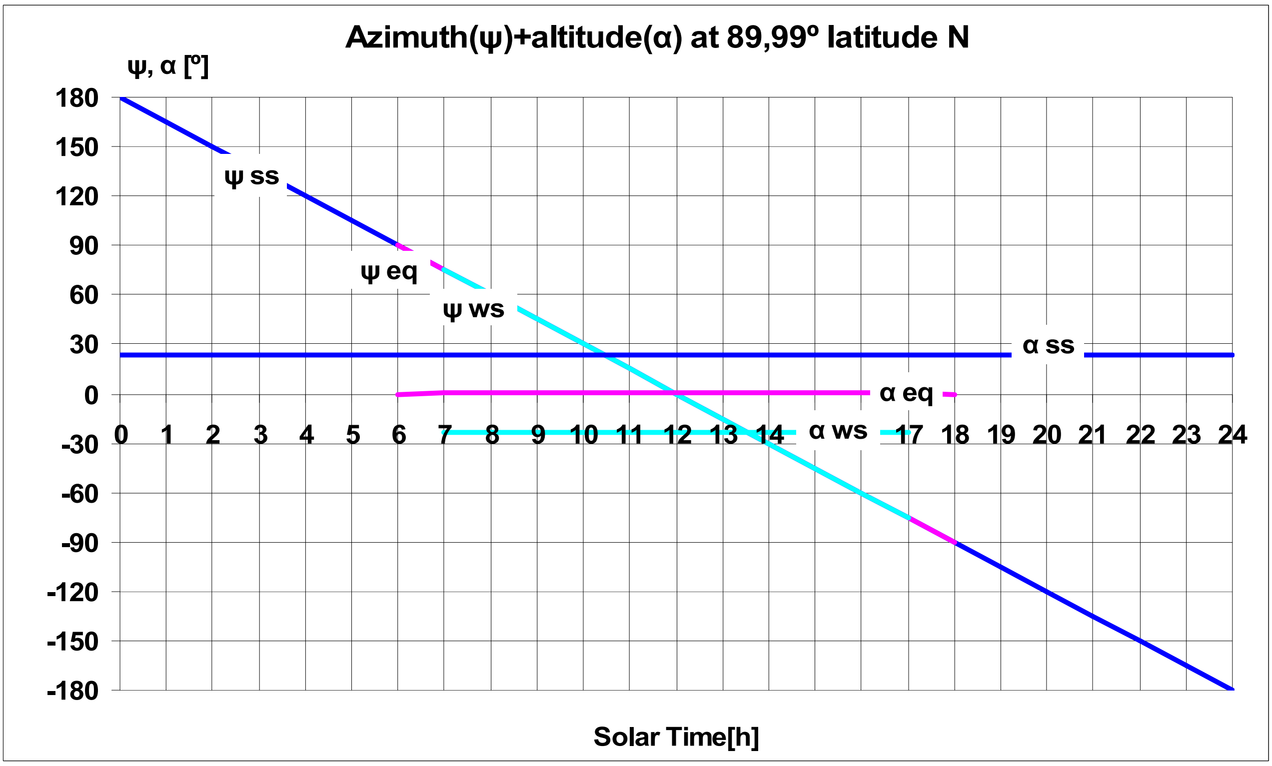

Fig. 14. *The variation of the azimuth and altitude at 89,99° latitude N*

The analysis of the Fig. 8, …, 14 leads to the following conclusions:

a) The azimuth angle has usually a decreasing variation without jumps, while the altitude angle has an increasing variation till the noon and a decreasing variation after the noon, without jumps too;

b) At the Equator (0° latitude) and at summer solstice the azimuth angle is unusually increasing (!) and at high noon has a jump from 180° to -180°; moreover, all modulus values of this angle are bigger than 90°.

This means that the plane in which the Sun's trajectory is situated is on the north side and therefore the shadow will be pointing the whole day to the south. This aspect disappears between the autumnal and the vernal equinox, when the azimuth angle is equal or lower than 90 degrees.

Also, at equinoxes, the azimuth variation is unusual: in the morning the azimuth is constant and has the value of 90°; at noon it has a jump from 90° to -90° and then remains constant at this value. Only at winter solstice the azimuth angle has a usual variation: it decreases constantly without any jumps.

c) The azimuth jump at the summer solstice noon remains for all latitudes between 23,45° N (Tropic of Cancer) and 23,45° S (Tropic of Capricorn).

d) When the latitude increases, the azimuth curves come near and tend to become a straight line segment. Moreover, nearby the equator the azimuth curves have approximately the same ΔT (see Fig. 8. and 9). When the latitude increases, the summer solstice azimuth curve lengthens, the equinoxes' curves remain unchanged and the winter solstice curve shortens.

e) According to Fig. 8, when the latitude is 0°, the variation of the altitude angle is the same for both solstices and has the biggest value (90°) at equinoxes; this means that:

- At the summer solstice the Sun lies towards north and at the winter solstice the Sun lies towards south;
- The Sun is exactly over the observer at the equinoxes' noons. Fig. 10 shows that the Sun comes also exactly over the observer at the 23,45° latitude during the summer solstice.

f) When the latitude increases, the altitude curves tend to become straight. Moreover, nearby the equator the altitude curves have approximately the same ΔT (see Fig. 8 and 9). When the latitude increases, the summer solstice altitude curve lengthens, the equinoxes' curves remain unchanged and the winter solstice curve shortens; this means that towards the North Pole the day duration lengthens at the summer solstice, remains unchanged at the equinoxes and shortens at the winter solstice.

g) At equinoxes, for positions between 66,55° and 90° latitude N, the altitude curves have only negative ordinates during the winter solstice; this means that it is only night.

5. Conclusion

The simulations of the Sun-Earth angles' variation (when the latitude varies between 0° and 90° N) and their interpretation give certain data which play an important role in the choice of the solar trackers' type, depending on the geographic position, and in their design.

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