REDUCTION OF INSOLATION DUE TO THE CLOUD FROM A COOLING TOWER

ZMANJŠANJE OSONČENJA ZARADI OBLAKA IZ HLADILNEGA STOLPA

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ABSTRACT

A model of the reduction of sunshine duration and solar energy due to the cloud from a cooling tower of a thermoplant is presented shortly, including some examples. Calculations are based on the known cloud characteristics and on determination of shadow-loaded area-elements around the tower in typical clear days of separate months. Diminishing of the influence of tower cloud due to natural cloudiness in real days is obtained afterwards by the introduction of weighting factors calculated from radiosonde and climatic data of the region.

POVZETEK

Emisija vode iz hladilnega stolpa večjega termoenergetskega objekta je nekaj ton vode na sekundo. Del te vode se v atmosferi kondenzira in tvori oblak nad stolpom, ki meče na tla svojo senco in vpliva tudi na osončenje v okolici stolpa. Določitev zmanjšanja trajanja osončenja in energije obsevanja v okolici stolpa je odvisno od mnogih faktorjev, prikazan pa je en način pristopa.

V prikazanem modelu je najprej določena navidezna pot sonca po nebu v času, ko je sonce več kot 9° nad obzorjem. Nato je določena lega sence za vsako uro ob predpostavljeno jasnem dnevu in je določen vpliv naravne oblačnosti,

končno pa so izračunane obremenitve posameznih površinskih elementov tal v okolici stolpa.

Model omogoča izračun sence za vsako uro tipičnega dne vsakega meseca in za vsako od 16 smeri orientacije oblaka oz. vetra nad stolpom. Velikosti oblaka v prostoru ob posameznih smereh vetrov so bile izračunane po posebnem modelu (Rakovec - te Razprave). Obremenitev s senco se računa za površinske elemente v okolici stolpa velikosti 200m x 200m. Seštetje vseh urnih obremenitev posameznih površinskih elementov za vse ure in značilnosti oblaka, nam da obremenitve tal ob jasnem vremenu. Vpliv naravne oblačnosti pa je treba izločiti.

Izčrpna obdelava oblačnosti ter višinskih podatkov o vetru in vlažnosti zraka da kriterije in podatke o naravni oblačnosti pri posameznih smereh vetrov in mesecih oz. jasnini v njih. Le ob jasnini se namreč pojavlja vpliv oblaka iz hladilnega stolpa. Ustrezni utežni faktorji nam omogočajo izračun obremenitve s senco vsakega površinskega elementa okrog stolpa za tipičen dan vsakega meseca, iz teh pa dobimo tudi letne vrednosti.

Iz zmanjšanja trajanja osončenja dobimo lahko tudi zmanjšanje energije sončnega obsevanja za vsak element površine tal okrog stolpa. Pri tem potrebujemo relacijo med trajanjem in energijo, ki jo dobimo iz drugih obdelav (Hočevar in sod.1982). Primeri kažejo, da je obseg zmanjšanja energije okrog stolpa ožji, toda jakost zmanjšanja je ob stolpu relativno večja. Rezultati modela se ujemajo z rezultati po modelu RWE AG(1981) in kažejo na pravilnost in uporabnost našega modela.

INTRODUCTION

The lack of cooling water and thermal pollution of rivers, especially at low water, demand the use of cooling towers at large thermoenergetic plants. They lead away the waste heat in amount usually greater than the useful part.

Although latent heat of water evaporation is considerable and the drop collectors are installed in the cooling tower, the water vapour and droplets emission from the tower can be some metric tons per second. At least a part of this water is condensed in the air above and/or around the tower, forming a cloud, which casts a shadow over the surface, diminishing the duration and energy of insolation and so changing the microclimate in the surroundings of the tower. However, determination of cloud influence on insolation is not simply obtained.

Momental size of the cloud, its height, direction of its spreading from the tower, as well as its influence on insolation, depend on the momental weather conditions. Its general climatic influence on the surroundings, however, depends on the climatic conditions at the location of the tower or thermoenergetic plant. These influences are roughly and generally known. They are studied more exactly and established in different ways, which are more or less exactly presented with different skill and probability (e.g. Hanna 1982, Thorp and Orgill 1984, Ćurković et al.1985). None of them are presented completely enough to be used directly. It is also true, that the problem is rather complicated, and a complete presentation of all necessary details and computer program would be far beyond any technical article.

Therefore we are presenting only main propositions and methods of work and a model for the determination of reduction of insolation on the ground surface will be presented together with some results as examples. Final consequences of reduction of insolation may be found on growth and augmantation of the local vegetation, but this is already another problem.

MAIN FEATURES OF THE MODEL

For determination of the reduction of insolation round the cooling tower due to its cloud in a day, the shadow and its daily travel round the tower should be determined. First we put the system of equations, supposing clear sky for the whole day and afterwards the influence of natural cloudiness is introduced. The duration of shadow of the tower cloud on separate parts of the ground depends on the geographic position and on:
a) apparent way of the sun over the sky, and
b) dimensions and direction of the cloud from the tower.

The first group of dependent variables depends on astronomic conditions: zenith angle of the sun (z), its azimut (α) or from the time in a day and in a year. These variables are determined with the known equations for the position of the sun:

$$\cos(z) = \sin(\varphi)\sin(\delta) + \cos(\varphi)\cos(\delta)\cos(H)$$

$$\sin(\alpha) = \frac{\cos(\delta)\sin(H)}{\sin(z)} \qquad (1)$$

where φ is latitude, δ declination and H stellar time. Knowing the dimensions and the position of cloud in a space, the position of cloud shadow on the surface can be determnined, although not quite simply, however.

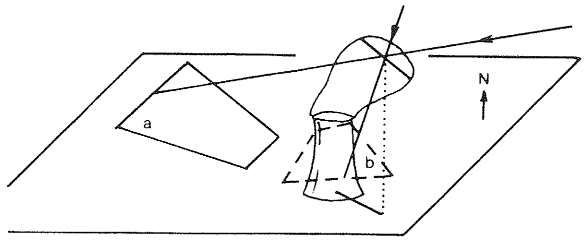

Fig. 1: Schematic presentation of cooling tower with the cloud and two of possible shadows

Slika 1: Shematičen prikaz hladilnega stolpa z oblakom in dveh od možnih senc

In our model the shadows are calculated for every hour of the typical day of every month and for each of the 16 directions of cloud orientation; it means in a direction rose with the steps of 22.5 angular degrees.

The dimensions of tower cloud and its spreading direction in space at separate wind directions were calculated with the help of a special model, given in the accompanying paper (Rakovec et al. 1987). The borders of the cloud were assumed to be where more than 5% of sunshine is dissipated.

Wind data are taken from the top of the tower and radiosonde station in the neighbourhood for the layer up to some hundred meters above the tower. By some wind directions the advection of more humid air can be greater and the tower cloud more extensive, but probably in the same time the sky is highly naturally clouded, and the influence of the large tower cloud on insolation can be smaller than by the lower air humidity and smaller tower cloud. The relative frequency of chosen or separate wind direction is of course very important, as well.

Using a cylindric coordinate system, cloud and sun position for every hour of daytime and the shadow in characteristic points at the surface are determined. As the sun apparently travels along the arc (mainly) south of the tower, the shadow is travelling in the opposite direction and has generally of the form of unsymmetric trapezoid (Fig. 1), which can be also overturned by high sun position and toward the sun oriented cloud (b in Fig.1), what demands additional care in programming. So, e.g., also the radius of the shadow on the

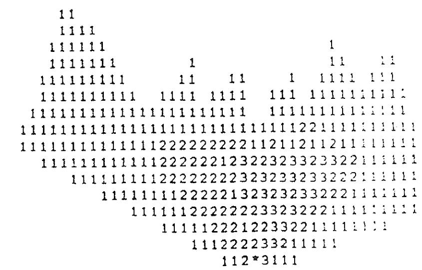

Fig. 2: An example of the shadow, cast by the tower cloud at one wind direction in a clear day

Slika 2: Primer sence, ki jo da oblak iz stolpa pri eni smeri vetra tekom celega jasnega dne

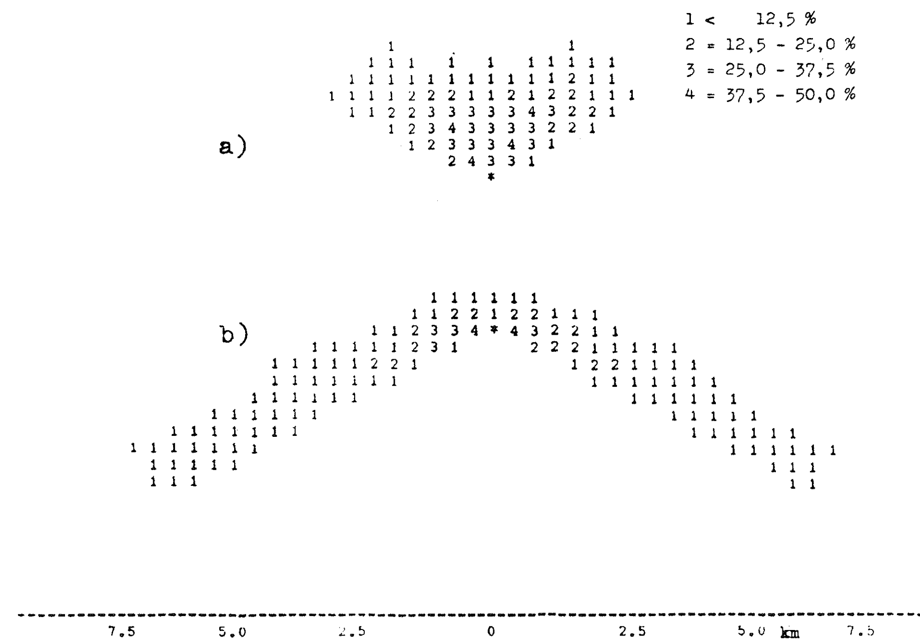

Fig. 3: Distribution of daily reduction of sunshine duration due to tower cloud shadow in a chosen month - a) wintertime, b) summertime

Slika 3: Razporeditev dnevnega zmanjšanja trajanja sončnega obsevanja zaradi sence iz stolpa v izbranem mesecu - a) pozimi, b) poleti surface (R^{*}) depends on real radius of the cloud (R^{o}) and on the connected position of the sun direction and cloud axes, given by the expression

$$R^{*} = R^{o}(1 + |(\sin(\beta - \alpha)[\sin(h) - 1]|) \qquad (2)$$

where β is the angle determining azimuth of cloud axis, α azimuth and h the elevation angle of the sun.

Apart from the projection of the cloud shadow axes on the surface, also border lines of the cloud shadow should be determined, and then transferred in a grid point system of elementary areas of e.g. 200m x 200m. By low sun (in the morning or evening) the shadow can be very long, but none of the shadow points is allowed to fall out of the treated or calculated area. Therefore, the extreme dimensions of the cloud have to be limited, as well as the smallest elevation angle of the sun above the horizon which in this case was 9°. On the other side, the treated area must be large enough, e.g. 32km x 32 km, which includes 161 x 161 grid points for the basic calculations. Their number can be diminished in final distribution presentations, as will be shown in examples.

So the shadow of the tower cloud can be presented in the separate month for every hour of the day at chosen direction and withappropriate characteristics of the cloud. Summation of shadow frequencies in separate area elements for all hours of daytime and all directions of the cloud, gives burdening of areas with the tower cloud's shadow in a typical day of the chosen month, supposing that the sky was clear all the time. An example is presented in Fig. 2. On the other side, however, if by one direction of wind (and opposite direction of cloud) the sky in climatic data was always overcast, there was no shadow of the tower cloud at all, and for this direction in this month no reduction of insolation due to the tower cloud exists. The majority of the cases lies between these two extremes. The appropriate weighting factors, depending on climatic characteristics of the region, should therefore bedetermined very carefully.

WEIGHTING FACTORS AND DURATION

From the data of the nearest radiosonde station the frequency of winds in the layers of the tower cloud can be calculated for all directions together with the relative air humidity in the layers. Cirrus clouds are neglected, but the middle and lower stratiform clouds and convective clouds being formed in the levels between 300 and 6000 m are effective. Computer treatment of upper level data of wind, relative humidity and cloudiness in the region, showed that the relative humidity of 85% is the most appropriate border value for determination of the natural cloudiness.

As in the upper levels there are no calms, the sum of all wind direction frequencies is 100%. However, the sum of cases with relative humidity above 85% in upper levels is mainly lower, than the difference between climatic cloudiness in % and 100%, because in upper levels the clouds can also be formed at the relative humidity under 85%. Therefore the frequency of natural "clearness" at the separate wind directions has to be corrected with the factor, the sum of cloudiness and clearness being just 100%. So the clearness (J) in the separate month and chosen wind direction is given by the equation:

$$J = P - U\,(\overline{N}/\overline{U}) \qquad (3)$$

where P is frequency of the wind direction, U relative humidity, $\overline{U}$ its mean value and $\overline{N}$ mean cloudiness in the chosen month on the location of the tower or on the nearest meteorological station with similar conditions.

Only at the time of "clearness", the tower cloud casts a shadow and reduces insolation in the surroundings. Therefore, to every shadow field or element of the field an appropriate weighting factor of clearness is applied, presenting partial reduction of insolation in that element. This method is used for all the 16 wind directions and 12 months in which 192 whole-day calculations have to be done using the same number of weighting factors. Summation of shadow loadiness in separate area elements for all hours and directions gives proper relative reduction of sunshine duration in separate area elements round the tower for a typical day of a month. From these the annual mean values can be obtained finally.

So the real climatic distribution of total reduction of sunshine duration round the tower in separate months and the annual average is obtained - examples are presented in Fig. 3. Every second value is printed here with the integers presenting the classes with 10% range - it means in relative values. The absolute values of reduction in hours are of course interesting as well. These can be obtained retrogradely from relative values by considering the duration of daytime or the number of hours in previous integration. This was done for the hours with the sun more than 9° above the horizon. Such a day is - in our latitudes - only 7 hours long in December and January, but 15 hours in June and July.

So e.g. the value 5 represents the reduction of sunshine duration in the range from 41 to 50 % which is in January (by its total clearness of 1.6 hour) only 0.8 hour but, about 3 hours in June. It is belived, however, that the distributions presented in relative values are more evident and more convenient for comparisons among the months with different day lengths.

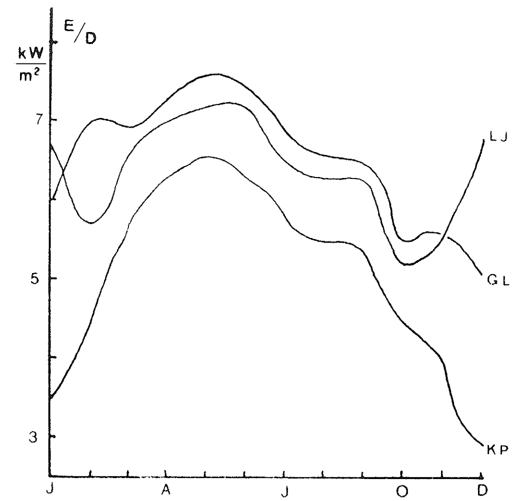

Fig. 4: Annual course of relation between duration and energy of insolation for three locations in Slovenia

Slika 4: Letni potek razmerja med trajanjem in energijo sončnega obsevanja za tri kraje Slovenije

REDUCTION OF SOLAR ENERGY

A good estimation of solar energy reduction on the surface round the tower due to the shadow of the cloud, can be obtained from the sunshine reduction. The method needs a correct determination of relation between duration and energy of insolation in the given conditions.

Relation between duration and energy of global radiation is known for 30 places in Slovenia (Hočevar et al. 1982). This relation depends on relief and climatic characteristics as well, and is rather different for different places - for three of them the annual distributions are presented in Fig. 4. Choosing - to the location of cooling tower - the most appropriate station and smoothing its annual distribution, the weighting factors for every month can be obtained. These enable us to calculate the amplitude of the insolation energy reduction in separate months due to the cooling tower cloud.

Like daily distribution of insolation energy also its reduction distribution is typical. This can be presented well with the "lifted" sinus curve. Here the

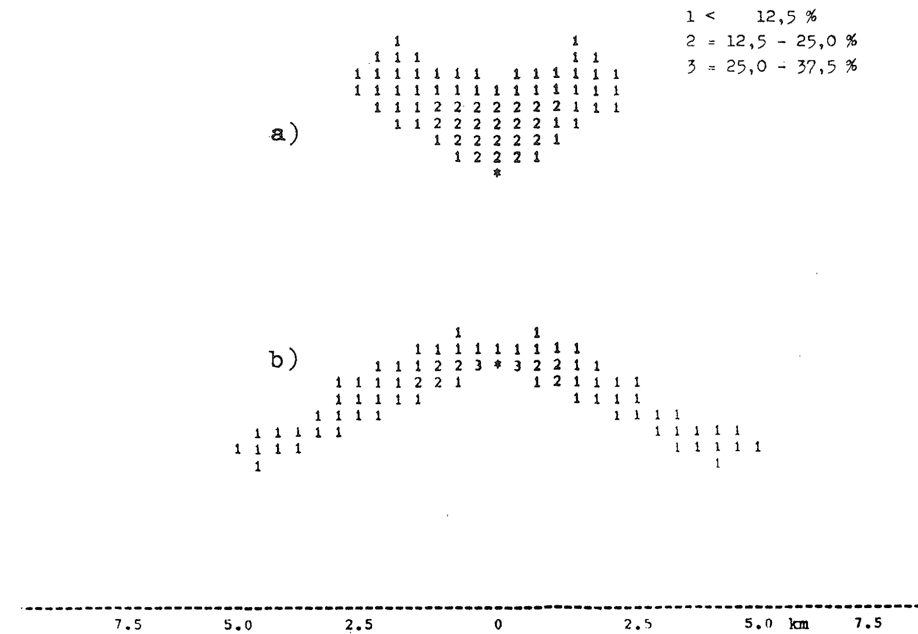

Fig. 5: Distribution of daily reduction of solar energy due to the cloud from a cooling tower in a chosen month - a) wintertime, b) summertime

Slika 5: Razporeditev dnevnega zmanjšanja sončne energije zaradi oblaka iz hladilnega stolpa v izbranem mesecu - a) pozimi, b) poleti

relative values are more appropriate than the absolute, as well - the examples are presented in Fig. 5. In comparison with the distribution of sunshine duration reduction (Fig. 3), the energy reduction is diminished on smaller area, but relative energy reduction near the tower is vigorous. This is the consequence of greater flux density of solar energy at noon, when the influence of the shadow is therefore the greatest.

In wintertime, as the sun travels apparently along the lower and shorter arc over the sky, the distributions of insolation reduction show the typical form of a heart; in the summertime, however, the shape of the shadow is like a thin kidney and has the opposite curvature. The results agree with those obtained by RWE AG (1981).

CONCLUSION

Considerations and test calculations show that the model is appropriate and useful. Although some simplifications were introduced, the calculations need a lot of computer' space and time due to many equations with trigonometric functions and different transformations.

Obviously the presented model can be used for similar applications with relatively little additional work. Most of that would take the determination of cloud characteristics and weighting factors, which includes the treatment of long set of radiosonde and climatic data for the tower's or analogous location.

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