E3S Web of Conferences **390**, 06023 (2023) https://doi.org/10.1051/e3sconf/202339006023
*AGRITECH-VIII 2023*

# Description of the algorithm and computer calculation program for the temperature regime of heliochambers intended for heat treatment of concrete

*Farkhod* Usmonov*

Bukhara Engineering-Technological Institute, Bukhara, Uzbekistan

**Abstract.** An algorithm for calculating the temperature regime of heliochambers for heliothermal treatment of concrete has been compiled. The algorithm includes heat release when cement is dissolved in water, since the change in heat release power when cement is dissolved in water is also subjected to harmonic analysis. Comparing the results obtained on a computer with averaged experimental data carried out over the past years, in natural conditions, in solar chambers with various design solutions, it has been established that it is possible to use the recommended method for calculating the temperature regime of a concrete mixture during heliothermal treatment to establish optimal design solutions for solar chambers from the standpoint of the best heating of concrete in them and as a result of gaining sufficient strength concrete.

## 1 Introduction

To analyze the temperature regime of concrete, heat-treated in a solar chamber, it is necessary to have a mathematical representation of the change in ambient temperature, the intensity of solar radiation, the heat release during dissolution of cement in water as a function of time, since the values of the outside air, the intensity of solar radiation, as well as the release of heat during dissolution cement in water will change during the day. The change in the ambient temperature and the intensity of solar radiation during the day are periodic functions, in connection with this, it is most convenient to show them using the harmonic Fourier series [1,2].

## 2 Methodology

The change in the value of heat release when cement is dissolved in water in solar chambers [3] also obeys a mathematical description

$$T_{oa}=T_{oao}+\sum_{k=1}^{a}*\left[a_k*\cos\left[K*\frac{2\pi\tau}{z}\right]+b_k*\sin\left[K*\frac{2\pi\tau}{z}\right]\right] \quad (1)$$

* Corresponding author: farxod_usmonov2022@mal.ru

$$J_s=J_{so}+\sum_{k=1}^{a}\left[c_k * \cos\left[K * \frac{2\pi\tau}{z}\right] + d_k * \sin\left[K * \frac{2\pi\tau}{z}\right]\right] \quad (2)$$

$$Q_{ch}=q_{cho}+\sum_{k=1}^{a}\left[u_k * \cos\left[K * \frac{2\pi\tau}{z}\right] + v_k * \sin\left[K * \frac{2\pi\tau}{z}\right]\right] \quad (3)$$

where, $T_{oao}$, $J_{so}$, $q_{cho}$, - *averaged values of ambient temperature, intensity of solar radiation and heat release during dissolution of active cement in water* $\alpha_к$, $b_к$, $c_к$, $d_к$, $u_к$, $v_к$, - *coefficients of the Fourier series;*

Z - *period of change / cycle of operation of the solar chamber;*

K= 1,2,3………… - *integer variable.*

Changes in ambient temperature and solar radiation during the day and at different times of the year for different regions of the country and the world are given in climate reference books, building climatological standards, and information on changes in power, heat release rate when cement is dissolved in water, depending on the temperature state of heliothermotreated concrete [ 3].

The method of approximate expansion of functions given graphically or tabularly in harmonic Fourier series using numerical integration methods is given in [2], which is based on calculating the coefficients of the series using the formulas:

$$a_k=\frac{2}{\pi}\sum_{i=1}^{n-1} T_t * \cos\left[K\frac{2\pi\tau_i}{z}\right] \quad (4)$$

$$b_k=\frac{2}{\pi}\sum_{c=t}^{n-t} T_t * \sin\left[K\frac{2\pi T\tau_i}{z}\right] \quad (5)$$

Where, n- the number of intervals into which the period of change of functions is divided; Ti–values of the function subjected to harmonic analysis for fixed time values τi. For K=0 according to formula (4), the zero term of the series is calculated, with the help of which the average value of the function is determined over the period of change of z.

$$To = ao / 2 \quad (6)$$

Based on the dependencies (1-3), a subroutine for calculating the coefficients of the Fourier series for a personal computer was compiled.

Using this computer calculation program, by determining the coefficients of the Fourier series, you can set the current values of the ambient temperature, solar radiation, heat release when dissolving cement in water, taking into account the finite numbers of harmonic components.

On Figures 1, 2 show the values of the outdoor temperature and the intensity of solar radiation, which were subjected to harmonic analysis, and the calculated values of these functions, determined using the first three harmonics of the series (1, 2).

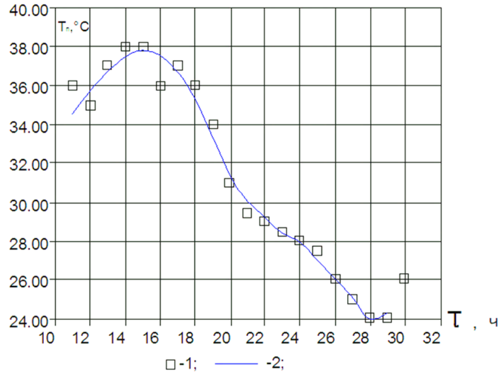


**Fig. 1.** The change in the values of the ambient temperature obtained in experiments carried out in natural conditions and the calculated values determined by the three harmonics of the Fourier series: 1 - experimental data; 2 - calculation results.

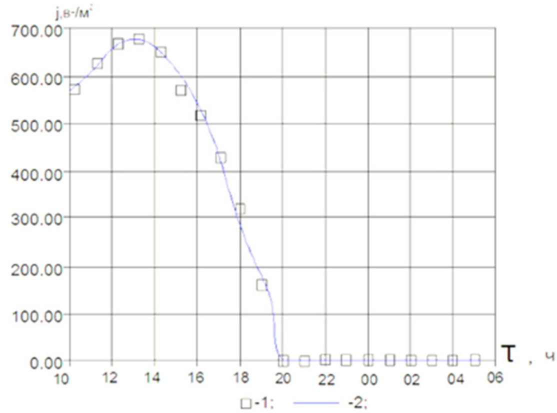


**Fig. 2.** The change in the intensity of solar radiation obtained in experiments conducted in natural conditions and calculated values determined by the three harmonics of the Fourier series: 1- experimental data; 2 - calculation results.

Comparison of the nature of changes in the value of the ambient temperature, the intensity of solar radiation, obtained by experimental studies carried out in natural conditions and the calculated values determined by the three harmonics of the Fourier series, showed a small relative error not exceeding 3%, which allows us to conclude that in practical calculations temperature mode of the solar chamber, you can use the first three harmonics of the Fourier series.

## 3 Results

As is known, the heat and mass transfer processes in the solar chamber and the power of heat release during the dissolution of cement in water depend on the temperature of the hardening concrete in the solar chamber, therefore, to assess the temperature regime of the solar chamber, according to equations (2 ÷ 32) [4,5,6,7] the best option is to use numerical methods. From this position, in the development of the algorithm and programs for calculating the temperature regime of the solar chamber, the finite difference method was used. At the same time, to implement this method, we introduce nodal points for the thickness of the heat-treated concrete sample, the concrete base of the chamber, the insulation layer, the expanded clay layer and the compacted soil, for which from the systems of equations (2 ÷ 16) [8] we obtain a system of equations in finite differences:

a) for a heat-treated concrete sample in a solar chamber, for unit № 1 (upper limit of a heat-treated concrete sample, $\delta_c = 0$):

$$T_{\delta(1)}^{K+1} = T_{\delta(1)}^{K} + \frac{2*J^{k},*C_{\text{th}}*A_2*\Delta\tau}{P_2*C_2*\Delta y_1} + \frac{q_{m(1)^{\text{K}}}*\Delta\tau}{C_2} - \frac{2\lambda_2\left[T_{\sigma(1)}^{k}-T_{\sigma(2)}^{k}\right]*\Delta\tau}{P_2*C_2*\Delta y_1} - \frac{\lambda_{\text{пр}_{(2)}^{\text{K}}}*\Delta\tau*\left[T_{\sigma(1)}^{k}-T_{C4}^{k}\right]}{\delta_3*P_2*C_2*\Delta y_1 2} \quad (7)$$

For a node with № n (at the lower boundary of the concrete mix, $\sigma_\sigma = \sigma_4$):

$$T_{б(n)^{K+1}} = T_{б(n)^{K}} + \frac{2\lambda_2*\Delta\tau}{P_2*C_2*\Delta_1^2}\left[T_{\sigma(n-1)}^{k} - T_{б(1)}^{k}\right] + \frac{q_{m(n)^{k}}*\Delta\tau}{C_2} - \frac{2\lambda_{\text{пр}_{(3)}^{\text{K}}}*\Delta\tau*\left[T_{\sigma(n)}^{k}-T_{\sigma(1)}^{k}\right]}{\delta_5*P_2*C_2*\Delta y_1} \quad (8)$$

For internal i-th nodes with №2÷(n-1):

$$T_{б(i)^{K+1}} = T_{б(i)^{K}} + \frac{2\lambda_2*\Delta\tau}{P_2*C_2*\Delta_1^2}\left[T_{\sigma(i-1)}^{k} - 2T_{\sigma(i)}^{k} + T_{б(i-1)^{K}}\right] + \frac{q_{m(i)^{k}}*\Delta\tau}{C_2} \quad (9)$$

Where n- *is the number of nodes along the thickness of the concrete mixture;*

$\Delta y_1$- *distance between nodes;* $\Delta y_1 \frac{\sigma_4}{(n-1)}$; $C_{th}$ - transmission capacity of the transparent coating; $\Delta\tau$- *time step;* $\lambda_{\text{thc}^{\text{K}}_{(2)}}, \lambda_{\text{thc}^{\text{K}}_{(3)}}$ -. *reduced coefficient of thermal conductivity for air gaps located between the transparent coating and the concrete mixture and the base.*

The index K means that the parameters are calculated for the previous moment of time, and the index (K + 1) for the next moment of time lagging behind the moment K for a time interval $\Delta\tau$.

b) for the foundation of a concrete plant for a node with №1 (on the upper surface of the base, $\delta_0$=0):

$$T^{K+1}_{\text{b}(1)} = T^{K}_{\text{b}(1)} + \frac{2*\lambda_{\text{thc}(3)}*\Delta\tau}{\delta_5*P_2*C_2*\Delta y_1}\left[T^{k}_{\sigma(\text{п})} - T^{k}_{\text{b}(1)}\right] - \frac{2\lambda_3*\left[T^{k}_{0(1)} - T^{k}_{0(2)}\right]*\Delta\tau}{P_3*C_3*\Delta y_2^2} \quad (10)$$

For a node with №n (on the border of the base with thermal insulation):

$$T^{K+1}_{\text{b}(\text{п})} = T^{K}_{\text{b}(\text{п}1)} + \frac{\lambda_3*\Delta\tau}{Z_2*\Delta y_2}*\left[T^{k}_{b(\text{п})} - T^{k}_{\text{ti}\,(2)}\right] - \frac{\lambda_4*\Delta\tau}{Z_1*\Delta y_3}*\left[T^{k}_{b(\text{п})} - T^{k}_{\text{ti}\,(2)}\right] \quad (11)$$

Where, $Z_1 = P_3 * C_3 * \frac{\Delta y_2}{2} + P_4 * C_4 * \frac{\Delta y_3}{2}$

For internal i-nodes with №2 ÷ (n-1)

$$T_{\sigma(n)^{K+1}} = T_{\sigma(n)^{K}} + \frac{\lambda_3*\Delta\tau}{P_3*C_3*\Delta y_2^2}*\left[T_{\text{b}(i+1)^{K}} = 2T_{\text{b}(i)^{K}} + T_0^K(i+1)\right] \quad (12)$$

Here $\Delta y_2 = \frac{\delta_6}{(n-1)}$; $\Delta y_{23} = \frac{\delta_7}{(n-1)}$

The distance between the nodal points fixed in the base layer of the solar chamber and the thermal insulation layer:

v) for the heat-insulating layer, for node №.1 (this is on the border of the concrete base of the solar chamber with the heat-insulation layer).

$$T_{\text{ti}(1)^{\text{K}+1}} = T_{\text{b}(\text{п})^{\text{K}+1}} \quad (13)$$

For node with № n (on the border of insulation and expanded clay layer)

$$T_{\text{bi}(1)^{\text{K}+1}} = T_{\text{bi}(\text{п})^{\text{K}+1}} + \frac{\lambda_4*\Delta\tau}{Z_Z*\Delta y_3}*\left[T_{\text{bi}(n+1)^{\text{K}}} - T_{\text{bi}(n)^{\text{K}}}\right] - \frac{5*\Delta\tau}{Z_Z*\Delta y_4}*\left[T_{\text{bi}(1)^{\text{K}}} - T_{ex(2)^{\text{K}}}\right] \quad (14)$$

Where, $Z_2 = P_4 * C_4 * \frac{\Delta y_3}{2} + P_5 * C_5 * \frac{\Delta y_4}{2}$

For internal nodes i th with №2 ÷ (n-1)

$$T_{\text{i}(1)^{\text{K}+1}} = T^{K}_{\text{и}} + \frac{\lambda_4*\Delta\tau}{P_4*C_4*\Delta y_3^2}*\left[T_{\text{и}(i+1)^{\text{K}}} - 2*T_{\text{i}(i)^{\text{K}}} + T_{\text{i}(i-1)^{\text{K}}}\right] \quad (15)$$

g) for a layer of expanded clay

For node №1 (on the border of insulation and expanded clay layer)

$$T_{ex(1)^{\text{K}+1}} = T_{\text{i}(\text{п})^{\text{K}+1}} \quad (16)$$

- for a node with No. p (on the border of expanded clay with the soil surface)

$$T_{\text{ex}(\text{п})^{\text{K}+1}} = T_{\text{ex}(\text{п})^{\text{K}}} = + \frac{\lambda_5*\Delta\tau}{Z_3*\Delta y_4}\left[T_{\text{ex}^{\text{K}}(\text{п}-1)} - T_{\text{ex}^{\text{K}}(\text{п})}\right] - \frac{\lambda_6*\Delta\tau}{Z_3*\Delta y_5}*\left[T_{\text{ex}\,(\text{п}-1)^{\text{K}}} - T_{\text{s}\,(2)^{\text{K}}}\right] \quad (17)$$

$$Z_3 = P_5 * C_5 * \frac{\Delta y_4}{2} + P_6 * C_6 * \frac{\Delta y_5}{2} \quad (18)$$

For internal nodes i th with №2 ÷ (n-1)

$$T_{\text{к}(i)^{\text{K}+1}} = T_{\text{к}(i)^{\text{K}}} - \frac{\lambda_5*\Delta\tau}{P_5*C_5*\Delta y_4^2}\left[T_{\text{к}\,(i-1)^{\text{K}}} - -2T_{k(i)} + T^{K}_{K(i-1)}\right] \quad (19)$$

d) for soil:

for node with No. 1 (on the border with expanded clay)

$$T_{\text{s}(i)^{\text{K}+1}} = T_{\text{к}(n)^{\text{K}+1}} \quad (20)$$

- for node with №n

$$T_{\text{s}(\text{п})^{\text{K}+1}} = T_{\text{к}(\text{п}-1)^{\text{K}+1}} \quad (21)$$

For internal i-th nodes

$$T_{\text{s}(i)^{\text{K}+1}} = T_{\text{г}^{\text{K}}(i)} + \frac{\lambda_6*\Delta\tau}{P_6*C_6*\Delta y_5}\left[T_{\text{s}^{\text{K}}(i+1)} - T^{K}_{\text{s}(i)} + T_{s^{\text{K}}(i-1)}\right] \quad (22)$$

The heat loss through the transparent solar coating of the chambers is determined by adding to the equations (17 ÷ 24) [4] the ratio for determining the temperatures of the surfaces of the transparent solar coating. The ratios are determined under the condition of quasi-stationary heat transfer ($q_{hfd}$ - heat flux density of heat loss through the transparent wall of the solar chambers):

$$\mathrm{T}c_3 = \mathrm{T}c_4 - \frac{q_{\mathrm{hfd}} * \delta_1}{\lambda_1} \tag{23}$$

$$\mathrm{T}c_2 = \mathrm{T}c_3 - \frac{q_{\mathrm{hfd}} * \delta_2}{\lambda_{\mathrm{int}\,(1)}} \tag{24}$$

$$\mathrm{T}_{c_1} = \mathrm{T}_{c_2} - \frac{q_{hfd} * \sigma_1}{\gamma_1} \tag{25}$$

Since the temperatures of the surfaces of the transparent enclosure $T_{c1}$, $T_{c2}$, $T_{c3}$, $T_{c4}$ depend on the heat transfer coefficients on these surfaces, which in turn depend on the surface temperatures, the calculation of heat losses and temperatures of the transparent coating of the installation is carried out by the method of successive approximations at each time step.

The general algorithm for calculating the temperature regime of the heliochamber is constructed as follows.

At the initial stage, the initial temperature value $T_0$ is assigned to all nodal points of the system.

Further, for a given process time, the values of the outdoor air temperature, the intensity of solar radiation and the power of internal heat release are calculated according to equations (1 ÷ 3). According to the known temperature values obtained using equations (17 ÷ 27) and (23 ÷ 25), the temperature on the surfaces of the heliocover and the heat and mass transfer coefficient in the air environment of the solar chamber are calculated using the method of successive approximations, with the help of which equations (4 ÷ 25) determine the temperature value in nodal points of the system after a certain time interval $\Delta\tau$. Further, the calculation process is repeated to determine the temperatures and coefficients of heat and mass transfer in the next time interval [8-10].

According to the developed calculation algorithm, a calculation program was compiled, which is given in Appendix 3. Below, the identification and dimension of the input parameters used in the program are given.

tf, $^0$ C - outdoor air temperature (24 values);

if, $\frac{\mathrm{W}}{\mathrm{m}^2}$ - intensity of solar radiation (24 values);

amptf, $^0$ C - outdoor air temperature amplitude;

amptf, $\frac{\mathrm{W}}{\mathrm{m}^2}$ -amplitude of solar radiation intensity;

kq - the number of harmonics in the Fourier series, to describe the parameters of thermal exposure;

d, m - an array of thicknesses, characteristic layers of the solar chamber structure;

a, $\frac{\mathrm{W}}{\mathrm{m.K}}$- array of thermal conductivity coefficients for chamber materials;

τo, $\frac{\mathrm{кg}}{\mathrm{m}^3}$- array of thermal conductivity coefficients for chamber materials;

c, $\frac{\mathrm{joil}}{\mathrm{кg\ K}}$- array of specific heat capacities for materials used in the solar chamber;

e- an array of degrees of blackness for materials used in the solar chamber;

hfd - transparent coating transmittance;

ac - degree of absorption of the transparent coating material;

tauh, hour - the start time of the heat treatment of the concrete mixture;

tauch,hour - the duration of the heat treatment of the concrete mixture;

PV, hour - the time interval after which the results of the calculation are printed;

$t_o$ - the initial temperature of the mixture;

ohe - coefficient evaluating the role of the side walls on the temperature regime of the solar chamber.

When carrying out calculations, the values of the arrays of temperatures of the concrete mixture $T_{bet}$(i), temperatures of the base $T_{baz(i),}$ insulation temperatures $T_{ins(i),}$ temperatures of the expanded clay layer $T_{exp(i),}$ mass-average temperature of the concrete mixture $t_{sm}$ for various points in time in during the operation of the camera.

To study the influence of the accepted assumptions of the recommended methodology for calculating the temperature regime of concrete in the process of its heliothermal treatment in a solar chamber, the results of calculations obtained by computer calculations were compared with experimental data carried out in real climatic conditions in different solar chambers with different design solutions. Figures 3 and 4 show the change in the temperature of heat-treated concrete over time in solar chambers with thermal insulation layers installed from the outside, 15 cm and 25 cm thick.

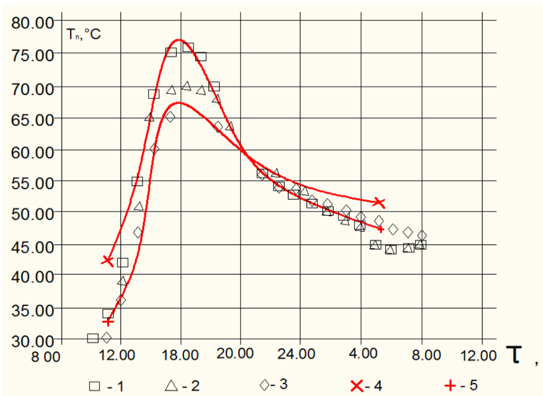


**Fig. 3.** Temperature change of heat-treated concrete in a solar chamber with a thermal insulation layer 15 cm thick (I-15), installed from the outside. 1, 2, 3 - temperature in the upper, middle and lower zones of the concrete sample obtained in experiments carried out in real natural conditions. 4, 5 - temperature in the upper and lower zones of the concrete sample obtained by calculation.

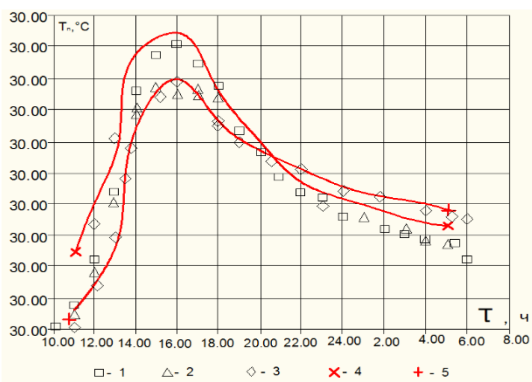


**Fig. 4.** Temperature change of heat-treated concrete in a solar chamber with a thermal insulation layer 25 cm thick (I-25), installed from the outside. 1, 2, 3 - temperature in the upper, middle and lower zones of the concrete sample obtained in experiments carried out in real natural conditions.4, 5 - temperature in the upper and lower zones of the concrete sample obtained by calculation.

## 4 Conclusions

The results obtained by computer calculations and experiments carried out in real climatic conditions and their comparison showed their coincidence with an error of 7.8%. This makes it possible to use this calculation method for analysis, studying the degree of influence of the constructive, thermal characteristics of the material of the solar chamber on ensuring the best temperature regime of the solar chambers intended for heliothermal treatment of concrete in them.

## References

1. B. M. Achilov, V. V. Chugunkov, Geliotekhnika **2**, 59-61 (1981)
2. B. M. Achilov, F. B. Usmonov, V. V. Chugunkov, Journal of Solar Engineering **4**, 77-78 (1994)
3. I. B. Zasedatelev, E. N. Malinsky, E. S. Temkin, *Solar thermal processing of prefabricated reinforced concrete* (Stroyizdat, M., 1990)
4. Farhod Usmonov, Journal of Physics: Conference Series **2388** 0121400, 1-6 (2022)
5. F. B. Usmonov, H. A. Khakhkhorov, East European Scientific Journal **10(50)**, 2019
6. M. M. Vakhitov, A. A. Tulaganov, I. I. Togiev, International Journal of Psychosocial Rehabilitation 3, **24(08)**, 6158-6172 (2020)
7. M. M. Vakhitov, A. A. Tulaganov, I. I. Togiev, Journal of Molecular & Clinical Medicine 07(07), 989-999 (2020)
8. M. M. Vakhitov, I. I. Tozhiev, *Physico-chemical studies of building materials of architectural monuments of Ancient Bukhara*. Materials of the XIII International Scientific and Practical Conference, Chelyabinsk SUSU Publishing Center, 155-158 (2020)
9. M. M. Vakhitov, I. I. Tozhiev, *Building solutions of architectural monuments of Bukhara.* Proceedings of the international symposium Modern resource-saving materials and technologies: prospects and application, Novosibirsk, 30-34 (2020)
10. K. Sh. Sodikov, J. Phys.: Conf. Ser. **2388**, 012169 (2022)