THE UPS UNIT COOLING UNDER SUMMER CONDITIONS

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ABSTRACT

The paper analyses the behaviour of the UPS (Uninterruptible Power System) cooling system under summer circumstances. The problem is that for the proper functioning of a UPS unit, the inside temperature must be less than 30°C. In other case the batteries tend to loose energy and electronic systems start to overheat. What is taken into consideration is the influence of solar radiation on a UPS container (it depends on the placement and time during the day). Next, there is a description of incoming and outgoing heat streams. Furthermore, the paper calculates the heat balance and discusses the installed cooling system. The question is: Is the cooling system capable of keeping the temperature in the container under 30°C in case of hot summer or not?

INTRODUCTION

Two UPS units (Uninterruptible Power System), 150 kVA each, belong to a commercial digital television "CANAL +", Warsaw, Poland. The main task of the UPS unit is to provide energy for the Canal+ devices in case of the loss of voltage in the power grid. A single UPS unit consists of one transformer, one rectifier, one inverter and 60 batteries. The role of UPS units is to supply TV equipment in case of electric energy loss. The UPS unit converts the electric energy of direct current into alternating current of 400V voltage.

The units are placed in a separated container (length 7200 mm, width 3029 mm and height 2880 mm). The door of the container is respectively 2000 mm high and 2000 mm wide. It is made of two zinc sheets 0.7 mm. Thick and filled with mineral wool 40 mm thick. All of the walls, the roof and the floor are made of zinc sheets and mineral wool (100 mm thick). The container is white. Pic.1 shows the container with the UPS units (Rusowicz A., 2003).

Additionally, according to the producer's recommendation, the container contains:
- internal illumination (2 x 36 W);
- a cooling system, two air-conditioners (SPLIT-type) with total cooling power of 17.9 kW;
- an indoor temperature sensor inside of container.

Fig. 1. A UPS container with two UPS units

The paper shows the analysis of the UPS unit under the influence of external as well as internal energy sources. This is to ensure the uninterrupted functioning of the transmitting devices. As it was mentioned the problem is that for the proper functioning of a UPS unit, the inside temperature must be less than 30°C (Rusowicz A., 2008). In other case the batteries tend to loose energy and electronic systems start to overheat. The winter period is not analyzed, as the temperature inside the UPS container never falls under 20°C, due to the heat generated by the work of the UPS units as well as good thermal insulation of the container. The temperature of 20°C has no negative effect on the functioning of the present devices.

SOLAR RADIATION

Solar radiation reaching the earth through the atmosphere is described by the use of different parameters, out of which solar intensity and solar heat gain factor are of high importance in air conditioning.

Establishing the density of the solar radiation

What we call the density of the solar radiation G, or briefly speaking the solar radiation, is a sum of radiation energy in the whole range of wave length reaching the surface unit [$W\cdot m^{-2}$]. In general, the solar radiation, which reaches every possible object regardless of its position, has 3 components (Pluta Z., 2000). The solar radiation is a sum of the direct solar radiation G_D , the diffuse solar radiation G_d and the solar radiation reflected from the surrounding surfaces G_r. The latter is a sort of derivative reflection, which is not a component of a direct solar radiation, and its track is usually not specified. Direct solar radiation depends on the current position of the sun on the horizon. The position is described in the following angles:

ϕ - latitude, for Warsaw $\phi = 52^o$ N;

δ - solar declination- the angular position of the sun during astronomical noon towards the surface of the equator. It can be assigned using the Cooper's formula:

$$\delta = 23{,}45 \sin (360\cdot(284+n)/365) \quad \text{[degrees]} \tag{1}$$

where: n – following day of year (n=1 January 1st);

ω - an hour angle, 1 hour is required for a 15-degree rotation of earth. The hour angle assumes a negative (-) value before and a positive (+) value after astronomical noon. At astronomical noon (12.00) $\omega = 0^o$; general equation (2) for calculating the hour angle is as follows:

$$\omega = 15 \cdot (\tau - 12^{oo}) \text{ [degrees]} \tag{2}$$

where τ - local standard time;

β - a tilt angle of the UPS container wall towards the horizon, $0^o \le \beta \le 180^o$, ($\beta = 0^o$ for a horizontal surface, $\beta = 90^o$ for a vertical surface and $\beta > 90^o$ for surface faced towards the earth);

γ - solar azimuth, $\gamma = 0^o$ south- oriented deflection from the closest meridian. Negative values for east directions, positive values for west directions;

θ_z - zenithal angle for horizontal surface;

θ_β - angle of inclination of solar radiation towards the wall surface measured between the direction of direct radiation and the normal to the vertical surface.

For any surface, the angle of inclination θ_β is related to β, γ, ϕ, δ and ω by:

$$\cos\theta_\beta = \sin\delta \cdot \sin\phi \cdot \cos\beta - \sin\delta \cdot \cos\phi \cdot \sin\beta \cdot \cos\gamma + \cos\delta \cdot \cos\phi \cdot \cos\beta \cdot \cos\omega + \cos\delta \cdot \sin\phi \cdot \sin\beta \cdot \cos\gamma \cdot \cos\omega + \cos\delta \cdot \sin\beta \cdot \sin\gamma \cdot \sin\omega \tag{3}$$

In case when the surface is horizontal the equation may be simplified to ($\beta = 0$):

$$\cos\theta_z = \cos\phi \cdot \cos\delta \cdot \cos\omega + \sin\phi \cdot \sin\delta \tag{4}$$

According to the Liu-Jordan's theory, the total flux of solar radiation in any direction G_β [$W\cdot m^{-2}$] inclined at an angle β to a vertical level, may be expressed by the following equation:

$$G_\beta = G_D R_D + G_d R_d + (G_b + G_d)\, \rho_o R_o \tag{5}$$

where:

G_D – flux of direct solar radiation on horizontal surface [$W\cdot m^{-2}$];

G_d - flux of diffusion solar radiation on vertical surface [$W\cdot m^{-2}$];

R_D - correctional coefficient of direct solar radiation;

R_d – correctional coefficient of diffuse solar radiation;

R_o - correctional coefficient of reflected solar radiation;

ρ_o – ground reflectiveness coefficient (dimensionless coefficient reflectance), which depends on the character of reflecting material. The container with the UPS units is surrounded by trees and has a ground reflectiveness coefficient of $\rho_o = 0.3$.

In equation (5) the correction coefficients (R_b, R_d and R_o) can be physically interpreted as a relation between direct, diffuse and reflected radiation, which falls onto an inclined surface to a certain radiation, which at the same time reaches a horizontal surface.

Correctional coefficients of diffuse (R_d) and reflected (R_o) solar radiation in equation (5) can be derived from the following dependences:

$$R_d = (1 + \cos\beta)/2 \tag{6}$$

$$R_o = (1 - \cos\beta)/2 \tag{7}$$

To calculate the correctional coefficient of direct solar radiation, one can use the Hottel-Woertz method (8):

$$R_D = (\cos\theta_\beta / \cos\theta_z) \tag{8}$$

In case of the container with the UPS units we have 4 walls and a roof, all exposed to solar radiation. Precise dimensions of the walls and their solar azimuths are given in Table 1. July 15th is the day taken into account in this calculation as, according to the data from *Environment 2001*, it is the warmest day of the Warsaw summer ((n = 196 day of year), solar declination $\delta = 21.51^o$ for Warsaw (latitude $\phi = 52^o$ N)). Pluta (2000) showed that the average flux of direct solar radiation on horizontal surface $G_b = 270$ $W\cdot m^{-2}$ and average flux of diffusion solar radiation on vertical surface $G_d = 280$ $W\cdot m^{-2}$ for Warsaw in July. These values for July are presented in Table 2.

Tab. 1. Surface dimensions and their geographical orientation

Surface	Dimension [m x m]	Area [m^2]	Solar azimuth γ
N	3.029 x 2.88	8.72352	180^o
E	7.2 x 2.88	20.736	- 90^o
S	3.029 x 2.88	8.72352	0^o
W	7.2 x 2.88	20.736	90^o
roof	7.2 x 3.029	21.8088	---

The walls (β = 90^o) and the roof (β = 0^o) were taken into account to calculate with the total flux of solar radiation G_β every hour from 10^{oo} to 13^{oo} o'clock. The results are shown in Table 2. The results are compared with data from a Polish Standard PN-76/B-03420 (Ventilation and air conditioning - Calculating parameters for outdoor air). The values from the Polish Standard for July 15th are in bold-faced type.

Tab. 2. Values of G_β [$W \cdot m^{-2}$] for all walls and roof of container with UPS units

Surface	hour $10^{o\,o}$ ω = -30^o	hour $11^{o\,o}$ ω = -15^o	hour $12^{o\,o}$ ω = 0^o	hour $13^{o\,o}$ ω = 15^o
N	140.0 135.0	140.0 142.0	140.0 145.5	140.0 142.0
E	382.5 556.3	299.7 366.6	145.3 145.5	145.3 142.0
S	518.5 506.3	521.9 591.3	522.9 621.5	521.9 591.3
W	140.0 135.0	145.3 142.0	145..3 145.5	145.3 145.5
roof	550.0 818.2	550.0 890.4	550.0 914.8	550.0 890.4

The solar temperature of the air (later called sol-air) was calculated on the basis of total flux of solar radiation from Table 2. The temperature was compared to those presented by Jones (2001), which were calculated for London (bold-faced type in Table 3). Calculations are based on the following dependence (9):

$$t_s = t_o + G_\beta (\alpha / h_o) \tag{9}$$

where:

t_o – current hour dry-bulb temperature;

α - absorption of surface for solar radiation;

α/h_o – surface colour factor, α/h_o = 0.15 for light colours;

G_β - total flux of solar radiation in any direction.

The outdoor temperature in July t_o = 35 ^{o}C, was assumed for the following calculations as the maximum summer temperature during the last ten years.

Tab. 3. The soil-air temperatures calculated for all walls and thicken from literature (Jones)

Solar time	Outdoor temperature [^{o}C]	Solar temperature of external air [^{o}C]				
		roof	N	E	S	W
10^{oo}	21.9	50.8 56.0	29.3 25.3	42.0 42.4	49.2 39.0	29.3 25.3
11^{oo}	23.3	52.2 60.5	30.7 26.9	39.1 31.3	50.8 43.5	30.9 26.9
12^{oo}	24.7	53.6 62.2	32.0 28.3	36.4 28.3	52.2 46.2	36.4 28.3
13^{oo}	25.8	54.7 63.0	33.2 29.3	33.4 29.3	53.3 46.1	41.6 39.4
Daily average	22.9	37.0	25.2	29.8	28.3	29.9

Qualification of heat flow through the walls

It needs to be emphasized that the character of the heat flow in the UPS units gained through the walls is unsteady. This fact is closely connected with the heat capacity of the container walls. The heat flow, which comes through to the inner side of the container undergoes the following conditions:

- daily fluctuation of outside air temperature,
- daily sinusoidal changes of solar radiation,
- the influence of wind.

On the basis of the average values it is possible to establish the average amount of heat flow, which is likely to get to the inner part of the UPS container. The heat flow to the container with the UPS units can be described as follows:

$$q'_{\theta+\varphi} = U\,(t_{sm} - t_w) + U\,(t_s - t_{sm})\,\nu \qquad (10)$$

where:
t_{sm} – daily average sol-air temperature;
t_w – indoor average air temperature;
t_s – sol-air temperature;
U – heat transfer coefficient for roof and walls;
φ - time lag; φ = 1.5h (Jones, 2001)
ν - effective absorption factor. (Jones, 2001)

On the basis of the data contained in the technical documentation provided by the producer of the container device, the overall heat transfer coefficient is: U= 0.38 W/m^{2}K, wall density ρ= 30 kg/m^3. These values are confronted with information presented by Jones (2001). The assumed time lag is φ = 1.5 h and effective absorption (decrement) factor ν = 0.75. The heat flows to container with UPS units are shown in Table 4.

Tab. 4. Heat flow values per square meter q' [W/m^2] for all walls and roof of the container with the UPS units

Surface	hour 10$^{o\,o}$	hour 11$^{o\,o}$	hour 12$^{o\,o}$	hour 13$^{o\,o}$
N	2.37	2.77	3.17	3.49
E	6.45	5.61	4.85	4.00
S	8.35	8.80	9.21	9.51
W	2.82	3.30	4.86	6.32
Roof	9.64	10.04	10.44	10.75

HEAT FLOWS FROM THE INSIDE-CONTAINER SOURCES

There are various types of heat-generating devices in the container: two air-conditioners (split-type), two UPS units, the control system and the batteries. Additionally, it is necessary to remember about the enthalpy of incoming and outgoing air.

The effectiveness of cooling devices

According to technical documentation the nominal power of cooling system is 17.9 kW. Inside the UPS unit there are two cooling devices with a power of 7.3 kW and 10.6 kW respectively. The results of the measurements applied show, that the average working time of these devices is 45 minutes per hour. Therefore, the average cooling power of the devices is 13.4 kW

Heat flows from the UPS units

According to the documentation of the UPS units' producer, heat flow from one UPS unit is about 10.95 kW, when the UPS unit is working on 100%. Two UPS units can transfer the maximum of 21.9 kW heating power to the inside of the container. However, under normal circumstances (everyday) the UPS units work on 30 %, so only 8.6 kW heating is transferred to the inside of the container. For 3 years there has not been any damages to the feeding system of the digital television.

Batteries- generated heat flow

There are 120 batteries in the container placed on steel racks. The indoor air can flow easily among all of them including the bedplate. Air can flows among all walls of batteries including the bedplate. The size of one battery is 410x210x170 mm and its surface is 0.383 m^2. Therefore, all batteries have 45.96 m^2 in surface. Experimental research was carried out to establish the average air velocity between walls of batteries. The experiment was conducted by the use of Testo425 measurer with a YF-160 K-type sensor. The average wall temperature was 23.25 ^{o}C ±0.5 ^{o}C and the average air velocity v= 0.4 m/s ±0.05 m/s. The air-wall heat transfer coefficient was calculated on the basis of from McAdams (1954) theory :

$$\alpha_s = 5.7 + 3.8 \cdot v = 7.22\ \mathrm{W/m^2K} \qquad (11)$$

This equation does not take into account the higher temperature electrodes, which during the experiment were 24.8 ^{o}C hot. Therefore, the estimated total heat flow from batteries is as 746.6 W.

Control system- generated heat flow

In the UPS container there is a control system and a high amount of electrical wires. According to Joule-Lenza's Law the power generated on the conductor, through which the electricity flows, is:

$$P = \sqrt{3}\,\Delta U\, I \cos\varphi \qquad (12)$$

where:
ΔU – voltage decline in the conductor [V];
I – current intensity [A], I= 50 A from specification of system control;
cosφ - angle of phase displacement [-], cosφ= 0.98 from the specification of system control.

The estimated voltage decline = 1% per 60 m of wire length. The estimated wire length in the UPS unit is 200 meters. The nominal voltage of the UPS unit is 400V. On the basis of this data the estimated heat flow from the control system is 1131.6 W.

HEAT BALANCE OF THE UPS UNIT

On the basis of the analysis to which the UPS units were exposed, the following data was gathered.

Tab. 5. Heat flows from inside and outside of container with UPS units

Heat flow supply from:	[kW]	Heat flow removing:	[kW]
solar energy	0.56	cooling system	13.4
UPS	8.6		
batteries	0.75		
system control	1.1		
Total:	11.01		13.4

CONCLUSION

The paper presents the analysis of the influence of the heat flow from outside and inside sources on the proper functioning of the UPS units. It was done to ensure the uninterrupted work of the TV transmition devices. The research was mainly based on the data from summer months, as the temperatures inside the UPS unit should not exceed 30°C. Exceeding this temperature might cause fast expenditure of the batteries as well as overheating of the electronic equipment. July 15th., which statistically is the warmest day of the season, was chosen for the analysis. Expecting high influence of the heat flow on the proper functioning of the UPS unit, both morning and afternoon hours were taken into consideration. The results show little influence of the solar radiation on the proper functioning of the UPS unit. The total heat flows from the solar radiation reach 600 W. In order to refer properly to this result, a comparison was made with a norm PN-76B-03420 as well as with data concerning the registered wall temperature. (see [3]).

The paper shows the universal approach towards calculations of the influence of the solar energy on the heat flow incoming to the UPS unit. The calculations make it possible to define this flow anywhere in the world regardless of time and date. A comparison with the data received from the PN-76B-03420 norm leads to the following conclusions:

- The total heat flow from the norm falling on the vertical surface is higher than the data in [1];
- There is a consistency between the diffuse flow in the norm and in practice [1].

Additionally, it was noted, that the positive influence of the correct wall insulation is significant. The value of the UPS walls heat transfer coefficient is directly proportional to the heat flow incoming to the UPS unit.

Summing up, on the basis of the conducted research, it is clear that the choice of cooling devices inside the UPS container was correct. Picture 1 shows a detailed description of the power of particular heat sources in relation to the power of the cooling system. It is important to notice that it is the UPS devices that have the biggest influence on air temperature inside the UPS container.

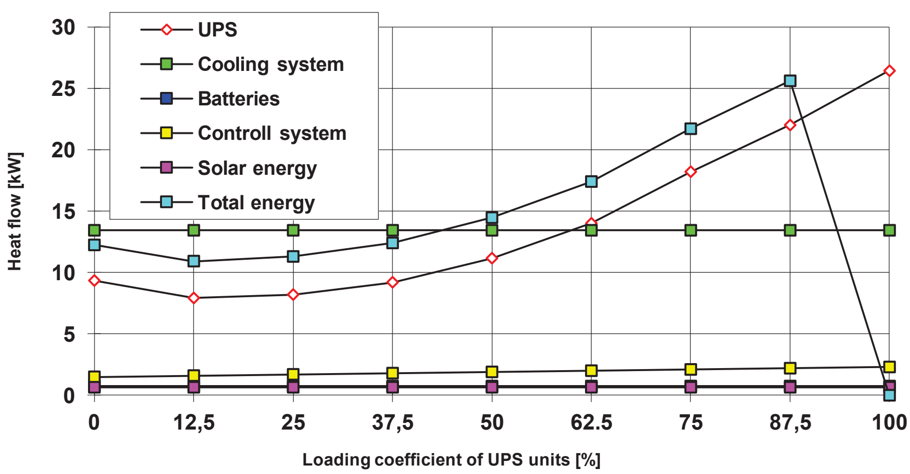

Fig.1. Graphic interpretation of heat profit and loss account in container with UPS units

The full analysis of the heat sources makes it possible to define important factors for the proper functioning of the UPS devices:

It is possible to use 43.7 % of the UPS feeders' nominal power to maintain the sub-30^{o}C temperature of the UPS units in the summer.

Not taking into consideration all other heat sources could lead to a "false" conclusion that 60% of the UPS feeders' nominal power should be used under the circumstances mentioned (summer).

In case of higher demands for the UPS feeders' power, additional cooling devices should be used.

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