10.2478/v10160-011-0022-y

Transactions of the VŠB – Technical University of Ostrava

No. 2, 2011, Vol. XI, Civil Engineering Series

paper #22

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THERMAL LOADING OF THE SWIMMING-POOL HALLS AND ITS EFFECT ON THE ENERGETICS MANAGEMENT

TEPELNÁ ZÁTĚŽ BAZÉNOVÝCH HAL A JEJÍ VLIV NA PROVOZ Z HLEDISKA ENERGETIKY

Abstract

The paper deals about three picked swimming-pool halls and the energy consumption from the view of the energy loading. This one has important rate in the energetics management.

Keywords

Energy savings, swimming-pool hall, ventilation.

Abstrakt

Článek zkoumá tři vybrané bazénové haly a jejich energetickou náročnost z hlediska tepelné zátěže, která má významný podíl na hospodaření s energiemi.

Klíčová slova

Energetické úspory, bazénová hala, větrání.

1 INTRODUCTION

In swimming pool halls, similarly to other buildings, a particular attention is paid to energy performance and economy which are closely connected with each other. At the same time, it is required to maintain or improve comfort for users and operators of the buildings. Many buildings which were built in past decades are facing now energy-related problems being typical not only for our region. The existing thermal load and impacts of the thermal load on the energy performance will be studied for three indoor swimming pools, this means for three swimming pool halls. Another issue which such buildings have to face is stability of indoor microclimate. The indoor swimming pools are located in the Ostrava and Karviná regions. Following criteria were taken into account during the selection of the buildings: the year of construction, the free space of water surface (all swimming pools have got the same length: 25 m), the method used with respect of the water surface, the building condition of the constructions and the method of supplying the thermal energy to the buildings).

2 SWIMMING POOL HALLS

2.1 The Ostrava-Vítek Indoor Swimming Pool

This indoor swimming pool was built in 1969 as a skeleton-type construction with reinforced concrete columns placed in a 6 m span. The external walls as well as the inside partition walls consist

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of (pursuant to the original project documentation) of reinforced concrete panels (CP1 300 mm). The wall thickness towards the dressing rooms and showers is made from 100 mm reinforced concrete. The wall towards the gym is made from CP1 300 mm. In the underground floor, there are facilities for swimming pool machines and equipment, a sauna, dressing rooms and an after-cooling swimming pool. The windows on the western wall are made from double-glass panes in a steel frame which starts disintegrating (there is a risk of the glass falling out). Glass blocks are used along other walls of the indoor swimming pools. The roof construction consists of lattice beams with a skylight window which is covered now. The roofing is made from reinforced concrete perforated panels and foam glass. Later on, a false ceiling was installed there (at the level of lighting) – it is, however, just a visual ceiling only. The building has not been reconstructed.

There is a floor heating with the heat gradient of 45/35 °C. The heat gradient of the heating register is 90/70 °C. Temperature control valves are not used there. Hot air heating is combined with the method mentioned above. The temperature of the incoming hot air is ~35 °C. HVAC heaters are pulse controlled once the temperature in the indoor swimming door reaches (drops down to) the set limit. Heat performance of this building is rather high.

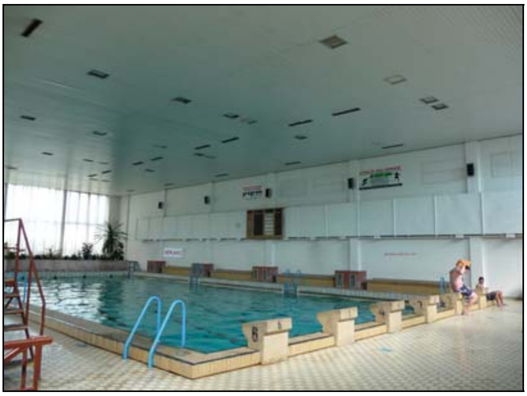
Fig. 1: The interior of the Ostrava-Vítek Indoor Swimming Pool [9]


Fig. 2: The heat exchanger [9]

2.2 The Indoor Swimming Pool in Havířov

The load-carrying structures are the reinforced concrete columns with a 6 m span. The external wall is made from transparent glass with steel profiles. There are steel carrying columns cast in concrete. There is the original double glass and the steel frame is rather corroded (there is a risk of tables falling out). The inside partition wall towards the gym is a double wall made from CP1 200 mm (from the both sides). The air gap which is a part of the expansion joint is slightly open (efforts were made to seal it). The wall towards the facilities is made from CD 32, (thickness: 140 mm). In the second floor (over the lifeguard station), the wall is made from gas silicate blocks (thickness: 300 mm). The roof construction consists of steel beams. At the lower face, there is a wooden lining (for noise protection and as a visual improvement). On the false ceiling, there is the original heat insulation. Probably, it does not serve its purpose anymore. The lighting is a part of the false ceiling. The roofing is made from reinforced concrete slabs with polystyrene overcladding (thickness: 65 mm). The building has not been reconstructed.

Fig. 3: The interior of the swimming pool in Havířov [9]

Fig. 4: The facade of the indoor swimming pool in Havířov [9]

There is a floor heating with the heat gradient of 50/40 °C. In 1993, the floor heating was reconstructed. There are the original heating registers and Kalor heaters with the heat gradient of 90/70 °C. Heat control valves are not used there. The hot air heating supplies the air with the temperature of ~40 °C). The heating is on until the temperature reaches θ_i = 28 °C. HVAC equipment is Janka Radotín there – it is fitted with air circulation and air recovery. The hot air for the indoor swimming pool is heated in a pair of finned heaters. The control valve in the heating water supply line is pulse controlled by the temperature in the swimming pool hall. There are two hot water heating circuits in the hall: for the gym and for the swimming pool. The heat performance of the building is rather high, the reason being, particularly, the glazed external wall.

2.3 The Indoor Swimming Pool in Orlová

The carrying structure of the building is again the reinforced concrete columns with the 6 m span and standardised pre-fabricated skeleton units. The external walls are made from slag pumic concrete panels (thickness: 300 mm) with the contact overcladding system (Baumit) where the thickness of the Baumit Open Polystyrene is 200 mm. The windows in the swimming hall pool were replaced and have got now the half of the original size. The heat transfer coefficient of the windows is now U = 1.2 $W/m^2 \cdot K$. The remaining parts of the external wall consist of the Porotherm 30P blocks (thickness: 300 mm). The roof construction consists of the reinforced concrete panels (thickness: 120 mm) and extruded polystyrene (thickness: 280 mm). Air above the false ceiling in the swimming hall pool is permanently withdrawn. In case of higher moisture, air ventilation automatically increases. The building was fully reconstructed in 2007.

The exchanging state processes the secondary heating water to reach the heat gradient of 92/67 °C and 70/40 °C in the winter and summer, respectively. The heating water system is designed for the heat gradient of 70/50 °C. The floor heating is designed at 50/40 °C. The both heating systems use equithermal control. There are radiator bodies (with the heating circuit out of the hall) – this is an additional system which should provide heat energy if the floor heating system and HVAC do not cover the heat demand. The HVAC circuit is a separate circuit; Two Menegra units (37.19.01 & 55.19.01) are used for air ventilation and hot air heating. The systems include air recirculation and air recovery functions (cca 70 %). The supply air temperature is optimised at cca 30 °C. There is also an additional cogeneration unit - Tedom Premi F25 AP which is used primarily for generation of electricity. This is an additional 20 – 40 kW source which supplies electricity for central heating hot water systems, hot water heating, water heating for the swimming pool and HVAC.

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Fig. 5: The interior of the swimming pool in Orlová [9]


Fig. 6: The cogeneration unit [9]

3 HEAT LOAD AND TOTAL HEAT BALANCE OF THE BUILDINGS

The heat power needed to heat up a building is calculated using methods set forth in ČSN EN 12831. The heat power/loss is affected not only by the heat passing through the construction and ventilation, but also by heat gains which contribute considerably to the overall heat performance of the swimming pools. In order to take reasonable measures which could decrease the energy performance of the swimming pools, it is necessary to determine the heat gain (the heat loss) from internal sources of energy and to make evaluation within the heat balance of the building.

3.1 Evaluation of the heat gain

The heat gain / heat loss were evaluated for all swimming hall buildings for both the existing and proposed conditions in line with requirements which are now in force with respect to the overcladding structures set forth in [2]. The evaluation was performed for the summer because solar radiation affects considerably the total heat load. On the other hand, the solar load is neglected in winter because the sunshine is rather low. The newly designed construction influences considerably stability of the inside climate. According to calculations, the heat load dropped by cca. 15 - 120 % for some swimming pool halls. See Fig. 7.

The inside environment is more stable now and it is easier to regulate ventilation/cooling there. This reduces the needed amount of the ventilation/cooling air which saves energy used to drive fans (or reduces the needed cooling power).

The calculation was carried out using QPRO – Tepelné zisky which is in line with [3]. Following components were included into the calculation as permanent heat gains:

- the bound heat from resistance of the swimming pool water,
- the air needed for ventilation of the swimming hall air (the minimum quantity is: 2 -/hour pursuant to [8]).

As mentioned above, the new heat transfer coefficients according to ČSN 73 0540-2 were used when calculating the new situation. The original windows in Ostrava-Vítek and Havířov were replaced with new ones ($U = 1.1\ W/m^2 \cdot K$). In Orlová, the original windows were kept $U = 1.2\ W/m^2 \cdot K$. The Ostrava-Vítek and Havířov swimming pools do not use any sun protection now. In Orlová, there is the glass with a slightly reflective surface ($s = 0.6$ pursuant to [3]). New windows were supplied with following sun protection:

- the sun protection foil with the sun protection coefficient s = 0.49 (LLumar Silver 50);
- the fixed outdoor shades (the sun protection coefficient is 0.13 pursuant to Table 8 [3]) which protect better against direct solar radiation

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Primary factors which affect the heat gain or total heat load inside the hall include:

- the position of the building towards the cardinal points,
- the position of windows towards the cardinal points,
- the size of the glasses,
- absence of outdoor sun protection,
- intensity of ventilation of the inside air by means of fresh air supply (without cooling).

Secondary factors which affect the total heat load inside the hall include:

- the specific thermal capacity of the overcladding structures,
- the internal heat gains.

Movements of the heat load peak between the months is caused by the total sum of the heat gains which are changing as a result of the construction measures taken on the site.

In Ostrava-Vítek and Havířov the heat load copies the outdoor environment, incl. immediate responses to the direct solar load. This means, it is more difficult to regulate. In case of the final designed situation, the development of the heat load is almost identical and copies mainly the temperature of the outdoor supply air which replaces, in summer months, the air conditioning that consumes quite a lot of energy.

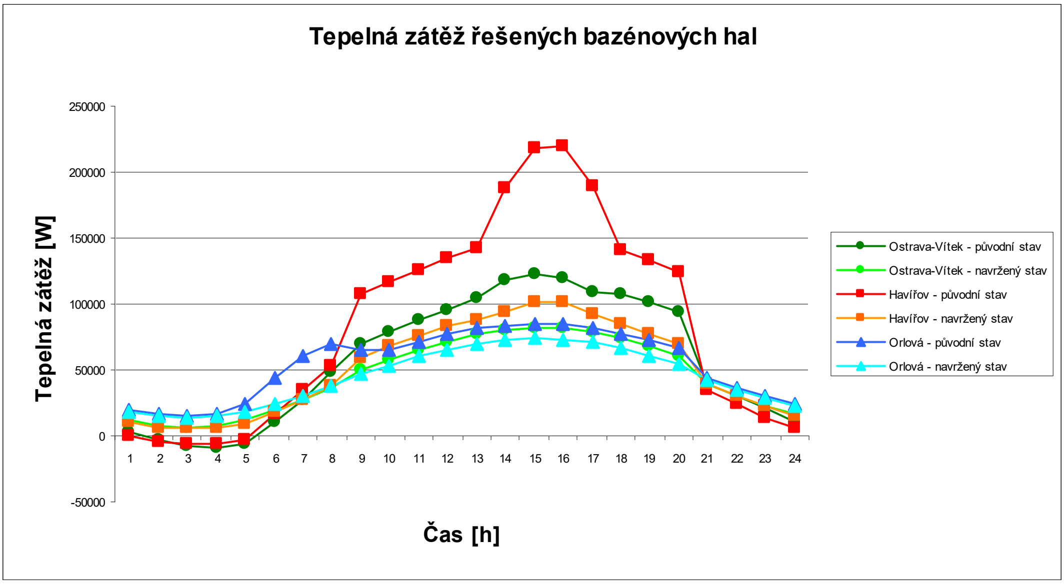

Fig. 7: Heat loads in the swimming hall pools (Ostrava-Vítek, Havířov and Orlová), *Remark: původní stav – original condition, navržený stav – proposed condition*

3.2 Total heat balance for the summer and winter

The total heat balance of the building is the sum of individual components of the heat gains and heat losses:

$$Q_C = Q_{OR} + Q_U + Q_U + Q_L + Q_{hl} + Q_l \quad (1)$$

Where:

Q_{OR} - is the heat solar gain from solar radiation [W],

Q_U - is the thermal transfer of heat through building constructions [W],

Q_L - is the heat gain from people [W],

Q_{hl} - is the heat transfer between the water surface and surrounding air [W],

Q_l - is the profile bound by heat resulting from free surface evaporation [W].

The total heat balance of the building is the sum of the sensible heat and bound heat. The heat components in the total heat balance have got different (positive or negative) signs. The table below shows the total heat balance for the summer and winter for both the existing and new situations.

4 PROPOSED VENTILATION

The proposed ventilation (for the summer) should be based on the total heat balance set forth for the specific period. The proposal is based on a directional scale which results from the following formula:

$$\delta = \frac{Q_c}{M_w} \tag{2}$$

Where:

Q_c - the total heat balance of the building [W],

M_w - the quantity of evaporated water [g/s].

The directional scale shows the direction of changes of the air condition and is related to a reference point in the h-x (Mollier) diagram.

Table 1: Total heat balance

Heat condition	**Ostrava-Vítek Indoor Swimming Pool**	**Indoor Swimming Pool in Havířov**	**Indoor Swimming Pool in Orlová**
Heat gain from people [W]	4,800	4,800	5,400
Heat transfer between the water surface and surrounding air [W]	3,000	3,125	2,985
Heat gain from lighting [W]	11,950	10,160	9,139
Heat gain from solar radiation – summer (the original situation) [W]	70,441	156,858	10,521
Heat gain from solar radiation – summer (after proposed improvements) [W]	16,005	38,305	1,416
Heat gain from bound heat [W]	64,818	67,518	64,493
Thermal transfer of heat through building constructions – winter (the original situation) [W]	190,597	154,677	107,169
Thermal transfer of heat through building constructions – winter (after proposed improvements) [W]	77,937	93,512	84,315

Note: According to the Decree No. 135/2004 Coll. the heat load from lighting is that from the lighting with the intensity of 250 lux at minimum in the swimming pool. The source of light is discharge tubes (15 W/m^2).

Total heat balance – summer (the original situation) [W]	132,259	221,251	72,029
Total heat balance – summer (after proposed improvements) [W]	77,823	102,698	62,924
Total heat balance – winter (the original situation) [W]	-116,829	-80,124	-36,522
Total heat balance – winter (after proposed improvements) [W]	-4,169	-18,959	-13,668

4.1 Summer

The proposal is based on the assumption that the maximum permitted moisture should not exceed φ_i = 65 % pursuant to [7], [8]. The limit was set at φ_i = 60 %. It is also necessary to exchange the air with the minimum intensity (the maximum being 9 - 12 times per hour). If the intensity were higher, there is a risk of draught. In summer, it is planned to supply 100 % air from the outside. The maximum proposed inside temperature is θ_i = 31 ± 1 °C. In case of the calculated interior parameters, the intensity of ventilation for the original condition of the swimming pool hall before improvements is as follows:

- Ostrava-Vítek: 14.2 -/hour, Havířov: 29.7 -/hour, Orlová: 2.9 -/hour.

This means that the ventilation intensity in Ostrava-Vítek is at the required limit. This might be permitted if the air supply inlets are properly made and if even ventilation of the air is possible there.

In Havířov, the heat performance is too high (the glass in the external walls makes up about 50 %) and this situation cannot be managed (cooled down) by supplying the fresh air from the outside only. For that purpose, active cooling of the inside swimming pool should be considered. The boundary conditions are identical. Even with the maximum ventilation intensity at the limit of acceptability I = 12 per hour, the temperature of the supplied air is t_{ich} = 18.97 °C which is not a good solution in terms of both comfort and energy demand (it is needed 460.7 kW for the cooling). The temperature of the air supplied into a room which should be cooled down should be below 7 K pursuant to [1]. This means, none of the alternatives is a good solution. In those cases, it seems to be advisable to improve heat parameters of the constructions or to pay a particular attention to sun protection and/or to use natural aeration in the building. The ventilation intensity for the proposed situation aimed at improvements of the heat parameters is as follows:

- Ostrava-Vítek: 2.9 /hour, Havířov: 7.4 /hour, Orlová: 2.6 /hour.

In case of the indoor swimming pool in Orlová, it is necessary to be careful not to exceed the limit of φ_i = 60 %. The parameters are fully compliant and sufficient to reach the required environment inside the building.

4.2 Winter

For an economic proposal of a hot air heating in winter, it is essential to save energy as much as possible. It would be unacceptable in terms of energy consumption to supply 100% fresh air because such air needs to be heated up and it would be necessary, for withdrawal of redundant moisture from the building, to exchange the volume inside the building too many times. For that reason, the proposed solution combines heat recovery and air circulation.

Boundary conditions were chosen pursuant to [8], this means θ_i = 28 °C, φ_i = 60 %. The planned efficiency of the recovery system is 70 %. The fresh air/circulated air ratio was set pursuant to [1]. The volume of the fresh air is 2,000 m^3/h. The directional scale was chosen again.

The difference in the supply air temperatures is calculated using the following formula:

$$\Delta t_p = \frac{Q_c}{c \cdot V \cdot \rho} \tag{3}$$

Where:

c	-	is the specific thermal capacity of the air [J/kg·K],
V	-	is the volume flow rate of the supply air [m^3/s],
ρ	-	is the air density [kg/m^3].

For the original condition of each case, the air exchange was chosen to be 4 times per hour because the supply air temperatures are:

- Ostrava-Vítek: 40.7 °C, Havířov: 37.8 °C, Havířov: 33.3 °C.

It is not recommended to supply the air with the temperature above 40 °C because of the heat comfort and energy performance. For that reason, quantitative regulation is used. For the proposed alternative, the air exchange was chosen to be twice per hour (considering requirements in [8]. The supply air temperature is:

- Ostrava-Vítek: 29.1 °C, Havířov: 32.6 °C, Havířov: 31.9 °C.

It is clear from the results that the total thermal balance is close to zero after structural improvement measures are taken. This means, the heat loss is compensated by total heat gains mainly thanks to the bound heat from the water surface.

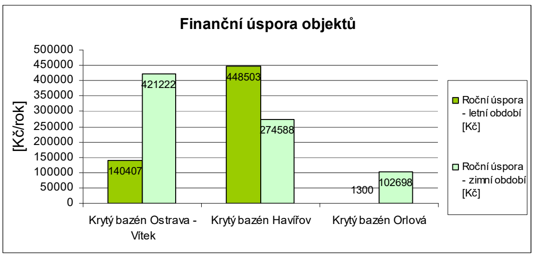

Fig. 8: Financial savings per year with respect to ventilation (summer and winter 2010)

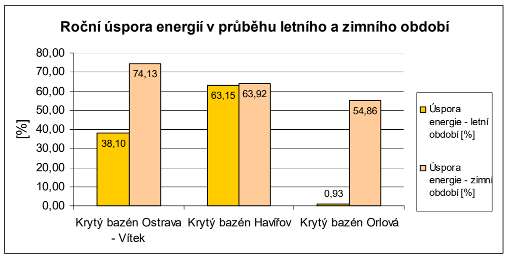

Fig. 9: Energy savings (in per cent) with respect to ventilation (summer and winter 2010)

Table 2: Energy performance and ventilation of the indoor swimming pools

Required power	Ostrava-Vítek Indoor Swimming Pool	Indoor Swimming Pool in Havířov	Indoor Swimming Pool in Orlová
Summer – the original condition [W]	123,100	258,900	75,200
Summer – after proposed improvements [W]	76,200	95,400	74,500
Summer – the original condition (cooling) [W]	-	460,790	-
Winter – the original condition [W]	189,800	156,600	100,800
Winter – after proposed improvements [W]	49,100	56,500	45,500

Note: The planned operation time is cca 2,160 hours per year.

Required energy	**Ostrava-Vítek Indoor Swimming Pool**	**Indoor Swimming Pool in Havířov**	**Indoor Swimming Pool in Orlová**
Summer – the original condition [kWh]	265,896	559,224	162,432
Summer – after proposed improvements [kWh]	164,592	206,064	160,920
Summer – the original condition (cooling) [kWh]	-	995,306	-
Winter – the original condition [kWh]	409,968	338,256	217,728
Winter – after proposed improvements [kWh]	106,056	122,040	98,280
Required energy	**Ostrava-Vítek Indoor Swimming Pool**	**Indoor Swimming Pool in Havířov**	**Indoor Swimming Pool in Orlová**
Summer – the original condition [GJ]	957	2013	585
Summer – after proposed improvements [GJ]	593	742	579
Summer – the original condition (cooling) [GJ]	-	3,583	-
Winter – the original condition [GJ]	1,476	1,218	784
Winter – after proposed improvements [GJ]	382	439	354
CZK/GJ (in 2010)	385	352.77	238.82
Costs	**Ostrava-Vítek Indoor Swimming Pool**	**Indoor Swimming Pool in Havířov**	**Indoor Swimming Pool in Orlová**
Summer – the original condition [CZK]	368,532	710,199	139,651
Summer – after proposed improvements [CZK]	228,125	261,696	138,351
Summer – the original condition (cooling) [CZK]	-	1,264,010	-
Winter – the original condition [CZK]	568,216	429,576	187,192
Winter – after proposed improvements [CZK]	146,994	154,987	84,495
Savings per year – summer [CZK]	**140,407**	**448,503**	**1,300**
Savings per year – winter[CZK]	**421,222**	**274,588**	**102,698**
Energy savings– summer [%]	**38.10**	**63.15**	**0.93**
Energy savings– winter [%]	**74.13**	**63.92**	**54.86**

It is clear from the calculation that improvements in Havířov would improve the situation at most in terms of the energy. The rapid change would be the result of the changed heat parameters of the external cladding (cca 50% of the external surface of the swimming pool halls) incl. sun protection.

On the other hand, adaptation measures would not almost result in financial or energy savings in Orlová. The situation is, however, different in winter months.

5 MODELLING THE MICROCLIMATE INSIDE THE BUILDING

It is possible to use a model simulation to forecast the behaviour of the indoor swimming pool during the year. The simulation provides certain information about behaviour of the inside microclimate in the summer. The data inform us about a possibility to adopt partial measures which would reduce consumption of energy and make the inside environment more stable under acceptable conditions. It was the indoor swimming pool in Havířov which was chosen for purposes of simulation. The reasons for choosing this swimming pool are following:

- much glass in the external cladding (50 % of the total area)
- the worst stability of the inside environment, see Fig. 7.

The software used for the simulation is CASAnova 3.3 which is based originally on EN 832/2000 Thermal performance of buildings which was later replaced with EN ISO 13790/2008 Energy performance of buildings [4], [5], [6]. A single-zone criterion was applied to the swimming pool in Havířov. This criterion meets requirements of the calculation software and standards. The inside microclimate was calculated using a single-zone dynamic heat model.

First, the original (the existing) condition of the building is evaluated and inside conditions, heat load and heating energy sources are assessed. The other alternative includes structural improvements pursuant to ČSN 73 0540-2. The model is designed for the hottest month of the year (the top heat gains). It describes all heat and technical features of the indoor swimming pool incl. its position among other buildings and orientation towards the cardinal points.

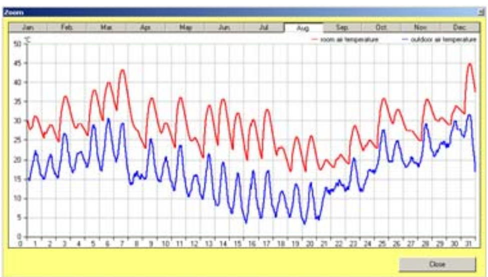

Fig. 10: Temperatures in the indoor swimming pool in the summer (the original conditions)

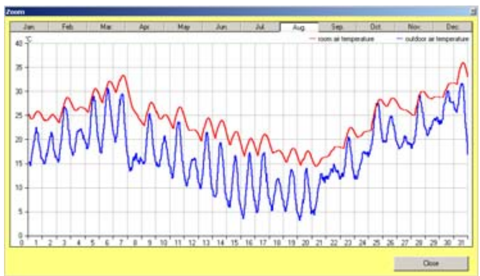

Fig. 11: Temperatures in the indoor swimming pool in the summer (after proposed improvements)

It follows from the figures that the inside temperature microclimate will be more stable in the summer when the temperatures will not copy the outdoor air temperatures and will not reach 45 °C, see Fig. 8 (the red curve). The calculation parameters were proved by the facility operator as well.

6 CONCLUSION

It follows from the paper that energy savings and, in turn, financial, savings, will be considerable for the indoor swimming pools, see Table 2.

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Partial adaptations of the building cladding structures affects positively not only heat losses in the indoor swimming pools, but also helps to eliminate considerable heat gains, typically those from solar radiation.

This change is most visible for the Havířov and Ostrava-Vítek swimming pools where partial measures would save 63.15 % energy in Havířov and 38.10 % in Ostrava-Vítek (during the summer months). The situation is different in Orlová where the facility has been reconstructed – the savings would be 0.93 % only. After measures are taken in line with ČSN 73 0540-2, the energy savings would be 54.86 – 74.13 %. A positive change in the heat and technical parameters of the indoor swimming pools reduces also the energy performance which affects ventilation and heating of the halls.

Partial measures improve the inside microclimate in the indoor swimming pool in Havířov and make the inside temperature more stable - this means, the inside temperature does not copy the outdoor temperature (the temperatures inside the swimming pool are not too low or too high). This also reduces the required power of heating/ventilation units for the swimming pool halls/buildings which, in turn, decreases the energy performance.

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