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INFLUENCE OF WIND VELOCITY TO SUPPLY WATER TEMPERATURE IN HOUSE HEATING INSTALLATION AND HOT-WATER DISTRICT HEATING SYSTEM

INTRODUCTION

At house hot-water heating installations, qualitative regulation is in common use. Regarding variation in the outside temperature, varied is supply water temperature while, water flow through heat emitting units is kept constant. Professional literature deals with equations relating to change in characteristic water temperatures in house installation vs. the outside air temperature, i.e., outdoor/indoor reset schedule [1]:

- supply water temperature

$$t_s'' = \Delta t_{mN}'' \cdot Z^{1/m} + \frac{1}{2}\Delta t_N'' \cdot Z + t_i \qquad (1)$$

- return water temperature

$$t_r'' = \Delta t_{mN}'' \cdot Z^{1/m} - \frac{1}{2}\Delta t_N'' \cdot Z + t_i \qquad (2)$$

where:

$$Z = \frac{t_i - t_o}{t_i - t_{oN}} \qquad (3)$$

Equations (1) - (2) are made considering prediction that building heat losses are linear function of the instantaneous outside air temperature; that building ventilation heat losses depend only on the outside temperature, not on the wind velocity; and that building heating system regulation is ideal, providing that heat emitting unit output is equal to the instantaneous room heat losses.

IMPACT OF WIND VELOCITY ON HEAT LOSSES

During heating season, other than air temperature, wind velocity is also variable. It predominantly influences building ventilation heat losses. In fact, there also exists the impact of wind velocity on transmission heat losses, because the film coefficient on the outside walls and windows depends on the air velocity, thus the overall heat transfer coefficient through the building envelope is also the function of the wind velocity. However, this impact on total building heat losses is relatively small, thus it is neglected in this paper. Observed is the impact of wind velocity only on ventilation (infiltration) heat losses.

When the instantaneous wind velocity is lower than the design one, both ventilation heat losses, as well as total heat ones are lower. According to German standard DIN 4701, at calculating heat demands, impact of wind velocity on ventilation heat losses is taken indirectly through building characteristic “H”. Each “H”-value corresponds to certain design wind velocity. Starting from the fact that wind is effective only to ventilation heat losses, introduced is factor “Y” which shows relative change of total heat losses at wind velocity lower than the design one:

$$Y = \frac{Q_{TN}}{Q_N} + \frac{H}{H_N} \cdot \frac{Q_{VN}}{Q_N} \tag{4}$$

Using general equations for hot water temperature (changed by the outdoor/indoor reset schedule or the so-called “sliding diagram” as water temperature “slides” according to outside temperature) (1) - (2) and previous equation for relative change of total room heat losses, equations for calculating necessary water temperature in hot water house heating installation may be formed, due to the outside temperature and wind velocity variation:

- supply water temperature

$$t_s'' = \Delta t_{mN}'' \cdot (Y \cdot Z)^{1/m} + \frac{1}{2} \Delta t_N'' \cdot Y \cdot Z + t_i \tag{5}$$

- return water temperature

$$t_r'' = \Delta t_{mN}'' \cdot (Y \cdot Z)^{1/m} - \frac{1}{2} \Delta t_N'' \cdot Y \cdot Z + t_i \tag{6}$$

It is possible to use more sophisticated ventilation model for the purpose of analyzing air infiltration in the single room or in a group of similar room models. But, in case of buildings with large number of rooms, different in size, shape, window type and area, air tightness, etc., all parameters in any sophisticated ventilation model have to be averaged (because they differ in real buildings), On averaging all these parameters, final result is almost the same as with simple ventilation model.

The other reason to use simple ventilation model adopted in DIN standard is that, in engineering practice, we calculate ventilation heat demands (and appropriate radiator surface) according to DIN 4701, for nominal (design) wind velocity. It is reasonable, and technically acceptable to calculate ventilation heat losses for the other wind velocities using the same, yet not quite precise methodology.

The outside design temperature for heating is t_{SN} = -15°C for Belgrade, and the average inside air temperature is t_i = +20°C. Regarding the commonly used hot-water heating system of 90/70°C in house installation under the design conditions, with cast-iron radiators taken as heat emitting units (exponent m=4/3), equations for characteristic water temperatures are in forms as follows:

$$t_s'' = 60 \cdot \left(Y \cdot \frac{20 - t_o}{35} \right)^{3/4} + 10 \cdot Y \cdot \left(\frac{20 - t_o}{35} \right) + 20 \tag{7}$$

$$t_r'' = 60 \cdot \left(Y \cdot \frac{20 - t_o}{35} \right)^{3/4} - 10 \cdot Y \cdot \left(\frac{20 - t_o}{35} \right) + 20 \tag{8}$$

Ratio between ventilation and transmission heat losses under the design conditions differs from one room to another. Therefore, this ratio is taken as the variable. The following ratios Q_{TN}:Q_{VN} = 80:20, 70:30, 60:40, 50:50, and 40:60 are analyzed. Higher rates correspond to former way of building construction (exterior walls were not thermally insulated), while lower rates represent current way of construction in our country.

Research regarding ratio between transmission and ventilation heat losses in large number of recently built buildings in Belgrade has shown that the average ratio for the whole building is 50:50±10 % [3]. Regarding single rooms in a building, this ratio has shown bigger deviations: 50:50±20 %.

The matter of analysis is a single building with open position, located in windy area. The building's characteristic "H" is 4.47 Wh $Pa^{2/3}/m^3K$, which corresponds to wind velocity of 8 m/s. Wind velocity is varied from the design velocity to zero, with step 2 m/s. Predicted is that ventilation heat losses are result of wind impact only, not of gravity force ("chimney effect") which, physically, correspond to less high building (up to 10 m). Together with the stated hypotheses, calculated are supply water temperatures in function of the outdoor temperature and the instantaneous wind velocity. In order to reduce the paper to rational scope, only two "sliding diagrams" of supply water temperature in house installation for the most common ratio $Q_{TN}:Q_{VN}$ in Belgrade's apartments are given. Figure 1 shows the supply water variation for the ratio $Q_{TN} : Q_{VN} = 50 : 50$ which corresponds to the currently built dwellings. Figure 2 is drawn for the ratio $Q_{TN} : Q_{VN} = 70 : 30$, relating to formerly built dwellings (up to 10 years ago) representing the basis of total dwellings in Belgrade. Values of corresponding water temperatures for other analyzed rates $Q_{TN}:Q_{VN}$ have similar character. The lower ratio is, the bigger impact of wind velocity on supply and return water temperature is noticed.

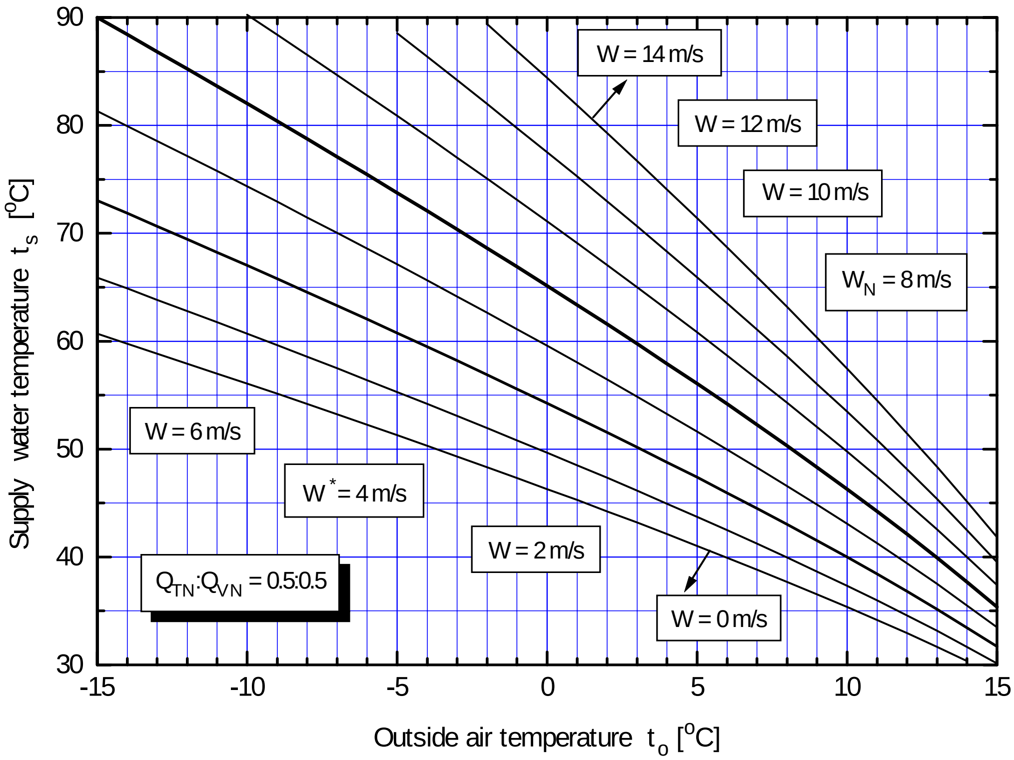

Figure 1. "Sliding diagram" of supply water temperature in house installation, in dependence on the outside air temperature and wind velocity, for ratio: $Q_{TN} : Q_{VN} = 0.5 : 0.5$

Necessary supply water temperatures for wind velocities higher than nominal, but combined with air temperatures higher than design ones, are also drawn in diagrams 1 and 2. Higher wind velocities are taken into consideration because, in winter time, at temperatures around zero, south-east wind is very strong. The only limitation is that supply water temperature may not overcome the design value, i.e. 90°C. Thicker line on diagrams 1 and 2 corresponds to supply water temperature under nominal wind velocity.

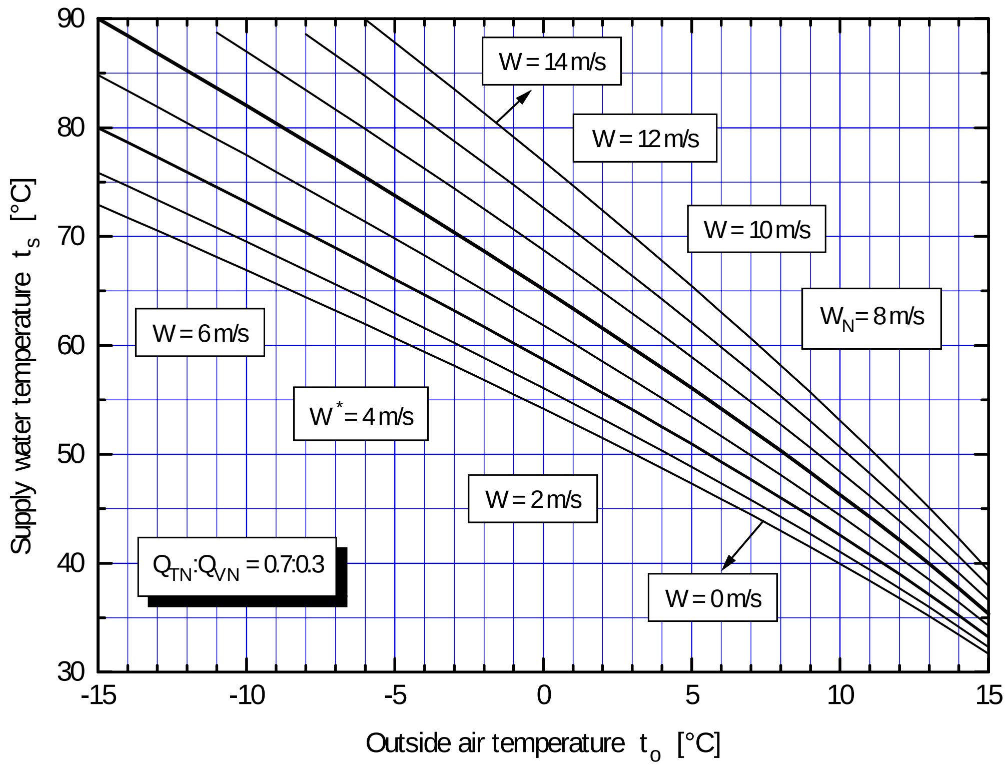

Figure 2. "Sliding diagram" of supply water temperature in house installation, in dependence on the outside air temperature and wind velocity, for ratio: $Q_{TN} : Q_{VN} = 0.7 : 0.3$

Due to heat accumulation within the building envelope, change of the outside temperature influences heat losses with the time lag (6 to 36 hours for typical buildings). Infiltration of the outdoor air causes instantaneous heat losses (or "almost instantaneous", as heat accumulation exerts certain influence even to the said heat losses). The fact is that wind profiles continuously change. In our model we have used the average wind velocity, averaged over short period (an hour, or couple of hours), not over the longer one! Our opinion is that the infiltration rate, calculated by wind velocity averaged per hour, and caused by real wind velocity (which profile oscillates in that period) does not differ significantly.

Even if the impact of wind velocity oscillation in the shorter time period (wind blows from time to time, in form of gusts) was of great importance for ventilation heat losses, hydronic heating system is not able to respond and promptly follow the changes. Hydronic heating system has to be regulated according to mean hourly wind velocity. Change of the infiltrated air quantity in shorter time intervals, caused by wind velocity profiles oscillation, would cause oscillation of the indoor air temperature; the effect would be reduced by heat transfer by radiation and convection from the building envelope internal surfaces.

BOUNDARY WIND VELOCITY

At wind velocity lower than the design one, lower are total room heat losses, thus lower temperature of supply heating water is needed. Boundary case, for the wind velocity equal to zero, involves water temperature required to compensate only transmission heat losses. However, for hygienic reasons, adequate room ventilation is necessary, i.e. certain number of air change rates per hour is obliged. When there is no wind causing air infiltration, room ventilation is made through open windows or in another way, which involves certain heat quantity for compensation of ventilation heat losses.

One of the aims of this paper is the determination of boundary wind speed w*, at which heat losses, caused by the infiltration, are equal to heat quantity necessary for heating of 0,5 air change per hour. Analyzed are over thirty room models, typical for current way of building construction in Belgrade, at which variables are: room's size, window's number, size and air tightness. This research is still under way, thus only preliminary results are given. The average window area in recently built buildings in Belgrade is between 1/7 and 1/5 of the floor area. Average boundary wind velocities for different window air tightness, calculated for the room models, as well as checked in citu, are given in table 1.

Table 1 Average boundary wind velocity

Air tightness [m^3/mh $Pa^{2/3}$]	Boundary wind velocity [m/s]
a = 0,3	$w^* = 5,2 \pm 0,6$
a = 0,4	$w^* = 4,2 \pm 0,5$
a = 0,6	$w^* = 3,1 \pm 0,3$

Boundary wind velocity depends on the window type (air tightness and crack length) and has values in range from 2,8 to 5,8 m/s. Averaging these values, and taking into account predominant window type in Belgrade's dwellings, it is found that the average boundary wind velocity is 4 m/s; for that value, supply water temperatures in diagrams 1 and 2 are marked with dashed line.

When wind velocity is lower than the design one, and higher than the boundary velocity, supply water temperature in house installation should be changed according to the appropriate curve (diagram 1 or 2), for certain wind velocity. But, when wind velocity is lower than the boundary one, heating system should operate according to the curve calculated for w*. Air quantity which does not enter the room by air infiltration through door and window cracks, will enter through room ventilation. For this reason, it is necessary to provide enough heat to heat emitting unit, for the purpose of air heating up to the room temperature.

Figure 3 shows supply water temperatures, calculated for critical (boundary) wind velocity (minimum supply water temperature) for different rates between transmission and ventilation room heat losses under design conditions. It is adopted that ventilation heat losses are constant (calculated for w*), and that total heat losses vary because of different building thermal insulation (different transmission heat losses). As already mentioned, at wind velocity lower than the design one, the bigger ratio Q_{TN} : Q_{VN} is, the higher supply water temperature is necessary (fig. 3).

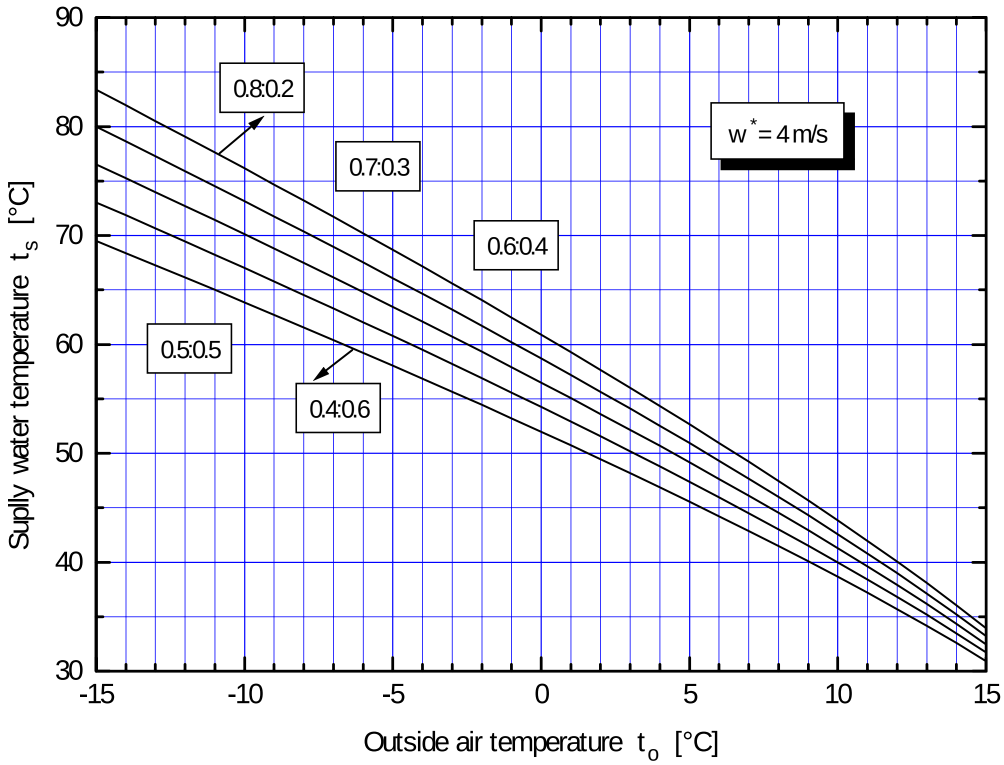

Figure 3. "Sliding diagram" of supply water temperature in house installation, in dependence on the outside air temperature and ratio Q_{TN} : Q_{VN} for boundary wind velocity w*=4m/s

DISTRICT HEATING SYSTEM

When house heating installation is connected to the district heating system, required temperatures of supply and return hot water in piping network depend on connection type (direct or indirect). Majority of house heating installations in Belgrade flat area is directly connected. As district heating system operates with constant water flow, constant mixing rate of primary and secondary water is adopted. For described technical solution, general equations for supply and return water temperature in primary loop (piping network) are:

$$t_s' = \Delta t_{mN}'' \cdot (Y \cdot Z)^{1/m} + \left(\Delta t_N' - \frac{1}{2} \Delta t_N'' \right) \cdot (Y \cdot Z) + t_i \tag{9}$$

$$t_r' = \Delta t_{mN}'' \cdot (Y \cdot Z)^{1/m} - \frac{1}{2} \Delta t_N'' \cdot (Y \cdot Z) + t_i \tag{10}$$

In case of district heating system 140/70^{o}C under the design conditions, mostly used by Belgrade Municipal DH Company, required variation of supply water temperature in hot water network vs. outside temperature and wind velocity ("sliding diagram" of primary loop) is shown in fig. 4. This diagram relates to fig. 1 - Supply water temperature in house heating installation. Type of heat emitting units and design conditions correspond to the example of water temperature in house installation. Ratio of Q_{TN} : Q_{VN} is equal to 50:50. Dashed line is drawn for boundary wind velocity of 4 m/s.

This outdoor - indoor reset schedule is suitable for the application in the district heating plants which supply the newly built residential areas. Applied at the operation of the district heating plants for heating of older dwelling areas, the outdoor - indoor reset schedule is given in figure 5. The ratio of transmission and ventilation heat losses for the design conditions is Q_{TN} : Q_{VN} = 70 : 30.

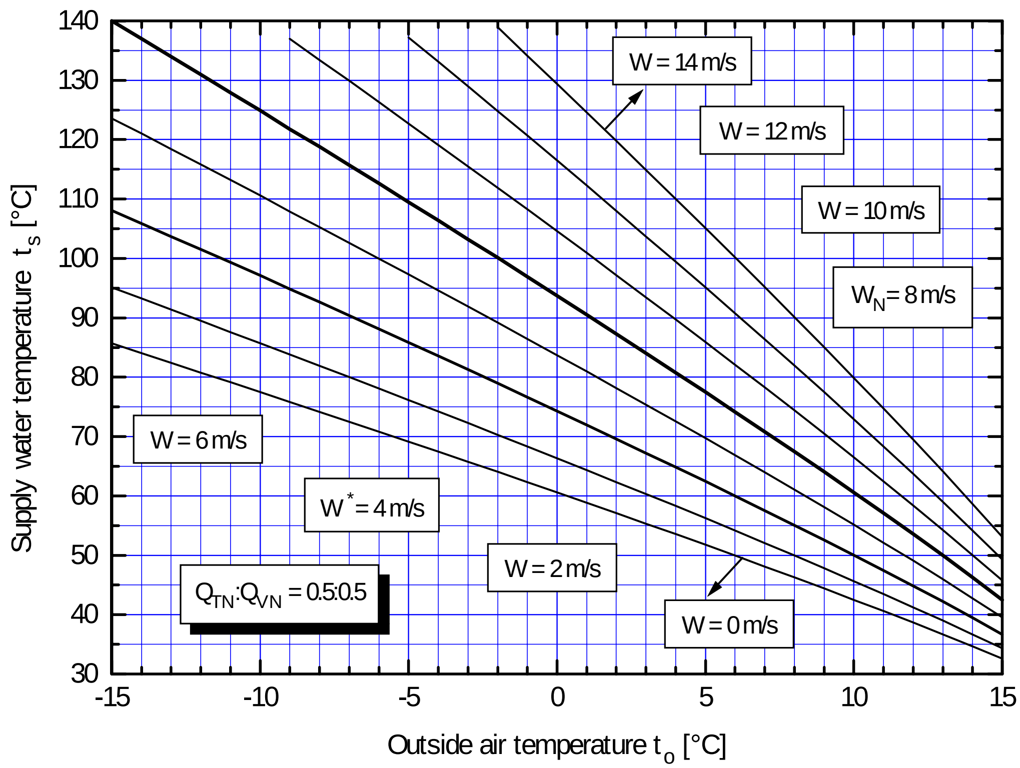

Figure 4. "Sliding diagram" of supply water temperature in district heating network, in dependence on the outside air temperature and wind velocity, for ratio: Q_{TN} : Q_{VN} = 0.5 : 0.5

The impact of Q_{TN} : Q_{VN} ratio for boundary wind velocity on required supply water temperature in district heating system network is shown in fig. 6. The character of the curves is equal to the ones in fig. 3; that concerns house installation, while all mentioned remarks are valid for DH system, too.

Wind direction certainly makes impact on the air infiltration, but it should be taken into account only if there is zonal regulation (due to the facade orientation). For “pure” central regulation of supply water temperature (with no either zonal regulation, or the local one by thermostatic valves) wind direction is meaningless. Supply water temperature is determined according to the outside temperature and average wind velocity. Rooms on leeward side will be overheated.

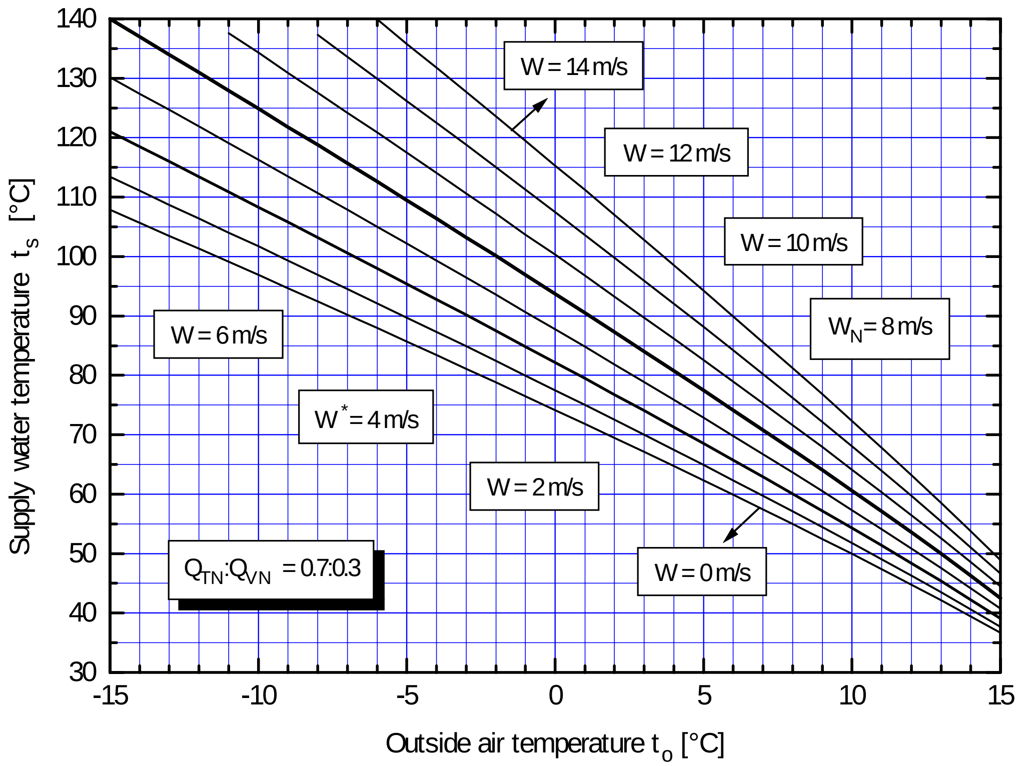

Figure 5. "Sliding diagram" of supply water temperature in district heating network, in dependence on the outside air temperature and wind velocity, for ratio: $Q_{TN} : Q_{VN} = 0.7 : 0.3$

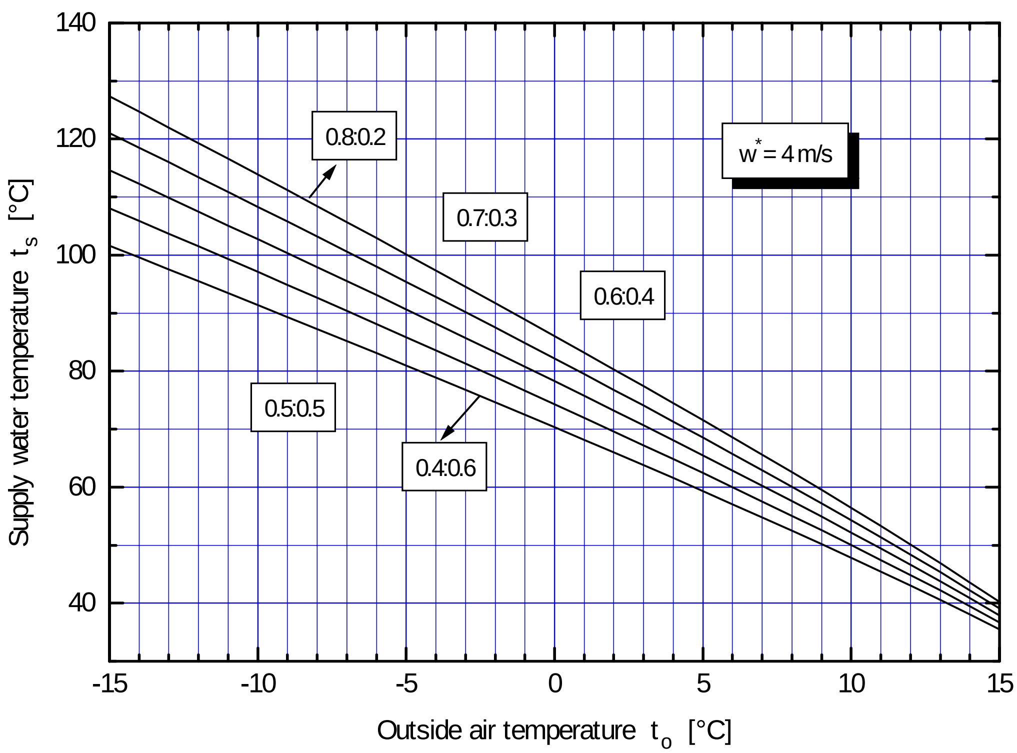

Figure 6. "Sliding diagram" of supply water temperature in district heating network, in dependence on the outside air temperature and ratio $Q_{TN} : Q_{VN}$ for boundary wind velocity w*=4m/s

The main purpose of this part of the paper is to determine the appropriate supply water temperature (outdoor-indoor reset schedule) in district heating system with direct connection. There exists only central regulation in heating plant with fare or no regulation in the house installations. From the aspect of rational energy consumption, although far from the ideal technical solution, this type of regulation still exists. It was designed some 20 years ago, when buildings were not thermally insulated and when ratio between transmission and ventilation heat losses was very high. For small ratio of ventilation heat losses, the impact of wind velocity on the supply water temperature was not significant and therefore central regulation of hydronic heating systems was adopted.

For up-to-date mode of building, rate of ventilation heat losses is higher, and wind velocity is important factor in defining required hot water temperature at heat emitting unit inlet. Diagram 2 clearly shows that optimum operating of hydronic heating system involves local regulation. Radiator valves with thermostatic heads, combined with slight control regulation stand as one of the best solution today.

CONCLUSION

At qualitative regulation of heating hot water, “sliding diagrams” of supply and return water temperature should follow both outside temperature and wind velocity. But, while supply water temperature follows the variation in the outside air temperature throughout the whole interval of change (from outside design temperature to the temperature at which the heating season is to cease), supply water temperature should follow wind velocity change up to the boundary velocity w*. For any outside temperature, when wind velocity is lower than the design one, supply water temperature for hydronic system may be diminished but only to certain level (the boundary level). If supply water temperature is determined according to very low wind velocity, certain problems may arise in buildings (insufficient heating). Boundary wind velocity causes the infiltration rate equal to minimum ventilation rate (for hygienic purpose). Boundary wind velocity depends on the window area and window type (air tightness and crack length). Bellow boundary wind velocity, heat losses due to infiltration are lower than heat demand for room ventilation, which is done by other measures (open windows, mechanical ventilation, etc.). At “sliding diagram” determination, considered is heat necessary for additional air quantity heating.

It should be pointed out that presented “sliding diagrams” are idealized, because certain simplifications are made: linear building heat losses dependence on the outside temperature, constant values of heat transfer coefficients through building envelope, neglected heat accumulation in building envelope and night heating setback (steady state conditions), constant room air temperature, ideal building heating regulation, and neglected usual “over-design” of heat emitting units.

LIST OF SYMBOLS

a - (m^3/mh $Pa^{2/3}$) - window air tightness
H - (Wh$Pa^{2/3}$/m^3K) - building characteristic for certain wind velocity;
Q (W) - room heat demands (total room heating losses);
Q_T (W) - transmission room heat losses;
Q_V (W) - ventilation (infiltration) room heat losses;

t (^oC) - water temperature;
t_i (^oC) - indoor air temperature;
t_o (^oC) - outside air temperature;
Δt (^oC) - difference between supply and return water temperatures;
Δt_m (^oC) - difference between mean water temperature in heat emitting unit and room air temperature;
Y (-) - relative room heat losses - eq. (4);
Z (-) - relative outside temperature - eq. (3).

INDEXES

m - mean;
N - design (nominal) conditions;
r - return water;
s - supply water.

EXPONENTS

m - thermal characteristic of the heat emitting unit.
$'$ - primary loop (district heating (piping network)
$''$ - secondary loop (house heating installation)

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ABSTRACT

This paper is about the analysis relating to simultaneous impact of the outside temperature and wind velocity on required supply water temperature. Introduced is boundary wind velocity at which infiltration heat losses are equal to the necessary heat for room ventilation. For hot water heating with radiators, presented are "sliding diagrams" (outdoor-indoor reset schedule) of supply water temperature, regarding the outside temperatures and wind velocities for both house heating installation and district heating system with direct connection.