Microclimate of low-energy buildings in relation to applied heating systems

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Abstract**—**Low-energy buildings have become wide spread within the Czech Republic. Therefore it is necessary to focus on evaluation of indoor microclimate of such buildings. As indoor climate is greatly influenced by heating system and building constructions (as the most important parameters of thermal-hygric and toxic microclimate), this paper compares two case studies – two low-energy family houses with different heating systems and constructions.

The aim of the paper is to determine optimal microclimate regarding particular heating systems and constructions. Since there have not been realized many of such case studies, this work might help designing healthy low-energy buildings with optimal indoor microclimate with is fundamental condition for a long-term inhabitation.

Keywords**—** indoor microclimate, heating period, forced ventilation, heat pump, solar system, combined system

I. Indoor Microclimate

REGARDING passive, low-energy and energy-saving houses the indoor microclimate has become a very important issue recently. The paper focuses mainly on the low-energy houses which have become wide-spread within the Czech Republic civil engineering.

Indoor climate is a specific part of environment which is formed by agencies represents energy and mass flows in between two environs. For the proper design the internal microclimate of buildings is essential [1]. The indoor microclimate is mainly influenced by building constructions and by heating system as well. The most important part of indoor climate is thermal-hygric microclimate which represents 30% of overall microclimate. Its fragmental components are: temperature (54%), humidity (23%) and speed of air flow (23%) [1].

Another important parameter of indoor climate which can be directly influenced by heating system and building constructions is toxic microclimate. The most monitored characteristic of toxic microclimate regarding low-energy houses is concentration of carbon dioxide - CO_2. It is the most significant pollutant of indoor air. It is produced by human breathing and its concentration is higher inside the building than in the outdoor air. Concentration of carbon dioxide is related to indoor air relative humidity: the higher relative humidity is, the higher is the concentration of CO_2. Therefore very important issue within low-energy and specifically passive buildings is the ventilation of building. There can be recognized two types of ventilation: natural of forced ventilation.

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A. Biological Post-strain - Influence of Indoor Microclimate on Human Health

Healthy indoor microclimate is a result of keeping all parameters of microclimate on an optimal level. Since there have not been paid proper attention to a behavior of indoor air quality it is essential to monitor it especially regarding low-energy buildings.

In connection with unsatisfactory indoor microclimate there is often mentioned the occurrence of molds resulting into allergies and asthma. Existence of molds within building constructions is related to permanent high relative air humidity (long-term values above 60%). Microclimate with high relative air humidity is typical for buildings designed with diffusion-closed masonry constructions where natural ventilation is mostly insufficient. Constructions designed as a wooden frame filled with mineral insulation create different microclimate comparing to the masonry buildings. The indoor air relative humidity keeps its values at the low limit set by the standard 6/2003 (published by Ministry of Health) which is minimally 30% during heating period.

Low indoor air relative humidity causes that mucous membranes of upper airways get dry which results in weakened filtrating ability of human organism (see Fig. 1). The mucous membranes of upper airways are covered with basal corpuscles which are at normal relative air humidity (40 – 60%) straight and therefore filtrating incoming air. If the relative humidity falls beneath 30% for a long-term period then basal corpuscles turn down and its filtrating function is minimal. This situation is ideal for bacteria and allergens which can easily flow into a human organism. Resulting post-strain develops as various allergies and asthma. There have been proceeded several medical studies explaining how the amount of bacteria in indoor air of buildings is related to relative air humidity. The percentage of surviving microorganisms is minimal when the relative air humidity is in interval 35 – 55% (see Fig. 2). There also has been monitored the absenteeism of children in schools regarding relative air humidity (see Fig. 3). All the realized biological studies show that optimal indoor air relative humidity is within the interval 40 – 55%.

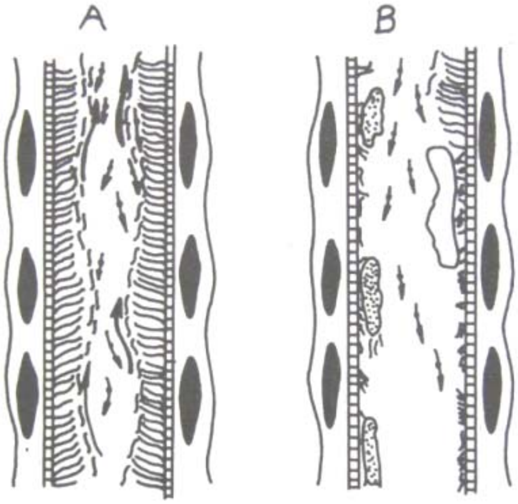

Fig. 1 Basal corpuscles of upper airways A) in optimal condition B) dried [1]

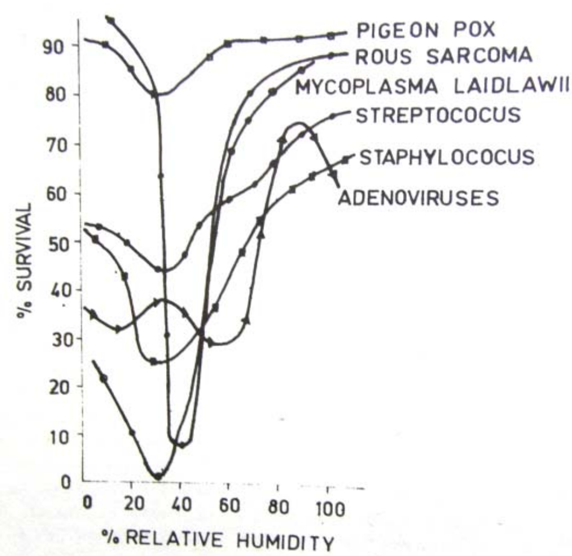

Fig. 2 Percentage of surviving microorganisms in relation to relative air humidity [1]

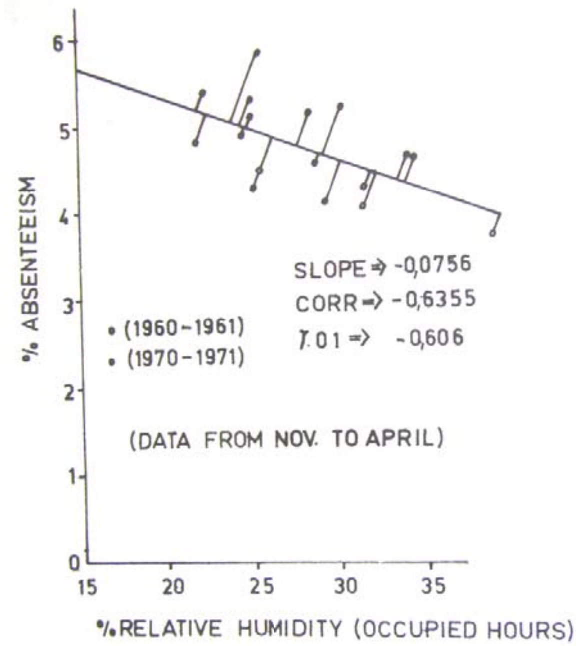

Fig. 3 Children absenteeism in relation to relative air humidity [1]

B. Sanitary Codes for Formation and Evaluation of Indoor Microclimate

Till July 1st, 2003 when the standard 6/2003 published by Ministry of Health came into effect, there have not been set direct limits for evaluation of indoor microclimate. The standard 6/2003 sets temperature limits for indoor air, indoor air relative humidity limits, concentration of volatile organic compounds (VOC) and other indoor air pollutants.

By the end of year 2007 there was published new standard ČSN EN 15251: Input parameters of indoor microclimate for design and evaluation of energy demand of buildings regarding indoor air quality, thermal environment, lighting and acoustics. This standard sets limits for broader parameters of indoor microclimate.

II. Combined System – Heat Pump and Solar System

There appeared a new conception of using heat pumps and solar systems (Fig. 4) in low-energy houses – combined system in which heat pump cooperates with solar system. This cooperation works on a simple principal – when the temperature in the suggested combined system falls under the temperature of bivalence, the solar collector activates and the thermal energy obtained from the solar system is used for increasing temperature at the heat pump input.

Increasing the temperature at the heat pump input leads to increasing the heating factor of whole unit. The main contribution of such assembled combined system is high effectively of solar system that works with lower temperature than the temperature of heating system.

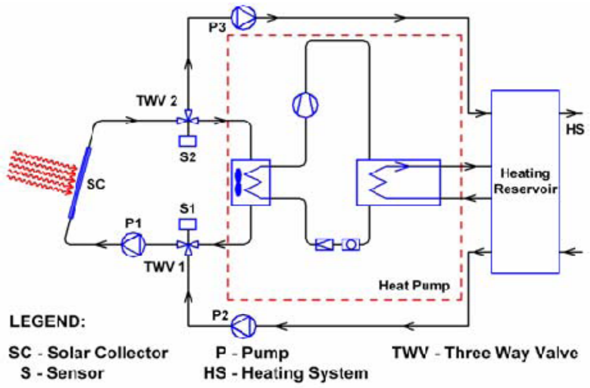

Fig. 4 Optimized system of heat pump and solar system [3]

III. Case Studies – Family House "Kubis"

Family house „Kubis“ is designed as a low-energy prefabricated wooden house with the principals of low-energy building: the south facade has most glass areas for reaching maximum thermal gains – but also using shading system for keeping temperature extremes under control, the north facade has only minimal glass areas. Regarding heating system there is designed forced ventilation and heating and solar collectors (primary pre-heating hot service water).

A. Results of Measuring

There have been monitored the most significant parameters of indoor microclimate (thermal-hygric and toxic) such as: indoor and outdoor air temperatures, indoor and outdoor air relative humidity and concentrations of carbon dioxide.

Fig. 5 Family house „Kubis“

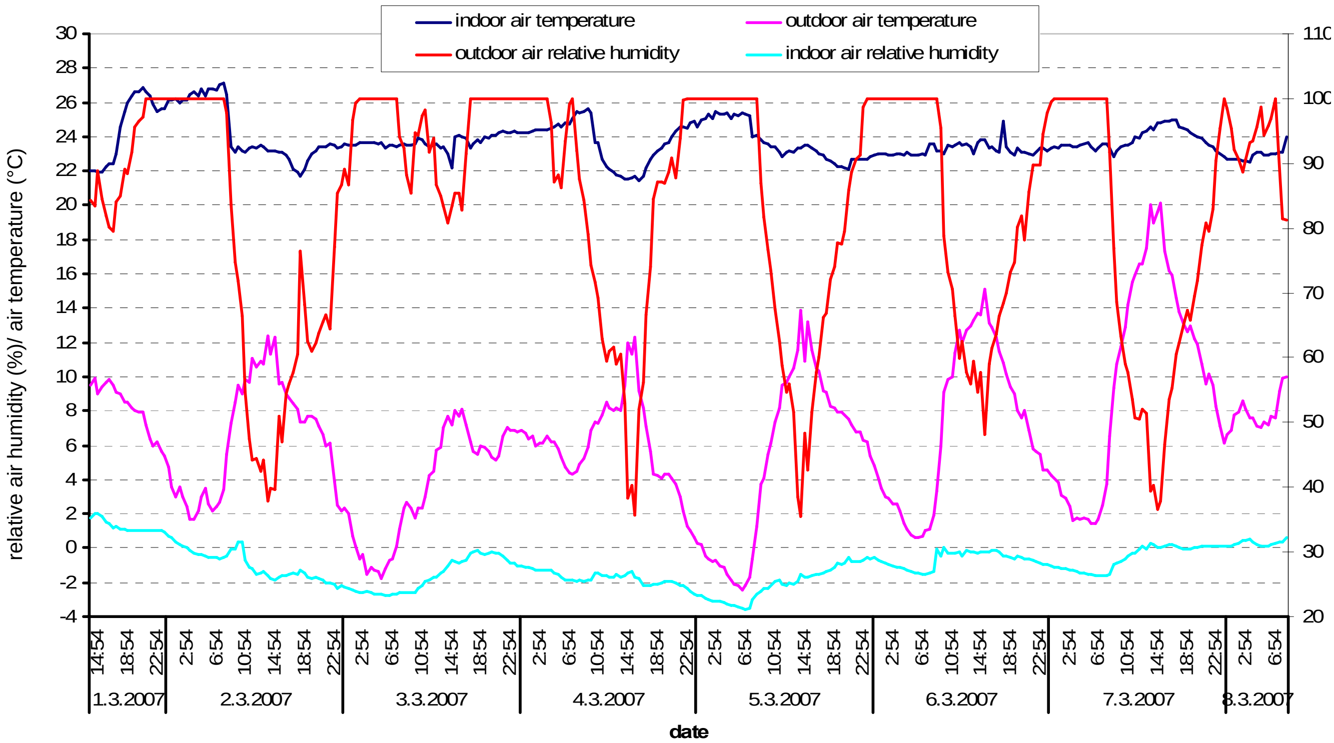

Fig. 6 Relative air humidity and air temperature

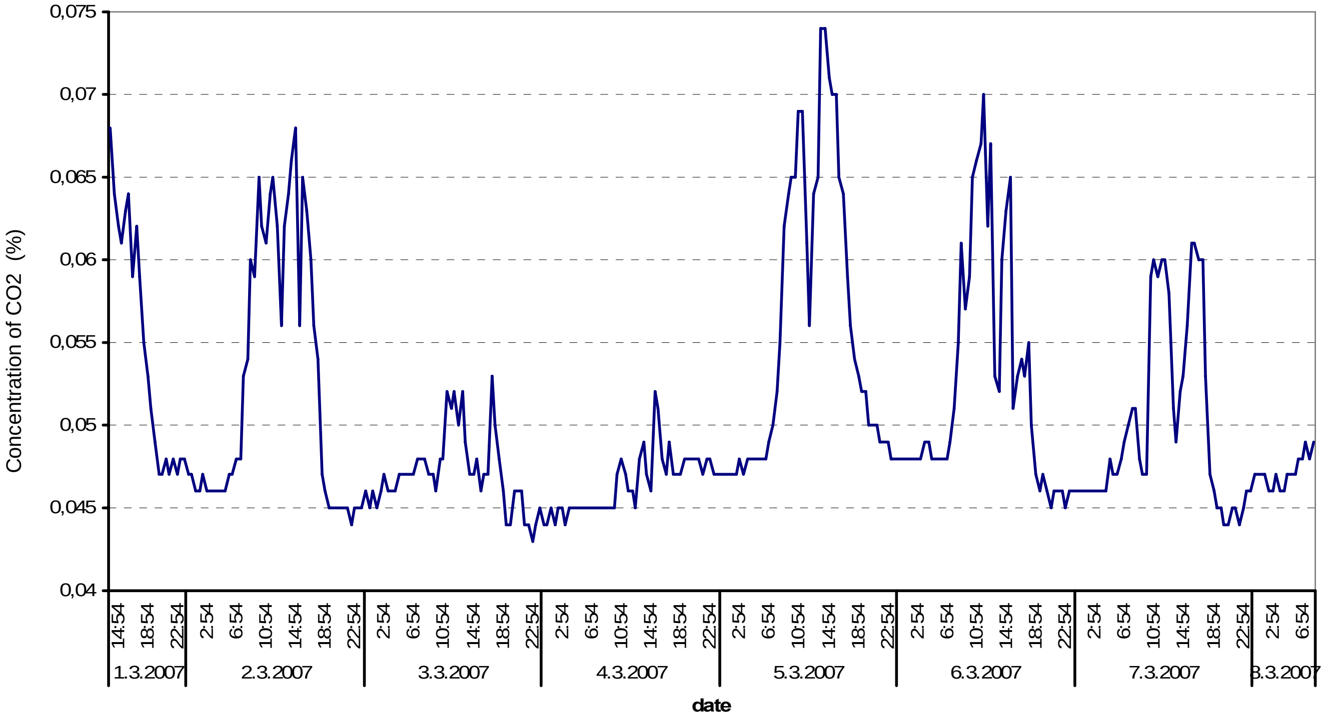

Fig. 7 Concentration of carbon dioxide

B. Evaluation of Family House „Kubis"

Regarding most significant parameters of thermal-hygric and toxic microclimate then the family house „Kubis" has not optimal microclimate.

- indoor air relative humidity is in between 25 – 35%, average value is 28% which is beneath the minimum set by the standard 6/2003 (Ministry of Health) – see Fig. 6
- average increase of daily temperature is 3°C which comply with the limit $_{\Delta}t \le 5$°C, but in Graph 1 there can be seen that average indoor air temperature is 23,75°C, the limit interval is 20°C $\le t_i \le$ 24°C, during measuring 43% of all measured values of indoor air temperature were above the maximum limit therefore the indoor climate of family house „Kubis" is not thermally satisfactory stable
- average value of concentration of carbon dioxide is 0,051% which does not exceed the maximum health-damaging limit 1,5%

IV. Case Studies – Family House "CHyne"

Family house „Chyne" is low-energy prefabricated wooden house with common two-store disposition. This house fulfils principal of low-energy building mainly by constructions composition. There are used shading exterior blinds. Common electric furnance and radiators are used for heating the house. Electric boiler is designed for heating hot service water. Total heat loss of „Chyne" family house is 6,5 kW.

Fig. 8 Family house „Chyne"

A. Results of Measuring

There have been monitored the most significant parameters of indoor microclimate (thermal-hygric and toxic) such as: indoor and outdoor air temperatures, indoor and outdoor air relative humidity and concentrations of carbon dioxide.

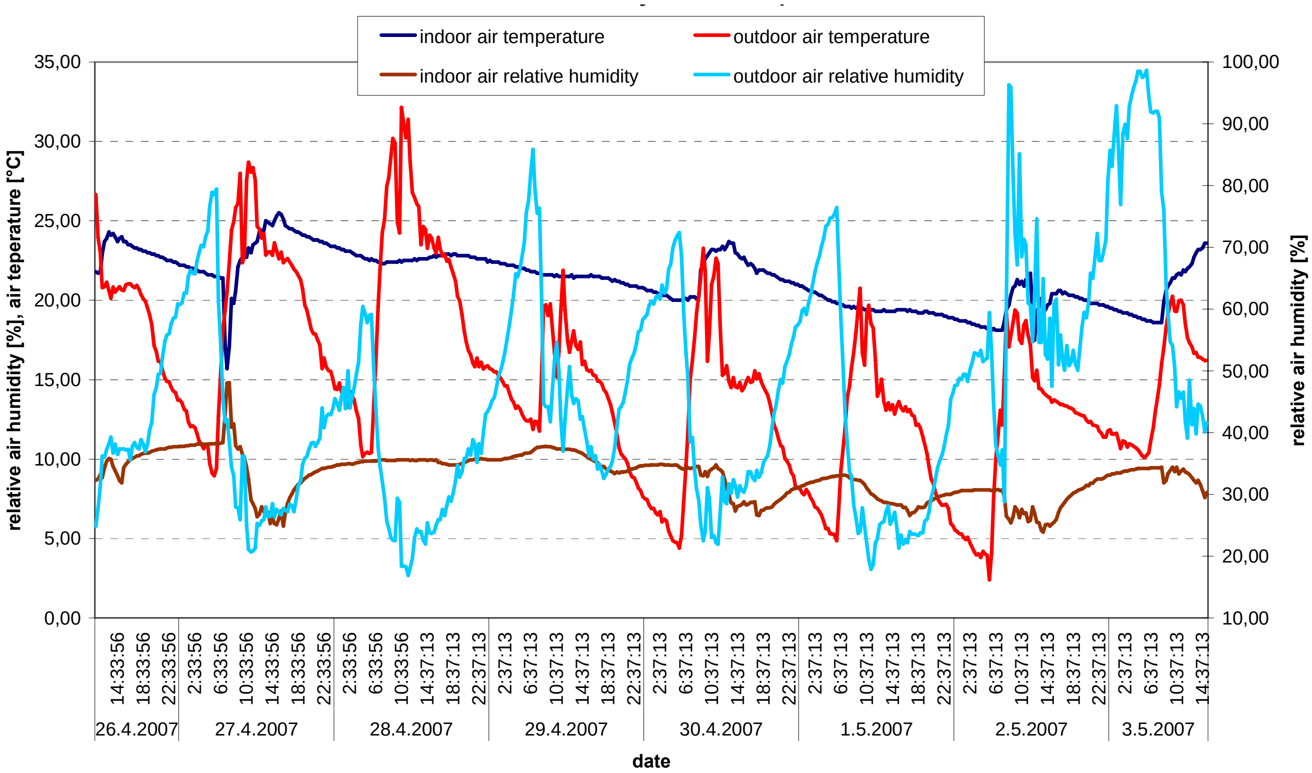

Fig. 9 Relative air humidity and air temperature

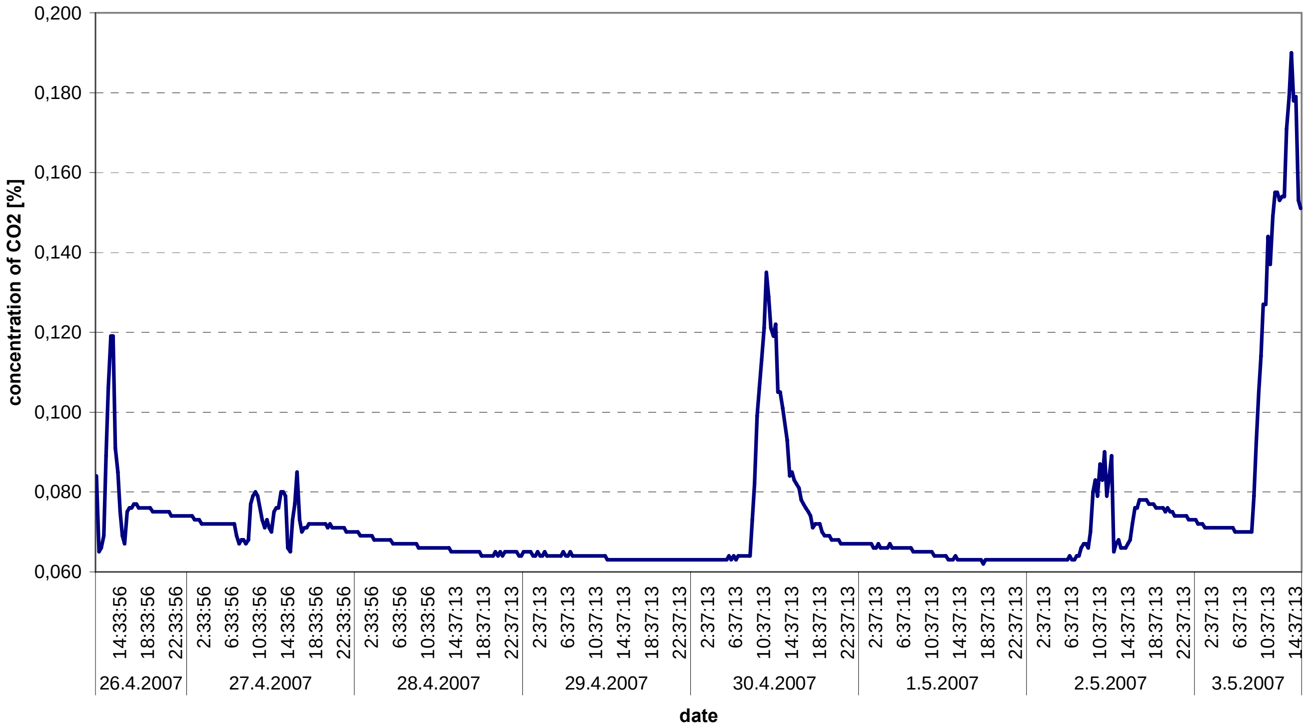

Fig. 10 Concentration of carbon dioxide

B. Evaluation of Family House „Chyne"

Family house „Chyne" is designed in the same constructional system as family house „Kubis", it has the same construction composition, the difference is only in designed heating system. But since heating system is one the most important factors influencing final microclimate that is why measurements indicated different indoor microclimate.

- indoor air relative humidity is 28 – 38%, average value of indoor air relative humidity is 33,01% which fulfils the minimum limit set by the norm 6/2003 (Ministry of Health) for heating season – 30%
- average increase of daily temperature is 3°C which comply with the limit $\Delta t \leq 5°C$, average indoor air temperature is 21,37°C and 4,84% percent of all measured values of indoor air temperature are higher than the interval set by the norm $20°C \leq t_i \leq 24°C$, therefore the family house „Chyne" is evaluated as thermally stable building
- average value of concentration of carbon dioxide is 0,051% which does not exceed the maximum health-damaging limit 1,5%

V. Case Studies – Family House "Medlanky"

Family house „Medlanky" is very similar to „Kubis" family house regarding lay-out and architecture. It is a low-energy highly insulated masonry house keeping the principals of low-energy building: the south facade has most glass areas for reaching maximum thermal gains – but also using passive shading system for keeping temperature extremes under control, the north facade has only minimal glass areas. Regarding heating system there is designed air-to-air heat pump in combination with solar system.

Fig. 11 Family house „Medlanky"

A. Heating System – Heat Pump in Connection with Solar System

Air-to-water heat pump with the 5,3 kW rated thermal output is designed in the family house „Medlanky". Having the prime source temperature 2°C and the output temperature 35°C, the rating performance is than P_t = 5,8 kW and heating factor is ε = 3,6. The type of heat pump is designed so the ratio of heat pump performance and heat loss of the building is 63% which corresponds to 90% of supplied energy for heating.

The rest of the energy needed for the heating and hot service water is provided by the cooperation of heat pump and the solar system. Air-heating combined solar collector is chosen for the cooperation with heat pump. It is intended for air-heating and hot service water heating. [3]

The solar system is during a faction of a year used as a bivalent power source supplementing heat pump while increasing heat pump input temperature. Air is an operating substance in this case. Solar collector is used for hot service water heating in the case when it is not necessary to increase heat pump performance – in such case water is an operating substance.

Based on performed measuring it is possible to derive the direct influence of assigned solar system on heating factor. Percentage increase of heating factor due to the various areas of solar system can be seen in figure 12.

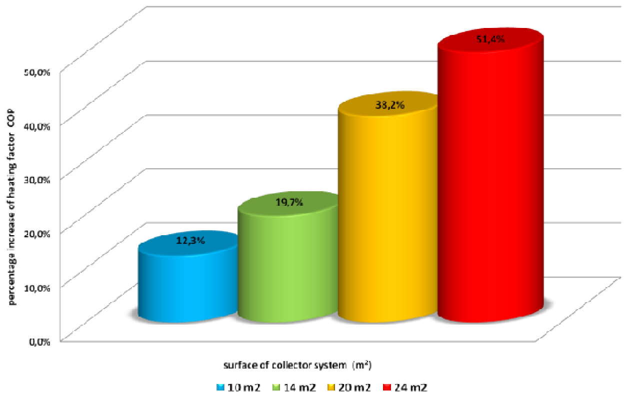

Fig. 12 Percentage increase of heating factor [3]

Regarding measured values on combined system (heat pump with solar system) there has been the energy-economic evaluation of such system feasibility elaborated. As it is mentioned above the influence of connected solar system to heat pump is – from the energy point of view – significant.

Economical-technical evaluation of operation of combined heat pump and solar system is based on the analysis of operational parameters. Energy evaluation results from measured values on the combined system. Economical evaluation is an integral part of the general evaluation.

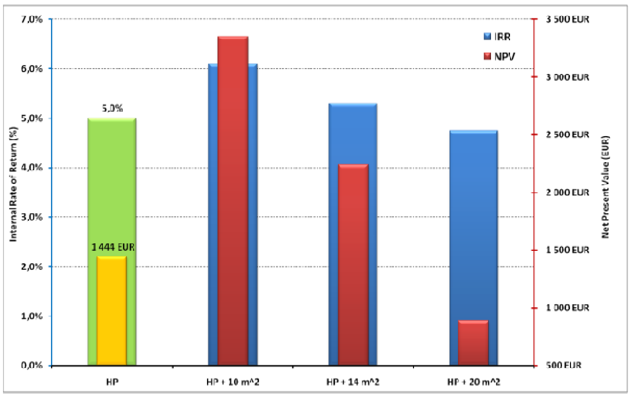

Fig. 13 NPV and IRR of combined system

Figure 13 shows the development of NPV and IRR in relation to the area of connected solar system. Stated values indicate that optimal area of solar system in connection with heat pump is between 11.5 - 17.0 m^2. These values derive from the combination of energy and economic evaluation of combined system. You can find more information about evaluation of combined system in [3] and [6].

B. Results of Measuring

There have been monitored the most significant parameters of indoor microclimate (thermal-hygric and toxic) such as: indoor and outdoor air temperatures, indoor and outdoor air relative humidity and concentrations of carbon dioxide.

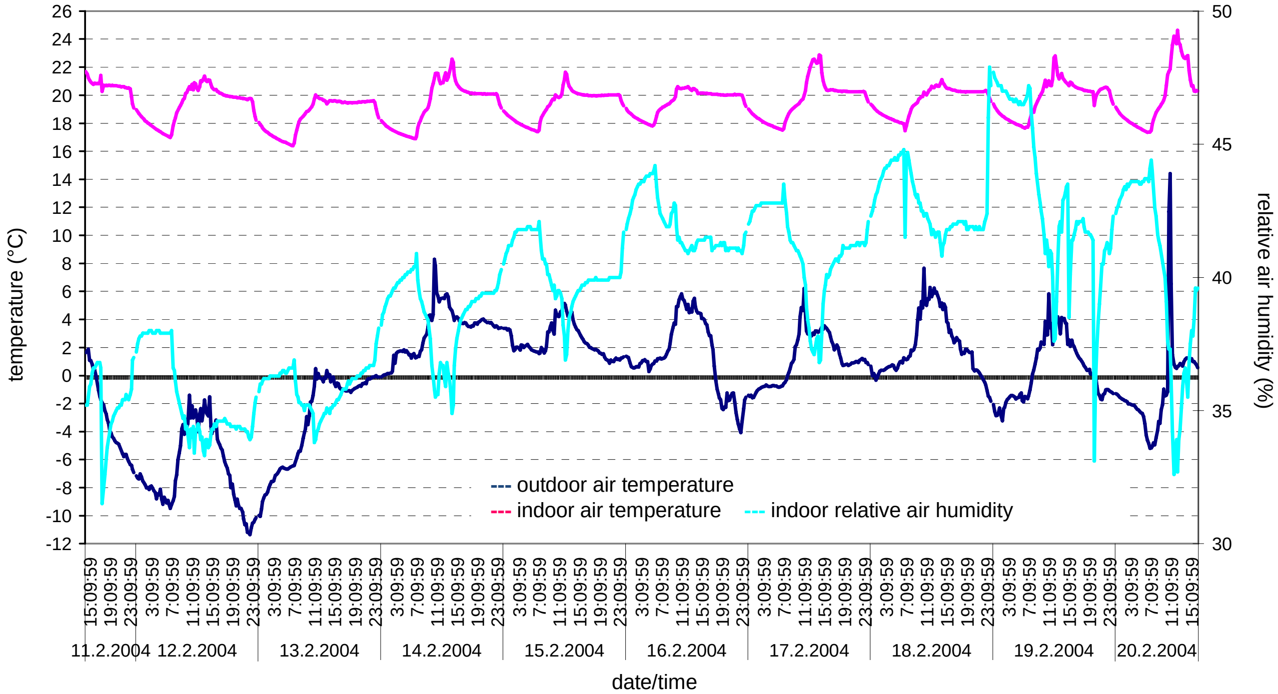

Fig. 14 Relative air humidity and air temperature

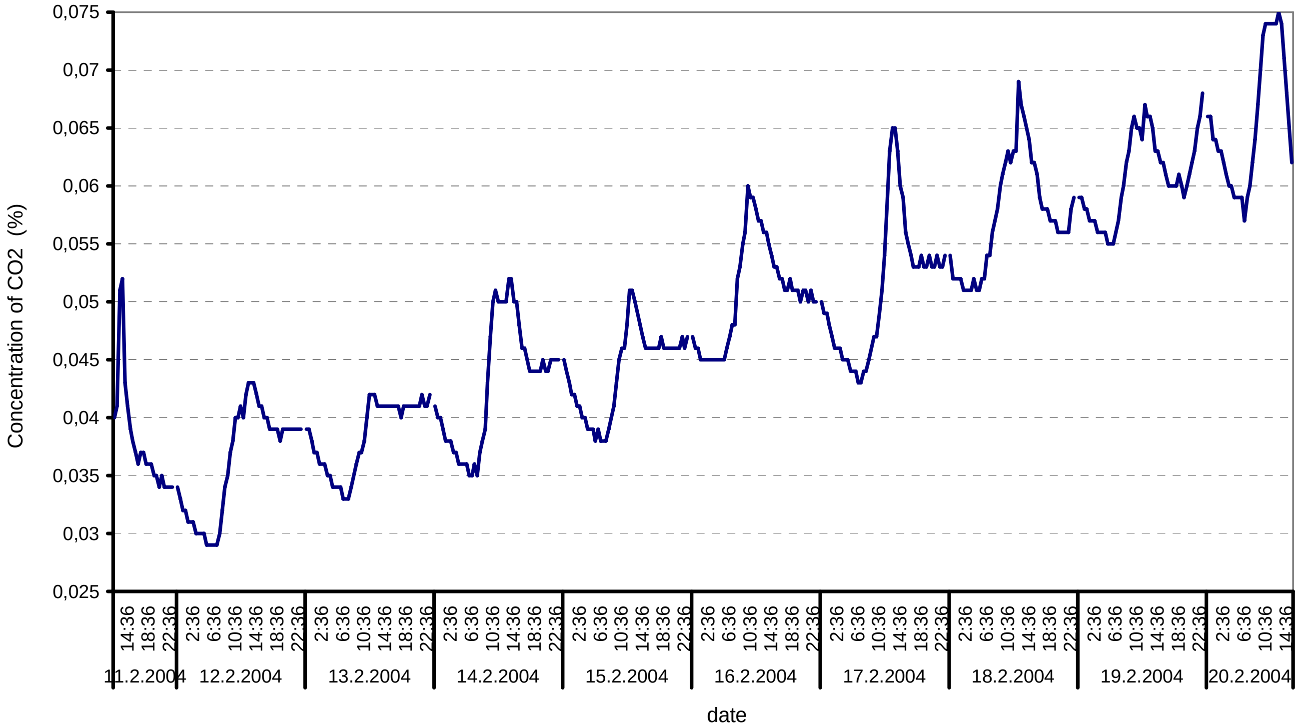

Fig. 15 Concentration of carbon dioxide

C. Evaluation of Family House „Medlanky"

Regarding most significant parameters of thermal-hygric and toxic microclimate then the family house „Medlanky" creates optimal microclimate.

- indoor air relative humidity is in between 30 – 50%, average value is 40,98% which is optimal level set by the standard 6/2003 (Ministry of Health) – see figure 14
- average increase of daily temperature is 4°C which comply with the limit $_{\Delta}t \leq 5°C$, but in Graph 1 there can be seen that average indoor air temperature is 21,94°C, the limit interval is $20°C \leq t_i \leq 24°C$, during measuring only 18% of all measured values of indoor air temperature were above the maximum limit therefore the indoor climate of family house „Medlanky" is thermally stable
- average value of concentration of carbon dioxide is 0,049% which does not exceed the maximum health-damaging limit 1,5%

VI. Conclusion

This study compares three family houses, all designed as low-energy houses. Each house has a different approach to heating system a there are designed two different construction systems. As these two building parameters (building constructions and heating systems) influence greatly the final microclimate, there are recognized three different indoor climates.

When comparing these measured buildings and its following evaluation there appears that family house „Kubis" (prefabricated wooden house with forced ventilation and heating) does not have optimal microclimate. This result is highly influenced by the forced ventilation and heating (hot air generally lowers the indoor air humidity and also the permanent air change does not keep the humidity inputs in the indoor climate as it is ventilated out of the house) and regarding wooden prefabricated houses there are used mostly building materials which do not have the ability to absorb neither much thermal energy nor humidity. On the contrary family house "Chyne" is designed with the same constructions as family house "Kubis", the difference is in applied heating systems. Both houses create different indoor climate. These results show that the influence of heating and venting systems is greater than the influence of building constructions. Family house „Medlanky" is heated by heat pump in connection with solar system. Since this house is built up of materials which have the ability to absorb thermal energy and humidity the indoor climate therefore appears optimal.

Generally wooden prefabricated houses are very advantageous for low-energy and passive buildings (high energy savings are apparent and these buildings are ecological an environment friendly) – the only thing which has to be followed is that there should be a different approach to the design of heating system in such houses. As there is not much absorbing „mass" in these buildings there should be preferred heating systems excluding air heating which decreases indoor air humidity.

At present the choice of power sources for heating low-energy buildings is not only a question of energy point of view but it is also a question of economy. The research held at the University of Technology in Brno tries to describe and define all aspects of development in the field of renewable power sources and present-day buildings.

The paper summarizes results of applied analyses on experimental combined system which consists of a heat pump and a solar system that is used as a bivalent power source for pre-heating input medium on a prime side of a heat pump. As the analyses show a pre-joined solar system significantly influences heating factor of the combined system which also results in overall higher efficiency of the system. The limiting factor for increasing the coefficient of combined system performance (COP) is besides energy parameters also the economic point of view. Combination of these two aspects allows defining the optimal area of joined solar system so the optimal energy effect of the combined system is reached.

The essential contribution of this research is the increase of operational efficiency of combined system. This fact has direct influence on the consumption of prime energy of combined system. New connection allows using heat pump with lower load which decrease the consumption of prime energy. This fact positively influences reducing the CO_2 concentration. It is true that present world-wide interest in broader utilization of renewable power sources greatly encourages its development but it is essential to understand that such power sources cannot be applied in all localities.

References

[1] Jokl, M., Prof., Ing., DrSc., *Theory of Indoor Microclimate*, reissue - Editorship ČVUT, Prague, 1993, 261 pages, 177 pictures, ISBN 80-01-00481-3

[2] COMPOSITE authors, *Indoor Microclimate of Buildings,* first printing, EXPO DATA Ltd, Brno, 2001, 126 pages, ISBN 80-7293-023-0

[3] Mastny, P.; Matousek, A. *Increase of Efficiency of Energy System with Heat Pump Using Solar Radiation.* Energy and Environment Proceeding of the RES'07, Arcachon, France, October 14 16, 2007: ISBN: 9789606766091

[4] Patkova, Z., Ing., *Forced Ventilation and Heating of Wooden Prefabricated Houses and its Influence on Indoor Climate.* Heating and Installations 3/2009, pages 46 – 49, May 2009, ISSN 1211-0906

[5] Patkova, Z., Ing., *Microclimate of Low-energy Houses and Building Services.* Treatise on dissertation thesis, Brno University of Technology, 2004

[6] Mastny, P., *Cooperation of Heat Pump and Solar System in the Common Power Unit*, WSEAS – Proceedings of the WSEAS International Conferences: EE'07, Slovenia, ISSN 1790-5095, pp. 186-194

[7] Mastny, P., Matousek, A., Machacek, J., *Renewable Energy Sources in Combined Systems - On-line System for Measuring and Collecting Data -*, WSEAS Transactions on Environment and Development, Issue 1, Volume 4, p. 6 – 11, January 2008, ISSN: 1790-5079

[8] Akram, A., Bahare, F., *Analysis of environmental emissions and greenhouse gases in Islamic Republic of Iran*, WSEAS Transactions on Environment and Development, Issue 4, Volume 4, p. 303 – 312, April 2008, ISSN: 1790-5079

[9] Conceicao, E., Lúcio, M., Lopes, A., *Application of an Indoor Greenhouse in the Energy and Thermal Comfort Performance in a Kindergarten School Building in the South of Portugal in Winter Conditions*, WSEAS Transactions on Environment and Development, Issue 8, Volume 4, p. 644 – 654, August 2008, ISSN: 1790-5079

[10] Pesl, M., Goricanec, D., Krope, J., *Response Functions and Thermal Influence for Various Multiple Borehole Configurations in Ground Coupled Heat Pump System*, WSEAS Transactions on Heat and Mass Transfer, Issue 3, Volume 2, p. 61 – 71, July 2007, ISSN: 1790-5079

[11] Barna, L., Barna, E., *Investigation of Combined Effects for the Modellingof Thermal Comfort Conditions in Building*, WSEAS Transactions on Heat and Mass Transfer, Issue 4, Volume 3, p. 229 – 239, October 2008, ISSN: 1790-5079

[12] Chowdhury, A., Khan, R., *Numerical Simulation of Building Performance under Different Low Energy Cooling Technologies*, International Journal of Energy and Environment, Issue 1, Volume 1, 2007, p. 28 – 36, ISSN: 1109-9577

[13] Patkova, Z., Ing., Sevcikova, L., Ing., *Ecohouses and Building Materials,* Juniorstav 2004 conference proceedings, Brno University of Technology, Faculty of Civil Engineering, 442 pages, ISBN: 80-214-2560-1

[14] Patkova, Z., Ing., *Indoor Climate of Low-energy Houses During Heating Period,* Juniorstav 2008 conference proceedings, Brno University of Technology, Faculty of Civil Engineering, 478 pages, ISBN: 978-80-86433-45-5

[15] Humm, Othmar, *Low-energy buildings,* Volume I, Prague, Grada Publishing, 1999, 360 pages, ISBN: 80-7169-657-9

[16] CSN EN 832, *Thermal Behaviour of buildings – calculation of energy demands for rating – civil structures,* Prague, Czech Standards Institute, May 1994, 40 pages