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Summary. The paper defines the task of ventilation and ventilation system. It gives an evaluation of ventilation procces quality by means of energetistic efficiency of ventilation. Then, the purpose and methods of the investigation on ventilation process quality are discussed.

THE CHOICE OF METHODS IN SYSTEM INVESTIGATIONS OF VENTILATION PROCESSES QUALITY

1. Task - system - system investigation of ventilation

The task of ventilation can be generally defined as maintaining required air parameters distribution in a room. It is realized by means of two groups of operations:

- Intake and removal of contaminants and excess that are emitted in the room
- Air supply and air flow pattern creation in the room including the supply of fresh air, suitably adapted with regard to its purity and thermal parameters.

In order to realize such the task some ventilation equipment arrangement and energy input are required. They depend on:

- The object design solution and thermal loads in the object.
- The assumed conception of ventilation process realization.
- The choice of equipment.

The problem of ventilation process quality can be considered:

- In a narrow aspect - in reference to the task realization and related to it expenditure within the ventilation equipment arrangement chosen for a room where thermal requirements and loads are defined.
- In a wider aspect - taking into account also the adaptation of the object by including into consideration the object parameters.
- In a wide aspect - including eventually also the problems of the choice of the type, power and location of energy sources as well as its transfer to receivers and its consumption in building objects.

In every case the set:

energy source - object - ventilation - equipment arrangement ought to be treated as a system being a set of elements related to one another functionally [5]. It is apparent that the limits of the system - set may be determined in different ways, adequately to the needs or to the possible range of optimizing analysis. Both the limits and the purpose of the optimization ought to be chosen in a sensible way. Then a system is a process or a part of a process selected for analysi [4]. The concept of a system can be related to the equipment arrangement.

For us here the central part of the system is a ventilation process and equipment arrangement - a ventilation system.

Those systems relevantly to their destination are differentiated with regard to the conception of the choice of the equipment, of the way of their performance and of energy use. They can operate with various air amounts: from several hundred to several million m^3/h and they can consume or transport thermal energy from about several dozen kW to some MW in one object.

The system investigation makes it possible to fill the gap between the knowledge about the process, factors conditioning its solutions and profitability and dealing with the process in an engineering undertaking [6]. It is to one's advantage to think and to act in the system cathegories particularly when the work refers to system simulation and optimization where boundary conditions as well as the characteristics and the description of the elements ought to be concrete, compatible with the assumed general conception of the complex problem.

If boundary conditions for the system elements are determined the tests of those elements can be properly placed and related to one another as well as they are given their part in recognizing the process and the system structure. Simulation of the system response in some determined situations results in its optimization when the task is efficiently realized.

2. Ventilation process quality

The quality of a ventilation process realized in an investigated system can be evaluated in different aspects, e.g.:

- considering the degree to which the ventilation task is realized, as ventilation effectiveness,
- considering energy consumption when ventilation task is satisfactory realized, as energetistic efficiency of the ventilation process.

2.1. Ventilation effectiveness

Ventilation effectiveness or the effectiveness of air exchange within considered ventilated space, may by estimated on the basis of air parameters distribution, e.g. by means of [9]:

- temperature simplex, m_t
- contaminants concentration simplex, m_c
- defining expressions for given by Rydberg or Sandberg [1, 2, 10]_

$$m_t = \frac{t_z - t_s}{t_e - t_s} \qquad m_c = \frac{C_z - C_s}{S_e - S_s} \qquad = \frac{C_e - C_s}{C_z - S_s}$$

where

t - air temperature,

C - contaminants concentration in the air,

z - reference to a considered working zone of the room,

s - reference to supplied air,

e - reference to removed air.

Ventilation effectiveness defined in this way may be then referred to the assumed, allowable or required parameters check values i $t_z = t_a$, $C_z = C_a$. Air exchange effectiveness is of essential importance to evaluate the quality of a ventilation task realization but it does not characterize the energy use for this purpose and it has no explicit relation to thermal and mass balances of the ventilation process.

2.2. Energetistic efficiency of ventilation

Energetistic efficiency of the process may be defined as the ratio of the effective result to the energy input i.e. to the driving energy of the system.

In the case of a ventilation process it is difficult to express the effective result in energy units in a way different that by means of energy demand in an assumed, comparative ventilation process, realizing the required distribution of air parameters in the room and thus realizing also the required ventilation effectiveness.

The choice of the comparative process is conventional since it is practically difficult to define one ideal ventilation process for a given ventilation task.

For instance, when warm air heating of a hall is considered, such a comparative energy demand may be a heat loss of the object, Q_o, at equalized calculation temperature of the air or at required temperature distribution in whole hall increased by kinetic energy, E_o of supplied air jets [3].

Driving energy in a ventilation process system is understood here as a real input of thermal and cooling energy, Q_R, and mechanical energy input, E_R, that is used for air transport, in the conditions of the considered variant of a real ventilation process system necessary to obtain required ventilation effectiveness.

Thus, considering exploitation periods: comparative, T_o, and real, T_R, in a year use of warm air heating or ventilation, the energetistic efficiency of the process or the system may be defined as follows, where Q_o and Q_R, E_o and E_R are expressed by means of the fuel consumption relevantly in a boiler house (η_B) and in a condensation electric power station (η_{El})

$$\eta_e = \frac{\int_{T_o} (Q_o/\eta_B + E_o/\eta_{El})d\tau}{\int_{T_R} (Q_R/\eta_B + E_R/\eta_{El})d\tau}$$

It is worth mentioning that in a ventilation case energy inputs depend not only on the loads in the object but also on the assumed design solution of the ventilation arrangement and on the energetistic efficiency of the equipment applied. Therefore it is difficult to define explicitly and to choose the comparative model of the system and the comparative energy demand. Thus, the energetistic efficiency may be helpful when evaluating various alternative design solutions of a ventilation system where the same comparative model and the same required ventilation effectiveness are assumed.

Energetistic efficiency of ventilation equipment may be concretely defined as for any thermal flow equipment according to the given above definition of the process efficiency. Equipment efficiency is an inseparable component of the equipment arrangement efficiency.

Energetistic efficiency of a ventilation process system imposes also additional aerodynamical requirements on the elements being the plant ends i.e. on ventilation openings fittings and on local exhauts forming. The fulfillment of those requirements remarkably conditions the required ventilation effectiveness air distribution in the room when the amount of supplied air is limited to the necessary minimum. It is essential since the amount of air flowing through the ventilation plant always conditions the cost of this plant building and the energy consumption for air treatment and transport.

3. The purpose and the methods of investigations on ventilation processes quality

3.1. The purpose of investigations

The purpose of investigations on ventilation processes quality is usually the complex optimization of the costs of the object building and its exploitation where rational energy use plays substantial part. In many cases the limits of the considered system may be confined to the object and ventilation air conditioning process together with the equipment.

Optimization is a process of defining the conditions in which the extreme of function values occurs at chosen criteria. When optimizing a complex system, in this case a thermal ventilation and air conditioning system, it is advantageous to observe a replacement system that immitates the features and behaviour of the real system - i.e. to apply system simulation.

Simulation of a system and of its elements is a tool for the system optimization. The optimization procedure of a complex system should include [6]:

- Working out a series of reasonable alternative systems being combinations of sub - systems and elements
- Optimization of each element, sub - system and alternative system
- The choice of the best alternative system.

It is, however, necessary to take into account that one cannot optimize a thermal system for the whole range of its parameters variability. Therefore the optimum is usually related to the conditions and to the time of exploitation.

Thus, the aims and the procedure of the system optimization stimulate the way of the use of various investigation methods to obtain needed information. At the same time, when testing the quality of ventilation processes, one may choose the methods of experiment, simulation and analyses in different ways according to one's knowledge, experience and the equipment in possession.

In this paper mathematical simulation is assumed as the main tool of optimizing analyses. Therefore, an active experiment serves as identifying, supplementary and verifying test. However, this is not the only possible solution.

3.2. System simulation

Simulation of thermal system requires to define the characteristics of all the components /the elements of the system as well as the equations describing thermodynamical working factors.

Simulation of a real physical process may be realized:

- By observing another physical process of the same kind or of another kind but showing the analogy of relations of operating parameters
- On the way of calculation.

Thus, physical simulation consists, above all, in physical modelling with the similarity principles applied or in analogue modelling. The possibilities of physical modelling are limited by the system complexity although such the kind of modelling is useful in many cases and even necessary e.g. quasi - free flow.

Mathematical simulation is based mainly on mathematical models. Simulation of a complex system depends on the models of its components and on their mutual relations that are substantial to recenstruct the system internal structure.

3.3. The choice od mathematical models

Mathematical models include the equations of the elements characteristics and thermodynamical equations of the processes based on mass, momentum and energy balances. The sulutions of the equation set, obtained at concrete boundary conditions form mathematical description of system simulation.

In order to simulate ventilation and air conditioning processes three main types of models may be applied, namely:

- Models of flow phenomena, making use of physical-chemical phenomena descriptions, i.e. phenomenological equations of mass, momentum and energy conservation.
- Models of population balance, operating with the distribution of the time of stay history.
- Empirical models in the form of e.g. polynomials, making use of data obtained experimentally.

Mathematical form of the models may be deterministic, when to every variable or parameter a concrete number can be assigned, or stochastic when uncertainty of parameter value is taken into account.

The characteristics of elements e.g. of ventilation equipment may be prepared as mathematical models or as "a black box" by empirical determination of the analytical form of the operator describing the transformation of the input into the output. In this case, however, the internal structure is still not determined as well as the properties of the elements included in the black box.

The accuracy of results and the sensitivity of numerical analyses depend directly on the least precisely described element in a certain range of parameter values and on the relevancy of the essential relations among the elements. This must be taken into account when composing the set and the structure of a complex replacement system.

Mathematical detailed models, so-called "reference models", of the system components e.g. of thermal processes in building and of outdoor climate influence, models of separate ventilation devices and of the ventilation system control - are usualy made to obtain possibly good accuracy of the description. This may sometimes cause great difficulties in the analyses of complex problems of rational energy input for ventilation and air conditioning purposes.

Therefore, a tendency to simplify detailed models is presently observed e.g. by means of using linear equations of heat exchange and one-dimensional aproximations, by means of parameter aggregation, by operating with lumped parameters and on the way of system decomposition. In order to maintain satisfactory accuracy of simulation results it is then necessary to have good basis of identification and the results confrontation within the active experiment.

Models with lumped parameters called "lumped models", where spatial parameter distribution is neglected, lose the physical sense of described phenomena in favour of empirical approach, thus do not yield proper information about the model structure. Therefore, when searching for a proper structure of the equations of a model with lumped parameters one may rely only on one's own knowledge and experience [7].

The advantage of those models is the simple form that can be maintained on the level of ordinary differential equations or even algebraic equations. Moreover, their accuracy may depend on the user. Such the models cannot, be however, extrapolated beyond an identified range of lumped parameters values.

An example of those models may be the model of air flow and heat exchange in a multi-storey building in which real distributions of air temperature and velocity are given be means of lumped values for separate rooms, group of rooms or storeys.

Another example may be empirical static and dynamic characteristics of ventilation equipment and arrangements operating with lumped parameters.

So-called "optimal models" [7] are the next step and level in system simulation. Their structure is adapted according to the range of use in a convenient, optimum way. Efficiency of complicated analyses is made easier by introducing of complex and aggregated parameters, simplexes or functions of parametes. Those values correspond to some physical sense. It may also be a parameter determining the result of the group of effects. Its value may even be measured in certain conditions e.g. "building temperature without heating" as the building response correlated with parameter complex of outdoor climate. When knowing this value it is relatively simple to correlate the model of climatic conditions with the building characteristic in calculations that make use of analitic formulation of degree days.

Such the approach to the compositon of the optimal model of a complex system makes it possible to reduce the number of variable parameters that would be contributed to the same complex analysis by detailed models. At the same time the optimal model may, if necessary, make use of detailed or lumped models, reasonably chosen.

Therefore, complex simulation analyses should make use of models with different forms of parameters and connections. One should, however, remember that, opposite to detailed models, the form and structure of lumped parameters models and optimal models should be conditioned by their application. It follows from the above consideration that mathematical models composition and the way in which they are adapted to the range of analyses is substantial to obtain relevant sensitivity of analysis and reliable results, as well as numerical technique is essential for computerization. Mathematical models and numerical analyses must be, however, closely related to reality by means of various identification techniques.

3.4. Methods of active experiment

In order to ensure reliability of mathematical models and of the results of numerical analyses it is necessary to introduce active experiment investigations in various forms i.e. investigations in natural objects and tests of existing ventilation equipment. Physical modelling of aerodynamical and thermal processes may be also included to this type of investigations.

The purpose of investigations in natural conditions should be getting data referring to the behaviour of ventilation and air conditioning systems and equipment, physical identification of real phenomena and processes in the tested system including particularly aerodynamical conditions of momentum and energy transfer and the ways in which aggregation ought to be made and parameters ought to be lumped. Some control tests are also necessary to estimate the correctness of algorithms used in analyses of energy conditions in buildings.

Some groups of subjects ought to be differentiated in those investigations such as investigations from the range of [8]:

- Building physics, referring to thermal properties of partitions
- Conditions of heat exchange and objects dynamics
- Static and dynamic thermal characteristics of equipment
- Efficiency of ventilation air-conditioning systems and the role of elements in such the systems
- Methods, measurement and control equipment and automatic control systems.

Physical modelling applied to ventilation processes may be useful partikularly in air distribution tests within ventilated space, to estimate spatial distribution of air parameters and effectiveness of air exchange as well as in tests of wind flow around buildings and building complexes. Technology of such the investigations enables to determine and to verify representative thermal lumped parameters and aerodynamical characteristics of ventilation equipment for mathematical modelling purposes.

Measuring apparatus problems. When applying numerical analyses and computers to system investigations of ventilation processes quality it is possible to digest a great number of measurement data at their versatile processing. Thus it is necessary to make use of electric data transmission, electronic data anylysing and processing, automatization of measurement work and computerized experiments with automatic measurement systems.

Methods and measurement equipment should be adapted to those requirements. They ought to enable good accuracy and repeatability of measurement results as well as current introduction of changes of averaging time constants.

Electric thermometers, anemometers and heat flow meters can be well adapted to such the requirements whereas methods and sensors for humidity and air flow rate measurements still ought to be improved.

4. Conclusions

1. When studying ventilation processes quality one should effeciently make use of possibilities and properties of modelling and simulation of the processes as well as of active experiment.

2. The form of mathematical models, their level and sets for the system simulation process ought to conform to the aim and the range of study.

3. When composing a complex replacement system it is profitable when the simulation users co-operate with specialists within the range of mathematical models composing as well as within the experiment range. This enables the improvement of the research tools and the application of the achievements of related domains in system investigation.

4. System approach to the investigation enables complex research and analyses carried out in various research centres co-operating according to an agreed program.

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DOBÓR METOD W BADANIACH SYSTEMOWYCH
JAKOŚCI PROCESU WENTYLACJI

S t r e s z c z e n i e

W artykule zdefiniowano pojęcia, zadania wentylacji oraz układu wentylacji. Podano oszacowanie jakości procesu wentylacji za pomocą efektywności wentylacji, jak również za pomocą energetycznej skuteczności wentylacji. Następnie omówiono cel i metody badań jakości procesu wentylacji.

ПОДБОР МЕТОДОВ В СИСТЕМНЫХ ИССЛЕДОВАНИЯХ
КАЧЕСТВА ПРОЦЕССА ВЕНТИЛЯЦИИ

Р е з ю м е

В статье определяются понятия задачи вентиляции и системы вентиляции. Даётся также оценка качества процесса вентиляции с помощью эффективности вентиляции. Дальше обсуждаются цели и методы исследований качества процесса вентиляции.