

# Applied modeling multiscale (1D-3D) methods for design, research and optimization of buildings air exchange systems

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**Abstract.** The work describes an application of multi-scale models for the simulation of air exchange systems in buildings and constructions. The model consisting of spatial (3D) and network (1D) elements at the same time is called a multi-scale model. The paper considers two options for their implementation: the spatial and network parts of the model are calculated separately and the spatial and network parts are calculated together (hydraulically unified model). The paper presents a practical examples number for each proposed methods.

## 1. Introduction

Usually, standard methods or 1D-network models are used for design, research and optimization of gas cleaning or ventilation systems of buildings. It is not always possible to solve the problem by means of this approach with the necessary accuracy, because handbooks of hydraulic resistances do not cover all the set of the system components, and formal compliance with requirements for the air discharge in the room does not get information about airflow in the room and between several rooms. These problems can be solved by applying full 3D models based on the methods of computational fluid dynamics (CFD). However, building 3D model of ventilations systems with all system components requires too much time and computational costs. From the point of view of the balance between the accuracy and the required resources, the best way is multiscale (hybrid) methods, based of unified 1D-network and CFD models. For example, 1D-network methods are used for modeling standard elements system of ventilations, and CFD methods are used for modeling non-standard elements or rooms. There are several ways of implementing multiscale models, so the main of them are the follows: 1. fully-separated models: the spatial and the network parts of the problems are calculated separately; 2. hydraulically unified models: the spatial and the network parts are calculated simultaneously; 3. hydraulically disconnected models: network elements go through the spatial part, and the connection is implemented by using the fluxes through the walls of the tube/channel.

All three approaches were implemented in the next program products, SigmaNet and SigmaFW with NetFlow module. These programs can be applied to solve the following problems:

- design, i.e. developing system of ventilation and heat-supply, taking into account the airflow in the room and between several rooms;
- investigation, i.e. construction of 1D network model for existing system for the detection of its problematic places;
- optimization, i.e. using the 1D and 3d models for improving the operating modes of equipment and reducing economic costs.



## 2. Fully separated model

In the process of this model applying, spatial and network parts of the task were calculated separately by means of different software products, and then the calculation data obtained from one of the model parts determine the input parameters of the other part. This is the most popular approach for constructions of hybrid models. Undoubted advantage of this method is the possibility to use existing software products to calculate both parts of the task without any modifications, because the transmission of information between the model parts is carried out through the peripheral data transfer. The main disadvantage of fully separated model is its limited applicability. For example, the calculations of hydraulic resistance on 3D models require obtaining dependence of the flow rate on the pressure drop for all inlets/outlets of the device, that requires a large number of 3D calculations for device with many (more than 2) inlets/outlets.

The example of fully separated model applying is the study of the gas cleaning system of a non-ferrous metallurgy enterprise (Figure 1), carried out by the authors. Several subsystems can be distinguished from this system. The main subsystems are the gas flue system and the treatment facilities. The gas flue system is used for not only gases transport from industrial installations and their delivery to treatment facilities, but also for first stage of the treatment by reaction of neutralization.

Two numerical models were made for simulations of this gas cleaning system: 1D-network model of all the systems (Figure 2a) and 3D models of the electrostatic precipitators section (Figure 2b) and liquid absorbents devices. The model of anisotropic porous medium was used to simulate constructional elements whose dimensions are less than grid steps. The hydraulic resistances of those elements were determined from handbooks of hydraulic resistance [1].

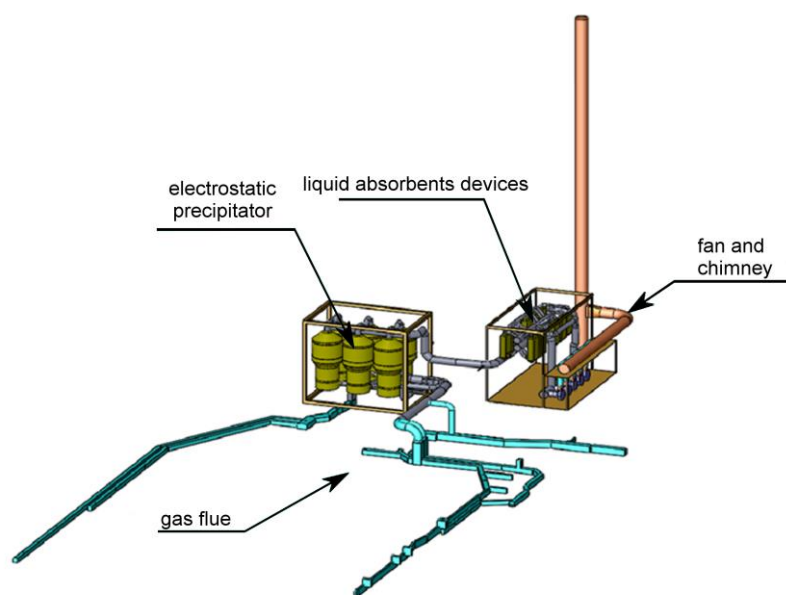


**Figure 1.** Gas cleaning system of a non-ferrous metallurgy enterprise.

The spatial CFD calculations were used to several problems. First, analyze gas flow in treatment facilities can show existing of improving reserve their work by optimization of their construction. Reserve of electrostatic precipitators was revealed to exist in case of more uniform flow in the electrode zone (Figure 3). Second, calculations for different combinations of treatment facilities defined the order of simulation network detailing. In this case, all the electrostatic precipitators were modeled as different elements of the network, but the liquid absorbents devices were modeled as a unit element, because they have large hydraulic resistance ( $\approx 75\%$  of the total hydraulic resistance of that

section). Third, spatial calculations were used to define hydraulic resistance of some elements of the gas flue.

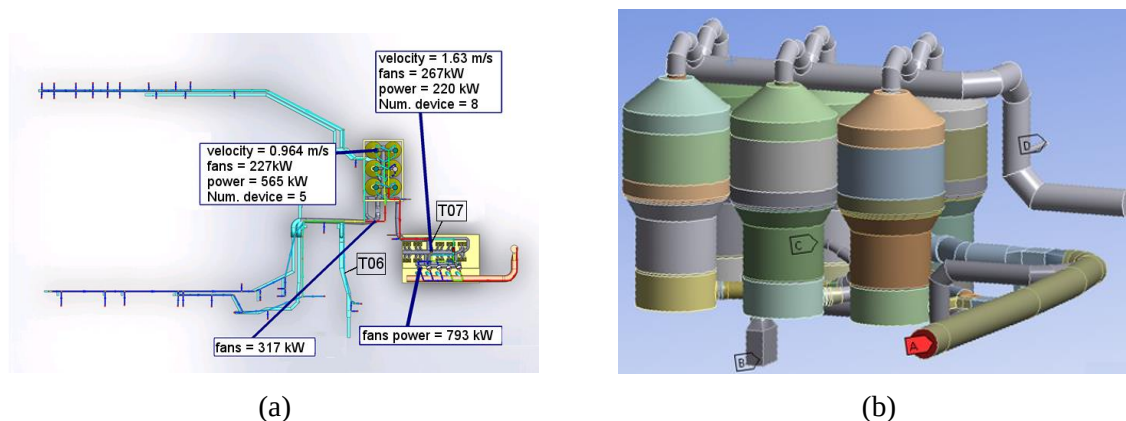


**Figure 2.** 1D-network model of gas cleaning system (a); geometric model of electrostatic precipitators (b).

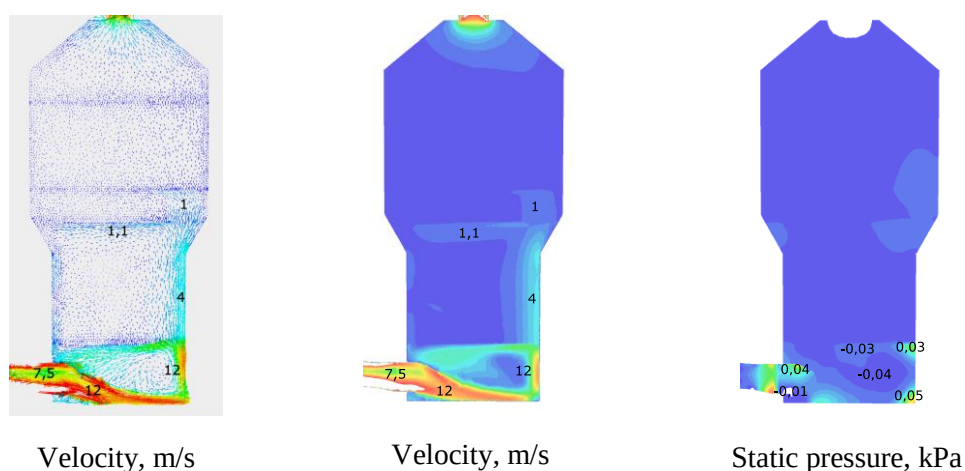


**Figure 3.** Central vertical cross section of electrostatic precipitator.

The results of the gas cleaning system numerical modeling by network simulation were compared with the data of the monitoring system (Figure 4). The network model was further used to develop the strategy of gas cleaning system control.

Another example of applying full separated model is the simulation of airflow in the industrial enterprise laboratory. The project system of several subsystems ventilation composed: 1 – technological exhaust from the high-temperature furnace (V1 shown in Figure 5), 2 - technological extraction from the mills, 3 – the forced ventilation.

At the first stage, network calculating was performed for all the subsystems. The boundary conditions were set as follows: the required flow rate was set on inlets (vent hoods) and a constant pressure was set on outlet. The hydraulic resistances of network elements were determined from handbooks of hydraulic resistances [1]. Criterion for the ventilation project verification was the comparison of the calculated pressure drop with the fan pressure (for this system  $P_{prj} = 500$  Pa). The result of calculation has shown (Figure 5) that the pressure drop is 30% higher than the projects fan pressure. Similar situations were observed for the other ventilation systems in this laboratory.

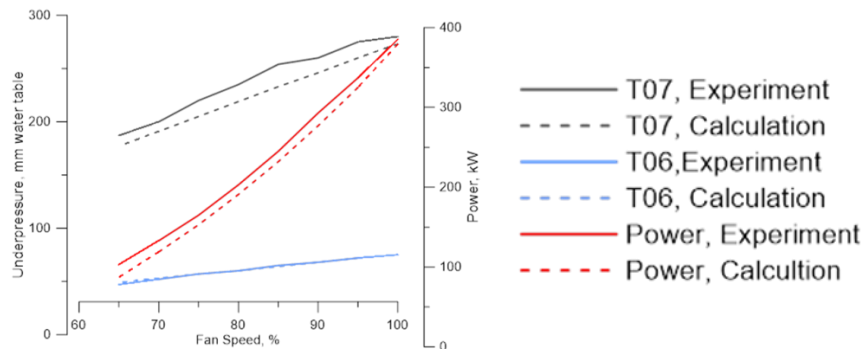


**Figure 4.** Comparison of the modeling results with the data of the monitoring system. Points of monitoring (T06 and T07) are shown in Figure 2 (a).

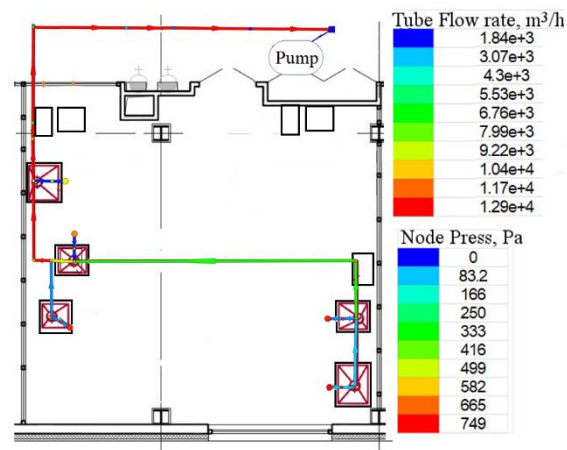


**Figure 5.** Layout plan of the equipment and the network model of the ventilation system (V1).

At the next stage, calculating of indoor airflows distribution was performed with applying 3D simulation. The 3D model is shown in Figure 6, size of calculating grid is 94000 cells.

Flow rates obtained from network model were set on the inlets and outlets. The results of calculations (Figure 7a) has shown a significant excess of the air velocity in relation to the established standards. In addition, on the last stage, moving mass particles was simulated in the flow and the sources of those particles were the upper surfaces of the furnaces. The most of the heavy particles, as expected, do not enter to ventilation system and fall to the floor.

### 3. The hydraulically unified model

If a building separated model for a certain task is impossible, i.e. it is impossible to obtain a definite parameters' dependence of one model part on the calculation result of the other part, then it is necessary to use a hydraulically unified multi-scale model. In this approach, both model parts are calculated simultaneously, and the data exchange between the parts occurs iteratively. In the vast majority of these method applications, different parts of the model are calculated by means of different software products. Therefore, there is a need to transfer data from one program to another using either third-party libraries, for example, MpCCi library is used to link ANSYS and Flow master [2], or via additional exchange files [3]. Even if the software package allows simulating both model parts, the problem of boundary conditions transfer remains relevant. For example, in [4], dealing with the simulation of blood flow, the values of the flow rate is transferred downstream, while the pressure values are transferred upstream.

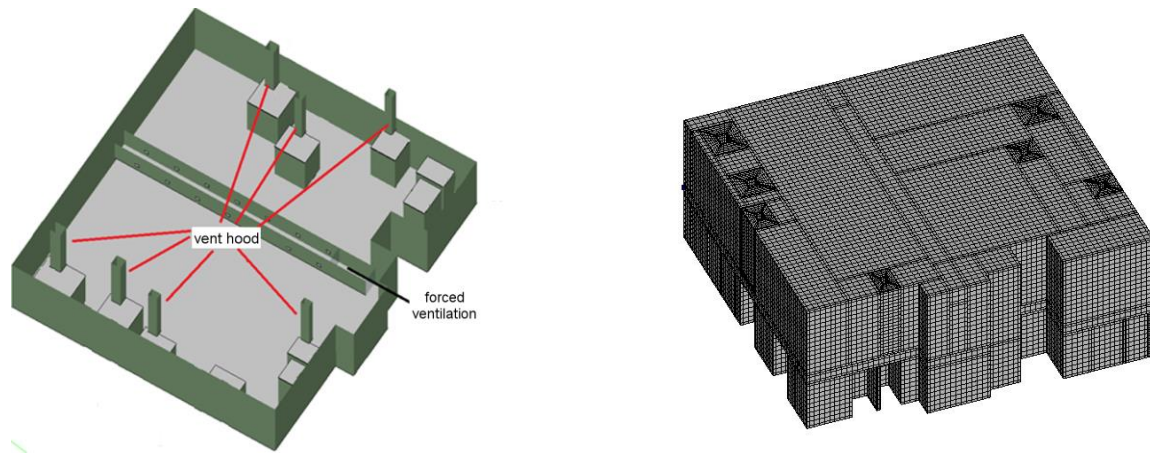


**Figure 6.** 3D model of the studied laboratory and its calculating grid.

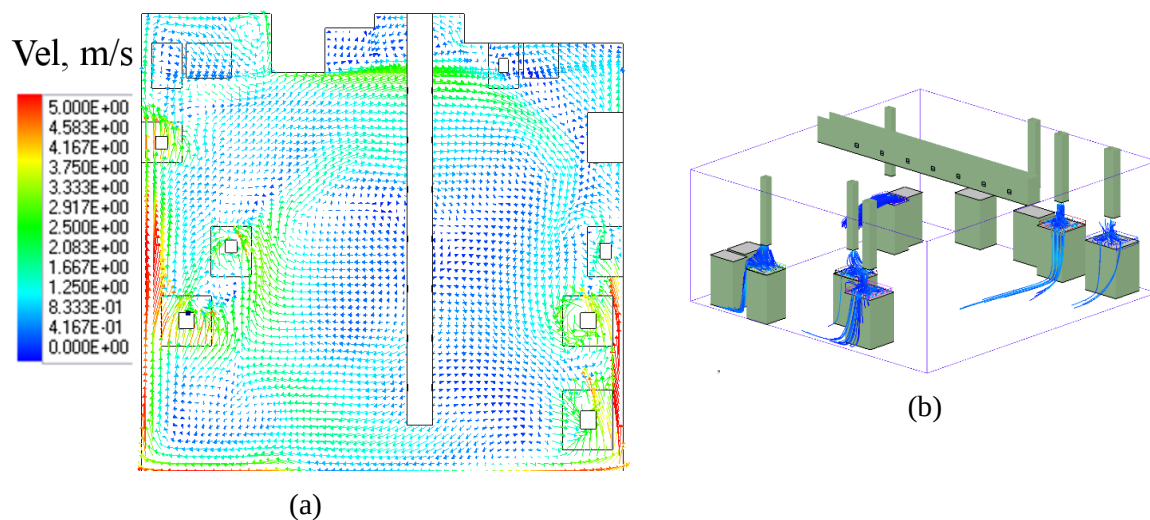


**Figure 7.** The results of the spatial simulation of the laboratory.

The example of the approach practical use is the problem on simulation of the gas removal system at an aluminum plant enterprise [5]. The gas removal system is designed to collect from electrolysis baths harmful gases and transfer them to the gas treatment facilities. The problem consists in the equalizing of flow rates from each bath in four spreads and estimating of the change in the required value of the rarefaction at the outflow on system. The main feature of the gas removal system consists in presence of the central collecting receiver (Figure 8), where pressure losses reach half of the total pressure loss in the investigated part of the system. In the general case, the simulation of this problem within the framework of a main approached (fully 3D or fully network) is impossible. The size of the computational grid to build a fully three-dimensional model of the whole facility will be too large, since the lengths of certain linear sections are more than 100 m. In the process of only network model building, it is necessary to know the hydraulic resistance of the collecting drain for different operating modes. Building a multi-scale model allows removing this obstacle. Extended elements are arranged in the form of a network, a collecting drain is presented in the form of spatial element (see Figure 8a), and the resistance of the collecting drain is calculated for specific flow rates.

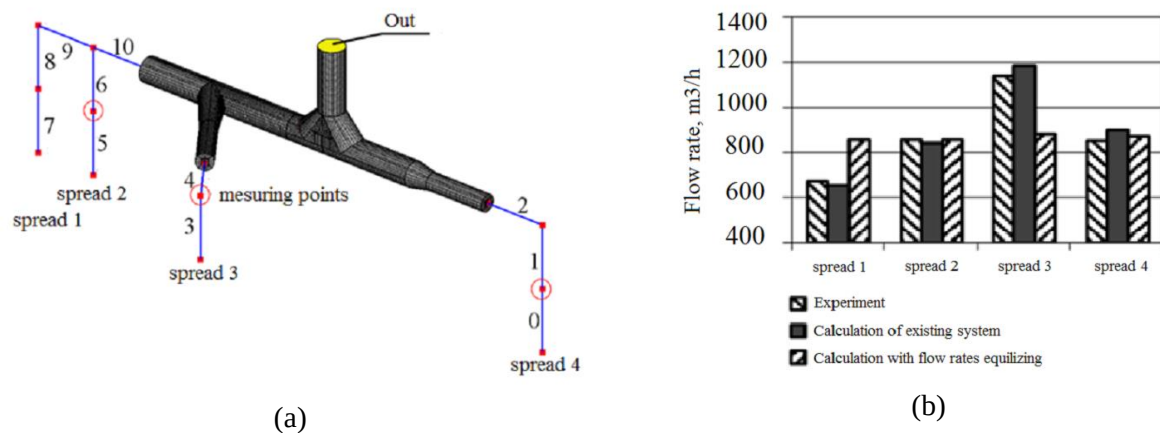


**Figure 8.** (a) multi-scale model of the gas removal system at the facility of aluminum plant. Spread 1-4 is the numbers of the spreads, 0-10 are the numbers of calculation edges, circles show measuring points; (b) the calculation results of the gas removal system.

The lack of a duct network and the geometry of the collecting drain were constructed according to the design drawings.

Network elements of the hybrid model are divided into three groups:

Edges, which parameters are defined based on the geometric characteristics (edges 2, 9, and 10).

Edges, which model the area for installation of the regulating gate valve (edges 1, 4, 6, and 8).

Edges describing the spread of below building exhaust duct (edges 0, 3, 5, and 7).

The parameters of the third group edges were determined based on the experimental data.

The results of the hybrid calculation were compared with experimental data. The rarefaction at the outlet of the collecting drain amounted to 2416 Pa. After the equalization procedure of the flow rates from electrolysis baths, identification of the additional resistance, a re-calculation was carried out, which results are presented in Figure 8b. The rarefaction in the system required for obtaining the desired gas flow rates from the baths, rose up to 2868 Pa – on 20%.

#### 4. Conclusions

This work shows importance of applying multi-scale models for practical problems and, accordingly, development of the hybrid methods, models and software complexes based on them. That allows simulating of complex hydrodynamic systems containing multi-scale and multi-sized elements. In spite of the obviousness of a fully separated model applying for calculating air exchange in buildings and construction of a single calculation area with communication between the network part and spatial part through a single pressure field is a promising way of development hybrid multi-scale models.

#### Reference

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