Natural and mixed ventilation design via CFD and architectural modeling

M. Todorovic and O. Ecim
Laboratory for Thermodynamics and Thermotechnics, Division for Energy Efficiency and Renewable Energy Sources, University of Belgrade

A. Marjanovic
VTI, Belgrade

I. Randjelovic
CIP, Belgrade

ABSTRACT

Numerical simulations and computational fluid dynamics can be usefully integrated with architectural modeling, providing designers with a powerful single CFD based architectural modeling and design framework. This framework can be interfaced with the building thermal performance modeling, integrating further fully thermal and flow domains within the architectural modeling. CFD analysis is generally restricted to the building's environment flows or indoor single rooms and spaces flows study, and the designer must supply boundary conditions in the form of external and internal building's envelope/wall surface conditions. In the case of natural and mixed ventilation, this presents a fundamental problem as the outdoor and indoor boundary conditions are dynamic, inter-related and interactive via building's architecture and in addition are dependent on external weather conditions and indoor environment control/related heat gains. Therefore, in this study both sides' boundary conditions are dynamically described, and integrated CFD, BPS and architectural modeling, as a unique framework – new design method, are developed, leading to natural and mixed ventilation energy efficiency optimization. In addition to the presented method, paper gives results of its implementation in designing the building complex in Belgrade. Finally, needs for further research and engineering development are outlined.

1. INTRODUCTION

Energy-related impacts - carbon dioxide, and other GHGs releases reduction by decreasing the energy consumption of equipment, systems, and buildings, and by controlling and optimizing the whole building operation, must be considered in designing phase of sustainable building, as well as in reconstruction phase of the existing building's energetic re-engineering.

Primary are those factors that affect the energy consumption in the operation of the building and its HVAC and other technical systems, during the useful lifetime in addition to the selection of energy-efficient equipment. Influential factors within the design process are facades concepts of building envelope, glazing and fenestration, types of building structure thermal mass and insulation, daylighting control, energy-recovery opportunities and natural ventilation.

The energy efficiency optimization of building's envelope and of the whole constructional structure, as well as of heating, ventilation, cooling/air-conditioning and other technological building systems are becoming more and more significant issues at the definition of the new buildings project tasks (Todorovic, 2003, 2004).

Conceptual energetic optimization is to be done side by side with the development of the conceptual architectural, constructional and other technical systems design. Based on the optimization results, elements of the design brief and main project tasks are to be defined. That is why the energy efficiency study should precede the main architecture and construction design, as well as the final design of the mechanical, electrical and other technical systems.

Special attention during the integrated building design is paid to the founding and evaluation of proper indicators and criteria, as well as to methodological content relevant for the development of the integrally sustainable structure. Its main goal is to establish faster, more efficient and more comprehensive communication and cooperation between the experts involved in planning, designing, construction and generally project development of both, new buildings, and reconstruction of the existing buildings (Todorovic et al., 2003).

Initial definitions, assumptions and simplifications are to be based on a mutual interdisciplinary understanding and performed sensitivity analysis. This is important, because disagreement of some assumptions and simplifications in design models of different experts in various fields of professional engineering expertise, differences of input values of relevant parameters, as well as differences in used initial/boundary conditions in preliminary dynamic simulations, may be a reason for limited certainty of results, and later causing non-reliability of more detailed simulations, and even leading to a failure of further planning process and attempt to approach the optimization.

It is very important to choose well the initial model for the building's performance analysis, so that later gradual model development may give, as real a picture of the structure behavior, as possible. An exaggerated model development may give divergent results with illogical values, and on the other hand, it is necessary to harmonize well all users' needs in the planning phase, so that one model analysis may solve as many vital issues related to the given task within the established multidisciplinary communication - integrated building design (architect, civil, mechanical, electro engineer, etc).

Indoor environment/comfort for building's users is not less significant than the energy efficiency, so that each energy efficiency improvement should be validated concerning its influence on comfort.

Dynamic simulations of the multizonal models of naturally ventilated buildings require definition of input parameters for each domain of the physical model.

Sustainable buildings, optimization of a structure's energy efficiency, use of RES/RMS[1] - renewable energy sources and materials and BPS[2] are inextricable linked areas, where cooperation in data and performance selection/validation are of the utmost importance for the application and the improvement of present knowledge, as well as for the further technological and technical advance (Todorovic, 2003).

2. METHODOLOGY

Practice today uses numerous methods in order to solve natural ventilation problems, while their selection depends on the specific design requirements. Some of these methods are used for preliminary modeling, while others are very complex and may describe the dynamics of the structure annual performance. Basis of all the methods is the way the structure is presented – as a one zone or multizone model.

Thermal models are very often obtained by a combination of elementary models, each one describing the thermal behaviour of the elements of the building. Once the elementary models have been chosen, this approach gives a rigid or *monolithic* building model. It replies precisely to the users needs (HVAC designer for example).

The most recent contribution to this problem, by a different approach, consists of the integration of a database of elementary and interchangeable models. On the other hand, when justifying the multimodel approach, it must be made evident that the implied models are greatly conditioned by the availability of necessary input data. In the initial stages of a project, these data are very limited (outlines and dimensions). At each stage of the building evolution, these data become more complex (materials, schedules, HVAC systems) and thus enable the use of much more complex models. At the final stage, varied levels of detail can be obtained, or proceeded to sensibility analysis.

CFD, a powerful tool, may help determine detailed data on velocities field in a space, and local air flows. By using CFD we may predict temperatures, air flow direction and velocities

[1] RES/RMS - Renewable Energy Sources/Renewable Material Sources
[2] BPS - Building Performance Simulation

early during the designing phase, and in this way make necessary architectural changes, i.e. modify building envelope and structure solutions until we get the desired building's behavior.

In case we want comprehensive building's thermal behavior analysis, special attention must be paid to programs connecting building thermal/energy simulations and CFD simulations (Beausoleil-Morrison, 2002).

The designers preoccupation to reduce energy consumption and to achieve better thermal ambience levels has favoured the setting up of numerous building thermal dynamic simulation programs. The progress in modelling and its transfer into the professional field has resulted in various numerical approaches.

In each of these cases, the objective results, the precision advocated and the time delay of the results are different parameters which call for a multiple-model approach of the building system. Since the initial significant diffusion of simulation and design models, one of the major problems is their appropriateness to a particular user during the design process.

In addition, in these simulations, it is necessary to check in detail the input data which shall condition the solution fast convergence (Zhiquiang, 2003). One of the biggest advantages of the method developed in our project is a synergetic prediction of the flow around the building, and optimization of the model architecture/geometry in order to get the desired results.

3. BUILDING'S ARCHITECTURE

Urbanistic design of the University Block 32 on New Belgrade was planned as a structure of seven groups of buildings, car pathways and footpaths inside, as well as an underground garage under the whole surface of the block. Its northeast part, i.e. the location closest to the church of St. Dimitrije, is planned for the business and residential building 1A shown on Figure 1.

In accordance with the set horizontal and vertical regulations, continuity of the city block existing on the whole complex, and respecting the location environment, disposition of the building has conditioned formation of two tracts of very dynamic forms. Namely, the southern tract toward the rest of the block is sloping down in

Figure 1: View of the 1A structure with atrium.

cascades from the sixth floor height to the fifth floor height, to be linked with the northern tract high (fourth floor), oriented toward the church.

The most rational ambient and functional solutions of the structure were made in two ways. The concept of double orientation of the residential area was applied on the wider part of the site, with adequate mutual distance of tracts and an option of the optimal use of the environment that is the daylighting, natural ventilation as well as the whole of the visual comfort.

On the other hand, on the part where two tracts get very close, in the zone of the acute angle defined by regulation, due to the smaller option to obtain adequate comfort, a gallery type of residence is planned, with covered inner yard - atrium. Such concept has caused functional residential area division to the primary one, with a view on the environment (living room and bedroom, dining room), as well as the secondary one, oriented to the atrium (entrance, kitchen, bathroom, pantry).

The atrium concept for a part of the structure was caused by the conditions and offers a specific technical and technological solution in order to achieve necessary comfort of the interior space. The main problem of such a concept was the issue of the indoor air quality, and the solution was searched for the adequate strategy of natural ventilation.

4. SIMULATION RESULTS

The CFD investigation goal was to determine the wind influence and relevant pressure conditions in order to determine natural ventilation effects in the A1 structure.

Ventilation of residential area of both buildings leaning on the atrium, has been planned to occur by the extraction of the polluted air from apartments into the atrium, and using the mechanism of natural ventilation, by further displacement into the atmosphere.

The atrium's natural ventilation is very important particularly in the summer period, when the temperatures of the outlet air from apartments can be much higher than the outdoor air temperature, primarily due to the influence of solar radiation and solar heat gains.

According to the meteorological data and the wind rose for the site, the main wind direction in the summer is westward, and during the rest of the year is the south-eastern one.

As the CFD methods allow an easy change of the model and simulation parameters, the obtained data were used to determine natural ventilation dependence on the building's architectural structure, and eventual changes on it, in order to increase the ventilation effects in the atrium, and thus increase the comfort for the structure users.

Simulation results shown in this paper are given for the conceptual building solutions, and they were used as basis for the model improvement: making more complete analysis of the air flow around the buildings, and in the atrium, and conducting farther optimization. To get the airflow picture in the whole building block, besides the structure 1A, surrounding structures in the campus were also analyzed; especially those located on the main wind flow directions.

Temperature change in the atrium was neglectable for both wind orientations. It can be explained by the simplicity of the referential model with neglected internal heat sources that is apartment outlets into the atrium, which also have higher temperatures; the fact that in the farther step will cause airflow due to the temperature and density difference on some levels in the atrium. Figure 2 shows contours of the static pressure in the atrium cross-section, in case of the southeast wind overflow, giving the contours of the static pressure around the building during the extensive part of the year.

The highest static pressure changes are caused by the atrium roof, and the strong vertical obstacle above the left lower structure. The higher structure is so located that it is open to airflow from this direction, so that it does not represent much of the obstacle to the airflow, though it is located in the higher pressure zone.

Figure 3 shows pressure distribution for the same cross-section of the atrium in case of the northwest wind airflow. Lower structure's position directly toward the airflow partly conceals the rest of the structure and causes lower pressure values, obvious when Figure 2 and 3 are compared.

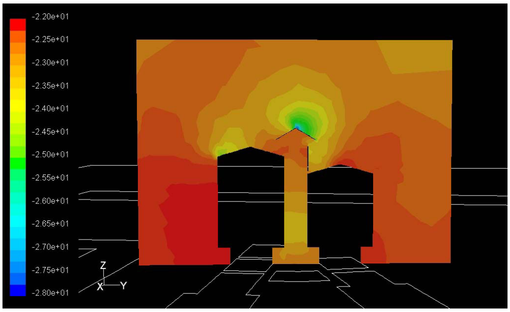

Figure 2: Static pressure distribution in case of the south-east wind.

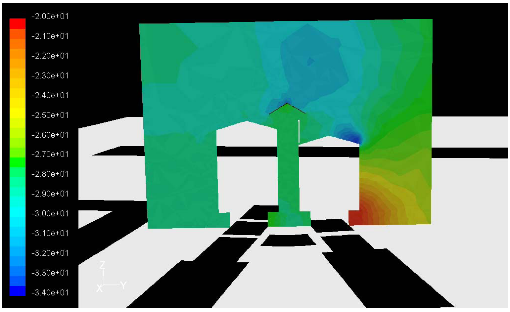

Figure 3: Static pressure distribution in case of the north-west wind.

Figures 4 and 5 show velocity vectors over the building surface in case of both winds. When the southeast wind blows, shown on Figure 4, direct air stream hits the side of the higher structure, so it was interesting to analyze the air velocity field in the yard in front of the atrium.

The main airflow stream of the northwest orientation goes along the whole surface of the lower building and the air overflows the roof all the way to the yard in front of the atrium.

The atrium roof position partly prevents airflow from the back side into the atrium, but flow speeding on the lower side is obvious, allowing for the modification of the referential model by enlarging the atrium lower back opening, so that in case the wind blows from this direction an airflow may be obtained of satisfactory velocity, streaming along the whole height of the atrium.

The main flaws of the referential model and

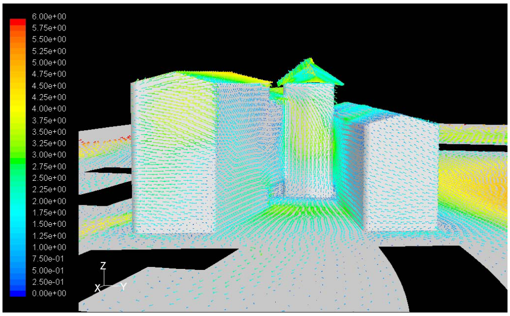

Figure 4: Velocity vectors over the structure surface for the southeast wind.

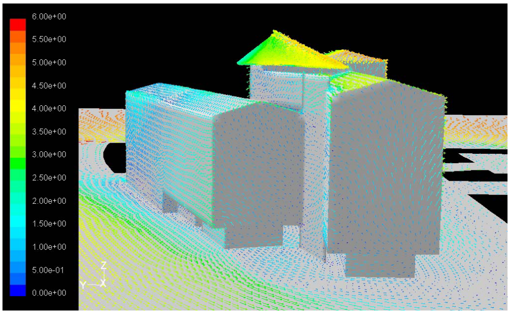

Figure 5: Velocity vectors over the structure surface for the northwest wind.

of the conceptual plan for the atrium are small openings for the air inlet. The obtained velocity and pressure values for both wind orientations inside the atrium are relatively small, though they show the potential air mass flow and obstacles on a model which needs to be modified. That means that certain walls have to be removed and openings enlarged.

The next analyses anticipate construction of pathways on the building facades, which at the same time will be channels and flow indicators. Partial changes may be made on the roof geometry, and the optimal form selected so that it does not represent an obstacle to the airflow, especially from the northwest direction.

It has been already mentioned that the vertical divider above the lower building part significantly decreases airflow through the atrium. If it is removed, larger air mass could circulate through the atrium, without removing the protection of a certain part of the building from weather conditions (rain and snow).

Together with the mentioned information, the airflow pattern also offers information on the building sides mostly exposed to strong wind blasts, so that obstacles may be projected, in order to stop increased convection on the most exposed sides. Finally, this contributes to the decrease of the heat losses during the winter period, increasing thus the total building's energy efficiency.

In general, situation in regard to air quality in the inner yard means lower comfort due to the smaller intensity of its change. That is why during the planning process we tried to find functional solution for the building part that will influence the solution of the problem, and obtain greater fresh air quantity for the residential space oriented toward the yard.

The figures show that the building position has caused the compression and acceleration of the airflow in case of the southeast wind. Organizing the vertical communication junction in this part, and lifting the elevator cabin above the surrounding profiles, we can manage to catch a component of the dominating southeast wind and redirect it into the critical zone of the minimal air flow, resulting in the improvement of the IAQ, both in the environment and in the functional residential area.

5. CONCLUSION

Performed study, aimed to the buildings complex energy efficiency optimization, demonstrates that numerical simulations and computational fluid dynamics can be usefully integrated with architectural modeling, providing designers with a powerful single CFD based architectural modeling and design framework.

Developed new framework can be interfaced with the building thermal performance modeling, integrating further fully thermal and flow domains within the architectural modeling. Different practical approaches, including relevant analytical methods, theoretical basis, computational techniques and implementation procedures are to be further elaborated.

CFD analysis is generally restricted to the building's environment flows or indoor single rooms and spaces flows study, and the designer must supply boundary conditions in the form of external (obstacles to the wind flow by the surrounding buildings and observed building itself) and internal wall conditions (surface temperatures or heat flow, and air passages to the flows entering or leaving the room or any other observed space).

In the case of natural and mixed ventilation, this presents a fundamental problem as a building does not exist in isolation, and therefore outdoor and indoor boundary conditions are inter-related and interactive via building’s architecture (geometry - forms) and its construction thermal mass.

Wall temperatures (outer and inner) and air flows around the building and through the buildings openings are dynamic and dependent on external weather conditions and indoor environment control, as well as on related heat gains and/or losses. Therefore, both sides boundary conditions dynamical description is necessary, for integrated CFD/BPS/architectural modeling. Hence, this unique framework, is to be further and in depth studied to improve knowledge and engineering data base leading to natural and mixed ventilation improvement and related reliable energy efficiency optimization. In addition, practical design/engineering procedure development, outlines needs for further study and investigation of presented new integrated CFD/BPS/architectural modeling as a new design framework, as well as practical results validation through wind – tunnel measurements.

REFERENCES

Todorovic, M., 2003. A Global Space for Building Performance Dynamic Simulation Science and Technology - Network of Excellence for Sustainable Building's Integrated Projects, International Building Performance Simulation Association Conference, Chicago.

Todorovic, M. and O. Ecim, 2004. Sustainable Buildings Energy Efficiency Optimization, RES Integration and Performance Simulation, International Conference Energy Efficiency In The Construction, Sofia, pp. 34-e, 1-15.

Todorovic, M., 2003. RES Integrated Building’s Performance Simulation and Energy Efficiency Optimization for Sustainable Local and Regional Development, ASHRAE Technical Committee Seminar - RES Integrated Sustainable Buildings, Kansas City.

Todorovic, M. et al., 2003. USCE Tower - Building Envelope and Construction Energy Optimization Study, EnPlus/DERES, Euro Construction, Belgrade.

Beausoleil-Morrison, I., 2002. The adaptive Conflation of CFD with Whole-Building Thermal Simulation, Energy and Buildings, Amsterdam, Vol 34, No. 9, pp. 857-873.

Zhiqiang, Z. and Quigyan et al., 2003. Solution Characters of iterative Coupling between Energy Simulation and CFD Programs, Energy and Buildings, Amsterdam, Vol 35, pp. 493-505.