RESEARCHES REGARDING THE OPPORTUNITY OF UTILIZATION THE NUMERICAL SIMULATION METHOD LBM TO CALCULUS OF THE MECHANICAL SOLICITATIONS OF GREENHOUSES LOCATED ON THE ROOF OF BUILDINGS

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Abstract): *The paper presents the opportunity to use the numerical simulation model of the solicitations on which the greenhouses placed on the roofs of the buildings are exposed to the air currents moving at certain speeds. After presenting the evolution of numerical computation methods, it is stressed that the dimensions of the field of study to which the greenhouse models to which the LBM method is intended to apply in order to determine the values of forces and moments caused by the wind blowing at different speeds on their front and side directions.*

Keywords: *greenhouses on buildings roofs, numerical simulation, LBM method*

1. INTRODUCTION

The rapid increase in computing power has motivated the scientific community to use Computational Fluid Dynamics (CFD) to solve numerical equations that govern fluid dynamics. Generally, mathematical models used in CFDs include the convective and diffuse transport of variables consisting of ordinary or partial differential equations (ODE or PDE). Because a large number of such equations, such as the Navier-Stokes equations, do not have analytical solutions, numerical methods have to be used. The difficulty of solving the Navier-Stokes equations is due to their nonlinear terms. In conventional numerical methods, macroscopic variables of interest, such as velocity and pressure, are usually obtained by solving the Navier-Stokes equations [1].

Meanwhile, in CFD, Finite Difference (FDM), Finite Element (FEM), and Finite Volume (FVM) methods have been increasingly used. FDM consists in establishing a uniform rectangular network in the field of the problem, discretizing the governing equations with respect to that network by replacing derivatives with their finite approximations and numerical solving of the resulting algebraic equations. For non-uniform networks, FDM requires a physical space transformation into a computational space with a uniform network. FVM does not require such a transformation because it solves the integral form of equations that are integrated by (generally) finite irregular shape volumes. The Finite Element Method (FEM) is less used in fluid mechanics than in structural engineering. In the last decades, a different numerical method has been introduced for CFD applications, namely Lattice Boltzmann (LBM). LBM has emerged as a new efficient CFD approach and has achieved considerable success in simulating fluid flows and heat transfer issues. In the LBM approach, the kinetic equation for the particle distribution function is solved, and the macroscopic variables, such as velocity and pressure, are obtained by evaluating the hydrodynamic moments of the particle distribution function. One of the most common and simplest approaches in LBM is the Boltzmann linear collision equation based on the Bhatnagar-Gross-Krook collision model (LBM-SRT). Through a Chapman-Enskog analysis, the continuity and moment equations for small values of Mach number [1] can be recovered.

2. PRINCIPLE OF THE METHOD AND MODE OF APPLICATION

In recent years, researchers have used the Boltzmann Lattice method for simulation and modeling in physical, chemical, social systems, including fluxes in magnetohydrodynamics [1], immiscible fluids, multiphase streams, porous media and isotropic turbulence. Historically, LBM comes from Lattice Gas Automata (LGA), which was first introduced in 1973 by Hardy, Pomeau and Pazzis. In the LGA, the Lattice term implies that it is working on a side that is dimensioned and, as a rule, regular. Gas suggests that a gas moves on the grid. Gas is usually represented by boolean particles (0 or 1), and Automata shows that gas evolves according to a set of rules. In 1986, Frisch, Hasslacher and Pomeau obtained the Navier-Stokes equations using a hexagonal mesh. Lattice Boltzmann equations were used on the Lattice Gas Automata (LGA) principle by Frisch et al. to calculate the viscosity. To eliminate statistical oscillations, in 1988, McNamara and Zanetti removed the LGA boolean operation by neglecting particle correlations and introducing medium distribution functions that give rise to LBM. Higuera and Jimenez made a significant simplification in LBM by presenting a Lattice Boltzmann (LBE) equation with a linearized collision operator that assumes that the distribution is close to the local equilibrium state. A particularly simple version of the linear collision operator based on the Bhatnagar-Gross-Krook collision model was introduced independently by several authors, including Koelman and Chen et al. [1].

It is known that the Boltzmann equation provides a more efficient representation of gaseous fluxes for a wider range of flow regimes than the Navier-Stokes equation. But researchers generally prefer to use conventional numerical methods (finite difference method, finite volume method, finite element method, etc.) based on the discretization of partial differential equations (Navier-Stokes equations) in continuous mode than solving Boltzmann equations. This is because the solution of the Boltzmann equation is a non-trivial task due to the complexity of the collision term. Lattice Gas Automatic (LGA) and Lattice Boltzmann Method (LBM) are promising methods that use different types of unconventional techniques for CFD applications

In the case of the numerical simulation of the Boltzmann Lettice Method (LBM), the veracity of the results is checked by means of the XFLOW [2] stability factor shown in Figure 1.

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Figure 1: Graphical representation of XFLOW stability factor evolution [2]

When executing the simulation, the user has the ability to monitor the evolution of the XFLOW stability factor over time. This parameter has values ranging from 0 to 1 and provides feedback on the stability of the numerical scheme in terms of the Courant-Friedrichs-Lewy condition. A stability parameter <1 means that the stability of the numerical scheme is assured and that the solution should therefore be consistent. If the value of the stability parameter is very close to 0, the required calculation time has to be increased. A stability parameter equal to 1 means that the stability of the numeric scheme is not assured, and the simulation can be altered, so adjusting the time required to ensure convergence. The ideal value of the stability factor is between 0.2-0.4. The stability factor can be monitored and selected in the Function Viewer window. This way you can see if the parameter is stable and is in the ideal range [2].

As a calculation tool, the Boltzmann Lattice Method (LBM) differs from methods based on Navier-Stokes' incompressible equations by the following:

- Navier-Stokes equations are differential equations with secondary partial derivatives (PDEs); the discrete velocity model from which LBM is derived consists of a set of first order PDEs (kinetic equations);
- Navier-Stokes equations have nonlinear convection terms; the convection terms in LBM are linear;
- Lattice Boltzmann (LBE) equation is a discreet kinetic equation; Navier-Stokes equations can take integral or differential forms;
- LBM depends on the structure of the network; Navier-Stokes equations are in vector form, being independent of coordinates and grids;
- Navier-Stokes solver usually uses iterative procedures to obtain a convergent solution; LBM is explicit in form and does not need iterative procedures;
- Limit conditions involving complicated geometries require careful treatment both in Navier-Stokes solutions and in LBM solutions. In LBM, the boundary condition is in the form of particle distribution functions;
- Because of the kinetic nature of the Boltzmann equation, physics associated with molecular interaction can be more easily incorporated into the LBM model.

The application of the Boltzmann Lattice Method (LBM) involves scrutinizing the three stages specific to the use of any CFD method, namely pre-processing, solvering and post-processing.

3. SPECIFIC ACTIVITIES FOR PRE-PROCESSING STAGE

3.1. Establishing theoretical research objectives by numerical simulation with LBM

The main objective of the theoretical research by numerical simulation is to determine the pushing forces, the overturning moments and the aerodynamic coefficients that the wind moving at different speeds on the front and side directions exerts on representative models of greenhouses located on the roofs of the buildings from urban areas. In order to achieve the main objective, it is necessary to cover and solve some subsidiary objectives, such as:

- choosing greenhouse models to be researched by numerical simulation;
- Establishing the speeds of the air currents that are subject to resistance structures, but also other components of the greenhouses placed on the roofs of buildings, mechanical stresses;
- specifying the directions of action of the wind towards the greenhouses under investigation;
- The calculation and graphical representation of the pushing forces, the overturning moments and the aerodynamic coefficients for the studied greenhouse models;
- The analysis of the influence of the number of roof slopes and angles between the slopes of the front and side push forces, the overturning moments, the aerodynamic coefficients, the shape and the magnitude of the whirlwinds caused by the interaction between the wind that diverges with different vines and the greenhouses on the roofs of the buildings;
- establishing the calculation method by numerical simulation and justifying it.

3.2. Establishment of objects undergoing research by numerical simulation with LBM

For the study of the mechanical stresses exerted by the wind on the greenhouses on the roofs of buildings, five forms of such constructions were considered, which could be considered representative, because in shapes and sizes they were consecrated among the greenhouses placed on the soil but similar to most of the hothouses so far housed on the roofs of buildings.

Figure 2: The real greenhouse forms (machetes at 1:20 scale) chosen to study wind loads using the Lattice Boltzmann Method (LBM)

Also, the greenhouse forms have roofs similar to those of the buildings presented in CR-1-1-4 / 2012 Code, mandatory for wind-sizing calculations. The 1:20 scales of the real greenhouses studied in this chapter are shown in Figure 2.

All greenhouses have base surfaces and equal heights, that is, 4m. The first three greenhouses have roofs with two slopes but with different inclination angles, the fourth greenhouse has a four-slope roof that forms a ridge (two equal to two) and the fifth greenhouse has a roof made up of four identical slopes meet in a peak (pyramid). The angles formed by the roof slopes horizontally or between them are specified in Table 1.

Table 1: The roof slope angles of the five greenhouses

No. model	***Tilt to horizontal,^{0}***	***The angle between the slopes,^{0}***
1.	35	110
2.	30	120
3.	45	90
4.	32,5	100
5.	40	80

In Table 2 other geometric characteristics of the greenhouses are required for calculation by numerical simulation with the Lattice Boltzmann method, ie: α1 - the angle formed between the side slopes of the roof; α2 - the angle formed by the front slopes of the roof; Base of the base, equal to all greenhouses; H-height dimensions, equal to all models; V - the interior volume of the greenhouses; A_{fv} -vertical front wall display; A_{fac}- front roof area business; A_{lv} - the vertical side wall area; A_{lac}. lateral roof surface area; At - total area of the walls and roof.

These constructive features are useful for ensuring the best possible conditions of the vegetation factors required by different varieties of vegetables or flowers grown in the respective greenhouses. Chapter 6 also makes recommendations for adopting one of the roof types according to the geographical area, the intensity of meteorological factors etc.

Table 2: The geometric characteristics of greenhouses used in LBM simulation research

Model no.	$\alpha_1{}^0$	$\alpha_2{}^0$	A_b, m^2	**H,** *m*	**V,** m^3	A_{fv} m^2	A_{fac} m^2	A_{lv}, m^2	A_{lac}, m^2	A_t m^2
1.	110	-	16	4	52,8	13,2	-	10,4	10	67,2
2.	120	-	16	4	59,3	13,8	-	11,6	9,2	69,2
3.	90	-	16	4	48,0	12,0	-	8,0	11,2	62,4
4.	100	80	16	4	50,0	10,0	3,2	10,0	6,27	56,9
5.	80	100	16	4	48,0	10,0	4,8	10,0	4,8	59,2

3.3. Determining the wind speed and its direction to the position of the greenhouses

After studying the zoning map of the reference values of the dynamic wind pressure, having a recurrence duration of 50 years, according to NMA data, for altitudes less than 1000 m (SR EN 1991-1-4: 2006 / NB: 2007), but and based on the aerodynamic tunnel performance used in experimental research, the following wind speeds were considered representative for research: 10 m / s; 15 m / s; 20 m / s; 25 m / s and 27.5 m / s. The highest of these speeds, ie 27.5 m / s, means 99 km / h, a speed that is rarely exceeded in Romania, but which in other geographical areas is considered normal (eg USA) [3].

Also, according to the provisions of CR-1-1-4 / 2012 Code for the theoretical and experimental research, as well as for calculations of wind loads of roofs similar to those of the greenhouses studied in this paper, two directions should be considered of the wind: frontal one and the other side, to the positions of the greenhouse roofs [4].

3.4. Establish the dimensions of the field of study

Correctly determining the dimensions of the field in which Greenhouse models fall to be studied by numerical simulation using the Lattice Boltzman Method (LBM) mechanical stresses to which they are subjected by the air flow moving in the front and side directions at different speeds , is particularly important for the veracity of the results obtained.

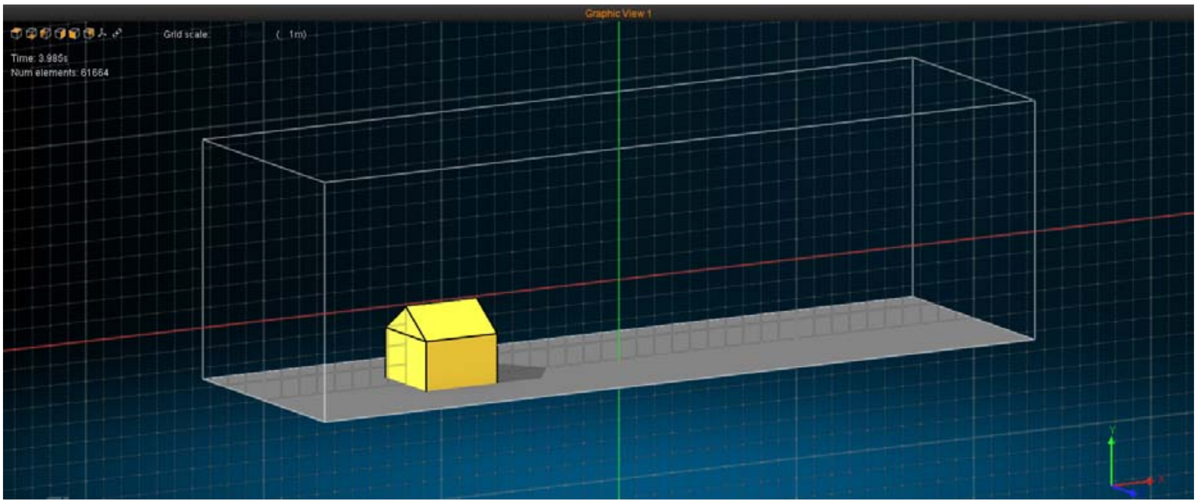

Figure 3: Dimensions of the field of study

In Figure 3 the intervals between two consecutive lines of the grids are 1m in size and the sides of the bases and the height of the greenhouses are L = 4m. The southern domain has 10L (40m) in the X direction of travel: 2L (8m) in front of the greenhouse and 7L (28m) behind it; in the Y direction perpendicular to the base plane the height is 3L (12 m) and in the Z direction, perpendicular to the vertical symmetry plane of the study field, the width of the field is 3L (12m).

The front fill factor of the section of the study area by the greenhouses under investigation is about 10%.

3. CONCLUSION

1. In the case of numerical simulation using the Lettice Boltzmann Method (LBM), the veracity of the results is checked by means of the XFLOW stability factor. When executing the simulation, the user has the ability to monitor the evolution of the XFLOW stability factor over time. This parameter has values ranging from 0 to 1 and provides feedback on the stability of the numerical scheme. A stability parameter <1 means that the stability of the numerical scheme is assured and that the solution should therefore be consistent. If the value of the stability parameter is very close to 0, the required calculation time has to be increased. A stability parameter equal to 1 means that the stability of the numeric scheme is not assured, and the simulation can be altered, so adjusting the time required to ensure convergence. The ideal value of the stability factor is between 0.2-0.4.
2. The main objective of the theoretical research by numerical simulation using the LBM method, which was carried out in this chapter, was the determination of the pushing forces, the overturning moments and the aerodynamic coefficients on which the wind moving at different speeds in the front directions and laterally, exerts them on representative models of greenhouses located on the roofs of urban buildings. In order to achieve the main objective, it was necessary to cover and solve six subsidiary objectives.
3. For the study of the mechanical stresses exerted by the wind on the greenhouses placed on the roofs of buildings, five forms of such constructions have been used, which can be considered representative, because these shapes and sizes have been consecrated among the greenhouses on the ground but are similar and with most of the hothouses so far housed on the roofs of buildings. Also, the greenhouse forms have roofs similar to those of the buildings presented in CR-1-1-4 / 2012 Code, mandatory for wind-sizing calculations.
4. All greenhouses have base surfaces and heights equal, ie, 4m. The first three greenhouses have roofs with two slopes but with different inclination angles, the fourth greenhouse has a four-slope roof that forms a ridge (two equal to two) and the fifth greenhouse has a roof made up of four identical slopes meet in a peak (pyramid). The angles formed by the slopes of the roofs horizontally, or between them, are specified in the work.
5. After studying the zoning map of the dynamic wind pressure reference values, having a recurrence duration of 50 years, according to INM data, for altitudes less than 1000 m (SR EN 1991-1-4: 2006 / NB: 2007) but also on the performance of the aerodynamic tunnel used in the experimental researches, the following wind speeds were considered representative for the research in this paper: 10 m / s; 15 m / s; 20 m / s; 25 m / s and 27.5 m / s. The highest of these speeds, ie 27.5 m / s, means 99 km / h, which is very rare in Romania, but which in other geographic areas is considered normal (eg USA). For altitudes greater than 1000m, you specify how to determine the dynamic wind pressure.
6. The field of study has a 10L (40m) dimension of air flow direction X: 2L (8m) in front of the greenhouse and 7L (28m) behind it; in the Y direction perpendicular to the base plane the height is 3L (12 m) and in the Z direction, perpendicular to the vertical symmetry plane of the study domain, the width of the field is 3L (12m), where L = 4m is the length and height) of the sides of the greenhouse.
8. The front fill factor of the section of the study area by the greenhouses under investigation is about 10%.

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