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COMPARATIVE ANALYSIS OF RESULTS OF THEORETICAL AND EXPERIMENTAL RESEARCHES REGARDING THE PUSHING FORCE EXERCISED BY WIND ON SOME MODELS OF GREENHOUSE FOR VEGETABLES AND FLOWERS

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Abstract: *This paper presents a comparison between results of the theoretical and experimental researches carried out on models of greenhouses for vegetables and flowers, placed on the ground or on rooftops of buildings. Theoretical research have been achieved with ANSYS 15.0 software based on finite element method and experimental researches have taken place in the wind tunnel. In both cases there were used five models of the greenhouses, with similar size that differ by number of slopes of the roof (2 or 4) and by the angles between these slopes. Airflow velocities were identical and based on the pushing forces obtained witch which can be calculate the coefficients of aerodynamic resistance specific for each researched model.*

Key words: *drag aerodynamic force, drag coefficient, greenhouses on rooftops, wind.*

1. Introduction

The greenhouses are shelters, which ensure environmental factors necessary for cultivating plants all year round, regardless of weather conditions outside [5], [8]. The greenhouses are used so much now that the calculation principles and their manufacture were normalized and standardized at EU level, therefore and in Romania [4], [11]. A new situation presents the greenhouses that have begun to be located on the roofs of buildings whose forms are required by urban architects, and mechanical loads on wind and other weather factors include them their causes aerodynamic drag, varied from those recommended in the rules used by civil engineers to design buildings with roof shapes like these greenhouses [7], [10].

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Code CR-1-1-4 / 2012 used for this purpose in Romania and inspired by European law, recommended that in cases of some forms of buildings other than those specified in this document, to determine the necessary data for the mechanical strength calculations by theoretical modeling with the most modern methods and verification of theoretical results with experimental research on similar models placed in performances wind tunnels [15]. The Pushing forces determined in this way can serve to determined by calculation of the coefficient of aerodynamic drag, whereon the greenhauses with also forms opposing to the wind action, which moving at different speeds over them [6]. These issues were addressed and resolved in this paper.

2. Materials and Method

2.1. Principle of Theoretical Method to Research and Mode of Application

Modeling and theoretical analyze refers to two types of greenhouses on the roof, which has 2 or 4 slopes with symmetrical angles of 110^0, 120^0, 115^0, 1000 and 90^0 between them, a situation pursued further and experimental research, where they studied five models of greenhouses, which had the same types of roofs [3]. There were two sets of researches, depending on the direction of action of the wind to the position of the models, one frontal and one lateral, positions established by the Code CR-1-1-4/ 2012 [12]. For theoretical research was used software ANSYS 15.0, which is based on the finite element method [1].

The geometric design is shown in Figure 1, where the models of greenhouse are built in a field of type cuboid, an area where it is considered that there is air flowing at a speed of 10 m/s, 15 m/s, 20 m/s, 25 m/s, 27.5 m/s and 30 m/s, i.e. the same speeds used and to experimental researches, which have been realized in the wind tunnel.

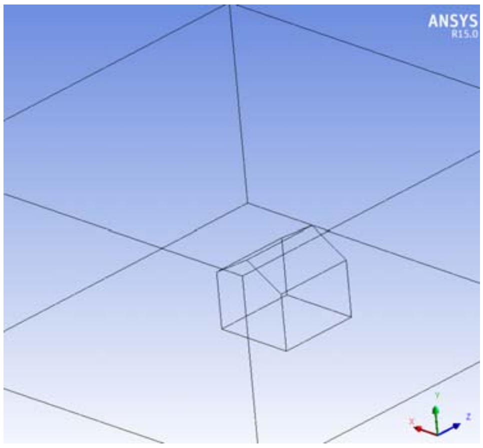

Fig. 1. *The geometric design of theoretical simulations*

The models with the numbers 1, 2, and 3 consist of two slopes roof; model # 4 is made up of four roof slopes forming a ridge, and the model no. 5 has roof slopes formed of four identical, forming a peak. Mockups to give sufficient rigidity to the action of wind, plastic panels were bolted profiles modeled on sheet thickness of 1.5mm.

For modelling it is considered tetrahedral finite elements, after meshing yielding 257 826 finite elements and 48 559 nodes. Boundary conditions relate, on the one hand, imposing a constant speed in laminar flow at the entrance to the air flow and the imposition of 101.325 Pa normal atmospheric pressure in that area; the second condition refers to the imposition of border normal atmospheric pressure of 101.325 Pa at the outlet of the air flow field [9].

The analysis is performed for sets of values of wind speed of 10 m/s, 15 m/s, 20 m/s, 25 m/s, 27.5 m/s and 30 m/s, to the frontal action and same values to lateral action of airflow velocity.

Solving model FEM involves selecting a number of iterations needed to stabilize residual error. In this case there was used a total of 50 increments, shown to be sufficient to stabilize the residual error, equal for frontal and lateral action of the air flow on the models of greenhouses.

2.2. The Method, Objects and Equipment Used in Experimental Researches

The experimental researches method of the mechanical solicitations at they are exposed the greenhouses on rooftops or at the ground, by air currents moving at different speeds, it is based on specifications of the Code CRI 1-4/2012 on conditions from tunnels that can be used in such researches. It is a laminar air flow with different velocities, over the positions frontal and lateral of the models of greenhouses, on the direction of movement thereof [2], [6].

Experimental research objects are represented by five models of greenhouses (Figure 2) made of plastic with the thickness of 2.5 mm.

In order to compare the results of experimental research among themselves but also with those of theoretical investigations, it was established that the bases surfaces and the heights of all the models to be identical, the differences between them consisting in the number of slopes of roofs, the thereof angles and their useful volumes.

Fig. 2. *The models of greenhouses made for the experimental researches*

The geometrical characteristics of the models used to the experimental research are given in Table 1, where the notations have the following meanings: α_1- angle formed by the main slopes of the roof; α_2 - angle formed by the side slope of the roof; A_b-the base area equal to all the models; H – the height, equal on all models; V- the interior volume of the models; A_{fv}- vertical front wall area; A_{fac}-frontal surface area of the roof; A_{lv} - vertical lateral wall area; A_{lac}.- lateral roof surface area; A_t - area of the walls and roof.

The models with the numbers 1, 2, and 3 consist of two slopes roof; model no. 4 is made up of four roof slopes forming a ridge, and the model no. 5 is made of four identical slopes, forming a peak. To give sufficient rigidity on the wind action, the plastic panels were reinforced with sheet metal strips with the thickness of 1.5 mm.

Table 1

The geometrical characteristics of the greenhouses models used to the experimental researches

Model no.	$\alpha_1{}^0$	$\alpha_2{}^0$	A_b, cm^2	H, *cm*	V, cm^3	A_{fv} cm^2	A_{fac} cm^2	A_{lv}, cm^2	A_{lac}, cm^2	A_t cm^2
1.	110	-	400	20	6600	330	-	260	240	1660
2.	120	-	400	20	7000	350	-	300	220	1740
3.	90	-	400	20	6000	300	-	200	280	1560
4.	115	120	400	20	5600	250	80	250	180	1520
5.	100	100	400	20	5200	250	120	250	120	1480

The forms of the 5 models of greenhouses were not chosen by chance, they are the result of analysis of most forms of greenhouses that are currently being used on the ground or on rooftops. Such forms not only meet environmental requirements for a large number of plants, but satisfactory and economically, meaning the use of materials and equipment available under the raport reliability/price, being checked by practice.

The main technical equipment used in experimental research has been the wind tunnel HM170 Educational Wind Tunnel. G.U.N.T. Gerätebau GmbH. Barsbüttel, Germany [12], located in Wind Energy Laboratory of the Department of Product Design, Mechatronics and Environment at the Transilvania University of Braşov, whose general view is presented in Figure 3.

Fig. 3. *The wind tunnel HM170 Educational Wind Tunnel. G.U.N.T. Gerätebau GmbH. Barsbüttel, Germany [14]*

This is a subsonic tunnel (air speed up to Mach 0.1), with open circuit (air is taken from outside and expelled all outside, with increased speed). Measurement area is 287x287 mm section length of 365 mm, is made of plexiglass and superstructure moving longitudinally for inserting and removing the models experimental research.

3. Results and Discussions

3.1. The Analysis of the Pushing Forces, Theoretically Determined, Exercised by Wind on the Greenhouses Models

The pushing forces that the wind with a certain intensity it exercises over superstructure of a greenhouses are important for correct sizing of the resistance structure and transparent surfaces of materials used in their construction. In all cases is necessary as the structures to withstand the toughest environmental conditions, but for a greenhouse located on the roof of a building this is not enough.

The roof must obstructing as little sunlight, so that the plants grown in greenhouses have from this point of view the conditions as close to those of open spaces. This means the use at construction the materials with high mechanical characteristics as well as affordable in terms of parameter reliability/price.

Also, we must not forget that a rooftop greenhouse, in all cases, to exert a minimum pressure on the roof of the building. If placed in a greenhouse on the floor, in which the transparent material is acrylic or plastic film is accepted that pressure building is about 15 daN/m^2, for the greenhouses placed on the roof this pressure must be substantially reduced. Greenhouses at which the material is transparent glass with a thickness of 3 - 5 mm will exert a far greater impact on the soil [13].

It follows that to satisfy these requirements simultaneously is required, together with knowledge of the thrust exercised by the wind, the use of lightweight metal profiles, such as duraluminium, and the replacement of heavy and dangerous breakage glass, with acrylic or foil of plastic material.

From Figure 4 it is noted that on the same surface of the base and the same height, the most convenient from the point of action of the biasing force of the wind is the model with the roof with four slopes symmetrical arranged to 90^0. Having a symmetrical construction, this embodiment is as advantageous in the case of the lateral action of the air stream. On the other hand, from Figure 6 resulted that the most disadvantageous in terms of the pushing force of the lateral wind action, is the version with angle of 100^0 between the roof slopes.

If the greenhouses located on the ground is recommended orientation E-V from the considerations to capture the maximum luminous intensity from the sun, in the case of the greenhouses located on rooftops architects planners may require different guidance for which knowledge to dominance wind direction and they pushing force exercised by it can to decisively contribute to the choice and implementation of a special calcul methodology from all points of view.

3.2. The Analysis of the Pushing Forces, Experimental Determined, Exercised by Wind on the Greenhouses Models

For each model and for each preset speed air flow in the wind tunnel there were forces pushing action listed in Table 2, to frontal action, respectively in Table 3, its lateral action.

The pushing forces exerted by wind in tunnel on the models are real ones only if the focal point of calibrated rod of system for measuring force is to the height of 302 mm [10].

In this case it was necessary correction of their specified of the equipment supplier, which take into account the fact that all the experimental models contacts with calibrated rods is made to the height of 150 mm, ie:

$$Fcor = Fm\frac{302}{150} \tag{1}$$

where:

- F_m is the measured value of force the wind in tunnel and read at the specialized equipment;
- F_{cor} – the corrected (real) force on models, exerted in the wind tunnel by air flow.

The corrected values of these pushing forces are listed in Tables 4 and 5.

It is observes that at the frontal action of air flow the models no. 1, no. 2 and no. 3 oppose the close resistance forces , especially at high wind speeds. The smaller pushing force was recorded, in the case of the frontal action of the wind on the model no. 4, which was with 12% lower than the model no. 3.

The values of drag forces recorded to the front action of the wind, N Table 2

Model \ Wind speed	10 [m/s]	15 [m/s]	20 [m/s]	25 [m/s]	27.5 [m/s]	30 [m/s]
1	2.0	4.5	5.8	6.6	7.2	8.0
2	2.0	4.3	5.7	6.6	7.2	7.9
3	1.8	3.9	5.9	6.5	6.9	7.6
4	1.7	3.5	5.1	6.3	6.5	7.2
5	1.7	3.7	5.6	6.4	6.8	7.6

The values of drag forces recorded to the lateral action of the wind, N Table 3

Model \ Wind speed	10 [m/s]	15 [m/s]	20 [m/s]	25 [m/s]	27.5 [m/s]	30 [m/s]
1	2.5	5.5	6.3	7.5	8.1	8.9
2	2.6	5.3	6.2	7.3	7.9	8.8
3	2.3	5.0	5.9	6.9	7.6	8.5
4	2.0	4.3	5.7	6.7	7.2	8.0
5	1.7	3.7	5.6	6.4	6.8	7.6

The corrected values of drag forces to the front action of the wind, N Table 4

Model \ Wind speed	10 [m/s]	15 [m/s]	20 [m/s]	25 [m/s]	27.5 [m/s]	30 [m/s]
1	4.0	9.0	11.6	13.2	14.4	16.0
2	4.0	8.6	11.4	13.2	14.4	15.8
3	3.6	7.8	11.8	13.0	13.8	15.2
4	3.4	7.0	10.2	12.6	13.0	14.4
5	3.4	7.4	11.2	12.8	13.6	15.2

The corrected values of drag forces to the lateral action of the wind, N Table 5

Model \ Wind speed	10 [m/s]	15 [m/s]	20 [m/s]	25 [m/s]	27.5 [m/s]	30 [m/s]
1	5.0	11.0	12.6	15.0	16.2	17.8
2	5.2	10.6	12.4	14.6	15.8	17.6
3	4.6	10.0	11.8	13.8	15.2	17.0
4	4.0	8.6	11.4	13.4	14.4	16.0
5	3.4	7.4	11.2	12.8	13.6	15.2

The pushing force on the model no. 5 of frontal air stream was located at a mean value between the forces pushing of the first three models and of the model no. 4. If the case of lateral action of the air flow is an increase by 10-13% of the pushing forces from models no. 1, no. 2 and no. 3, the highest value recorded is to model no. 1. The decrease of the pushing force manifested to model no. 4, by the action lateral air flow, is lower than the forces recorded in the first three models by over 10%.

4. Comparison between Theoretical and Experimental Research Results, Regarding the Pushing Forces of the Airflow over Greenhouses Models

If the theoretical simulations of the frontal air flow action (Figure 4) shows that at low speeds its pushing forces are grouped powerful, constructive differences between the models are insignificant. Instead, the speed of the airflow over 20 m/s are differences noticeable force frontal thrust on the model roof of 4 slopes and the angle of slope of 90^0 is about 75% lower than the thrust on the model with 2 slope and angle of 120^0.

If experimental research in the wind tunnel to frontal air flow action (Figure 5) there is a difference between pushing forces on the various models, starting at wind speeds above 15 m/s. The best results are found in model no. 4, the roof slopes of 4 main slope angle unequal and 115^0, with the front pushing force is about 12% lower than in the model no.1, the roof 2 slopes and the angle of slope equal with 110^0.

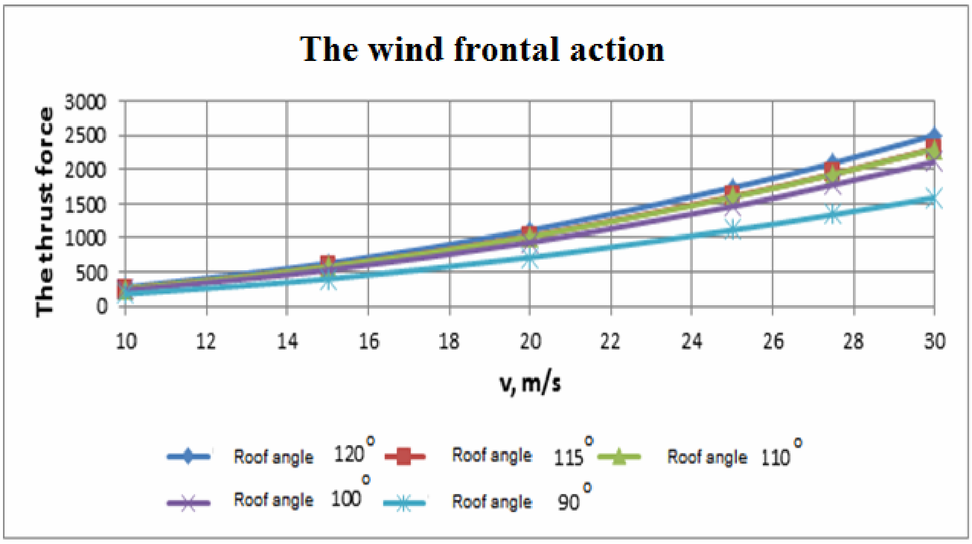

Fig. 4. *The variation of the theoretically determined thrust force against the models to the wind frontal action with different speeds*

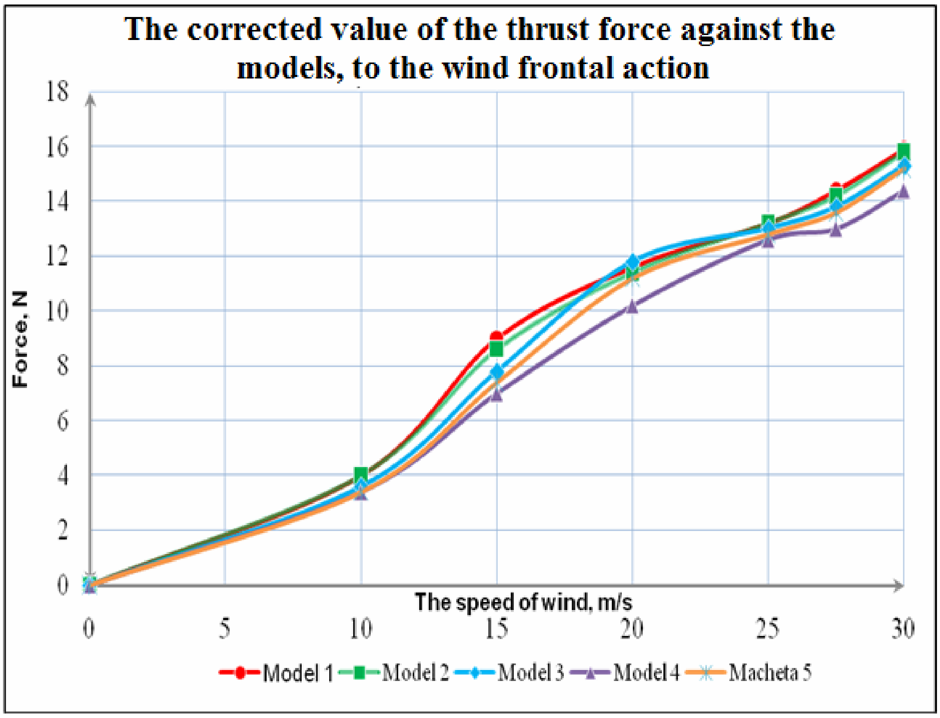

Fig. 5. *The variation of the thrust forces, exerted on the models to the wind frontal action, obtained as a result of the experimental research in the aerodynamic tunnel*

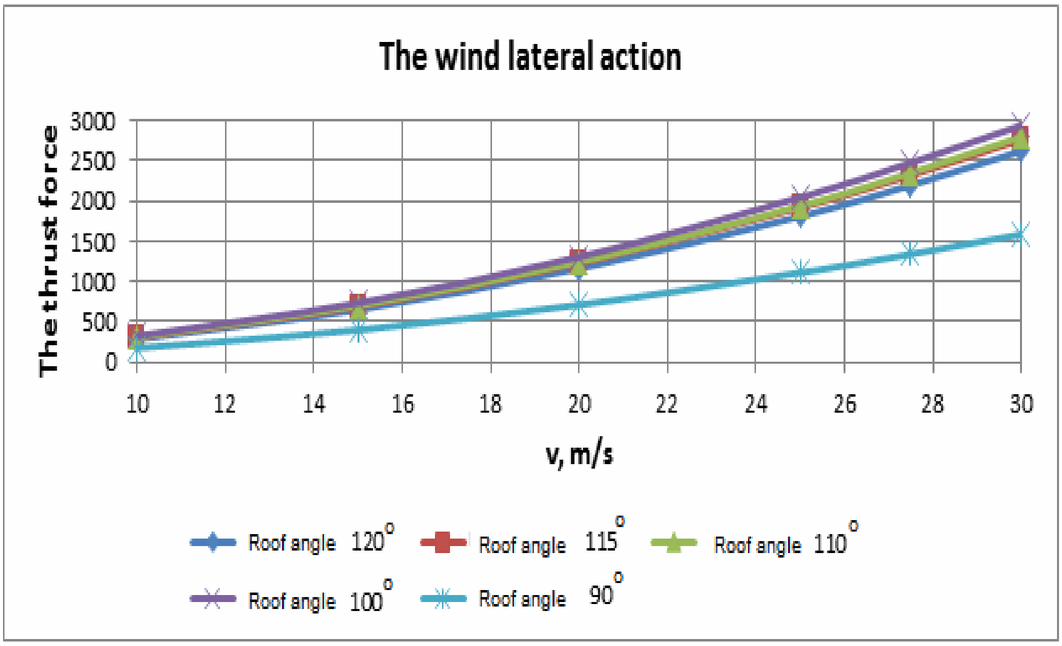

Fig. 6. *The variation of the theoretically determined thrust force, exerted on the models to the wind lateral action with different speeds*

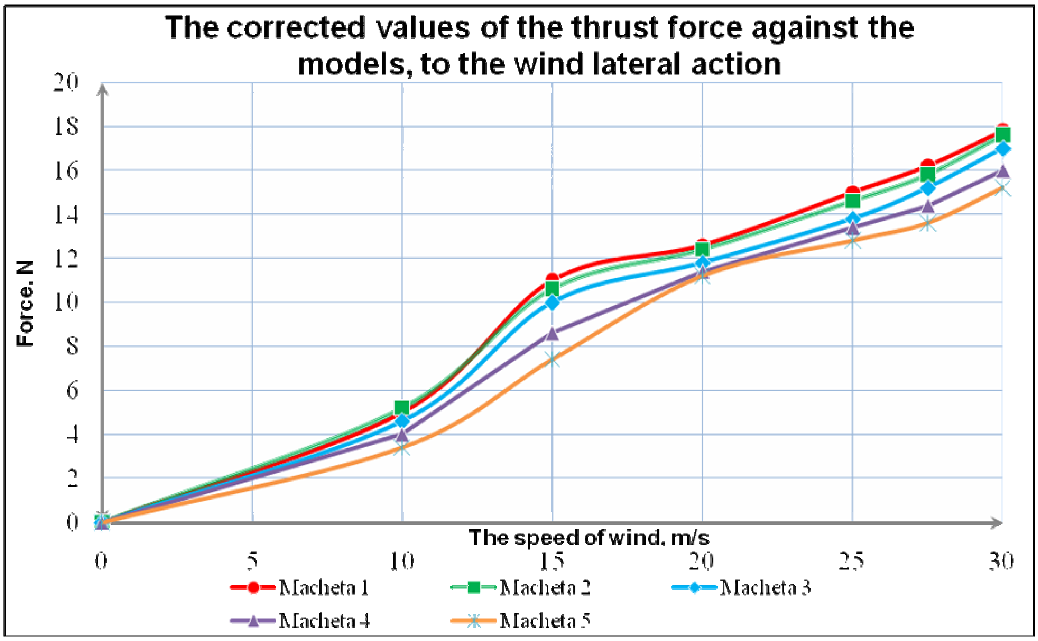

Fig. 7. *The variations of the thrust forces exerted on the models to the wind lateral action, obtained as a result of the experimental research in the aerodynamic tunnel*

Figure 5 present the variation of the pushing force on the models, produced by theoretical simulation, on the lateral air flow action of the greenhouses models used for research. In this case, the lateral pushing force on the roof slopes of the model 4 and the angle of slope to 90^0 is about 100% less than the biasing force of the model with two slopes and the angle of 100^0.

Figure 7 present the variation of the pushing force on the models, on the lateral air flow action, resulting from experimental research in the wind tunnel. In this case the best results provide model no. 5, the roof 4 equal slopes, forming a peak. In fact, this model thrust is identical for the two strands of the air flow, which means that the action of the air flow laterally force that is greater than the other models, especially those with roof 2 slopes.

5. Conclusion

- The results obtained from theoretical and experimental research on the 5 models of greenhouses are significantly close and confirm the validity of research methods, the ANSYS 15.0 software and wind tunnel used.
- By using the same shapes and sizes of models in the two types of researches is can bring the necessarily corrections on the theoretical research program so that results can be applied with this calculation and to design of similar models of greenhouses.

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