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Towards more sustainable patterns of building design through ventilated rainscreens

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Towards more sustainable patterns of building design through ventilated rainscreens

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Abstract. Ventilated rainscreens are a very powerful tool for reducing whether winter or summer power consumptions, besides to procure effective defense from rain penetration. Moreover, if suitably designed and realized, they can determine façades not unlike that of the traditional Mediterranean habitat, continuous, plaster finished, jointless, which don't have some of the flaws that have become typical of strongly isolated ETICS (in particular poor durability and moulds growth in cold and damp environment). Difficulty in the use of the ventilated rainscreens follows also from the difficulty of express their functioning in a physical-mathematical algorithm, which can allow you to optimize the choices regarding the factors that influence their behavior. Of these, the main ones are typology of the cladding (with open intermediate joints or not); height and depth of the cavity; presence inside of horizontal structures (which modify repeatedly the depth of the interspace); presence of wind and its angle of incidence. The Authors, through a research made as part of the activities of *Constructions Technology Laboratory - La.Te.C.* of Basilicata University (Potenza, Italy), developed a software, utilizable whether for opaque or windowed parts of the façades (Double Skin Façades), which allows you to easily design and optimize the ventilated rainscreens, thus adding another important step in the way for realizing more sustainable patterns of building design.

1. Reason of interest, definition of the problem, brief state of the art, research objectives

Intelligence is a renewable and unlimited resource, even if it is not free, since it must be nourished by study and culture. The transformation of existing cities in the direction of sustainability, as well as the design of new cities that are nearly zero energy, makes it necessary to apply intelligence first of all in planning, in the choice of housing types and construction types; but then also in the articulation of the project and the realization, as well as in the management of the building system. In this regard, ventilated rainscreens are the most intelligent and performing way of ensuring both maximum winter insulation and maximum summer protection at the same time, thus making it possible to reduce energy consumption practically to zero for both heating and cooling. Moreover, they constitute an effective screen with respect to atmospheric agents (rain, wind, sun, night sky radiation, abrupt temperature variations) and to animal attacks (peaks and magpies on the upper floors, Doberman on the ground floors), ensuring long life to the buildings that protect. With the spread of buildings entirely made of wood, which constitute the real means of achieving sustainability in buildings, the importance of having a shell of the highest impermeability to rain, but permeable to steam, acquires a primary value. Furthermore, ventilated rainscreens can be easily maintained and renewed or replaced, thereby contributing to the sustainability of the building's management over time. Finally, there are types of continuous ventilated rainscreens, jointless, with a plaster finish, which make it possible to obtain the appearance of traditional historic buildings of Mediterranean architecture. The presence of ventilation can help to dehumidify buildings located in humid environments, with capillarity rising problems. They can allow, through appropriate surface finishes, to imitate the exposed concrete surfaces of the "brutalist" architecture of the 70s and 80s, thus allowing their energy upgrade to become nZEB. In conjunction with the Double Skin Façades for glazed parts [1] [2], ventilated rainscreens can solve almost all the problems of a poorly designed building [3].

Despite all these reasons of interest, the diffusion of ventilated rainscreens is limited. An important reason is certainly their price, which for high quality systems is equal to two or three times that of a high quality ETICS with the same thickness as the insulation material itself; and it is even greater in the case of finishes of particular value. Hence the spread of solutions like the one adopted for the Grenfell Tower; worse than the defects they intend to cure. Another reason is that, even if there are software that allow performing evaluations of thermal flows in variable regime (EnergyPlus, ESP-r, TRNSYS and others), it is not easy with them to optimize all the characteristics of a ventilated rainscreen. Its efficiency varies depending on the typology of the cladding (with open intermediate joints or not); height and depth of the cavity; presence inside of horizontal structures (which modify repeatedly the depth of the interspace); presence of wind and its angle of incidence. A more limited influence has the different thickness and the different quality of the cladding material, and the coloring of the external covering and of the surface of the insulation inside the cavity.

The proposed software started from the initial calculation model developed on the basis of mathematical modeling and experimental validations conducted by Di Maio, Van Paassen e Stec [4, 5, 6, 7, 11], Swami and Chandra [9, 10]. Then was implemented on the basis of the recent legislation UNI EN ISO 52016-1:2018 and UNI EN ISO 52017-1:2018, for the evaluation of: 1- the thermal flows in hourly dynamic regime; 2- the determination of the surface temperatures at the points of separation of the different layers and of the temperature of the internal environment, and 3- of the sensitive and latent thermal loads. The UNI 10349-1:2016 standard guided the evaluation of the daily distribution of the maximum summer temperature and the maximum solar irradiance incident on the vertical surfaces. These rules require that the inertial properties of all the layers and therefore also of the external cladding be taken into account. Therefore, the proposed model is applicable to all situations, both to a thin metal cladding and to a thick masonry, or to a ventilated rainscreen that does not have thermal insulation, or to a strongly isolated one. The advantage of the model is the simplicity of its use.

The variables considered were, for the different types of components of the ventilated rainscreens, and for claddings continuous or with joints open to the passage of air: total absence of wind or its presence, with incidence angle variable between 0° and 90°; cavity height: up to 23,50 m, 30 m, 50 m; depth of cavity: 4 or 8 cm; presence or absence of horizontal structures inside the cavity, which reduce the section repeatedly; color of the external cladding and of the surface of insulation inside the cavity: white or black. The following performances have been determined, with hourly variation in the 24 hours, differentiating the daytime cycle from the nightly one: temperatures in the different components of the ventilated rainscreen; pressure variations; air flows; air speed inside the cavity in the widest section (in the case of the presence of horizontal structures inside the cavity) and in the narrower section; Reynolds number in the widest and narrowest section.

2. The ventilated rainscreen system

In the common understanding of those who read it must be assumed that a ventilated rainscreen consists of: 1.) a basic structural layer, which supports it and provides it (if desired) the useful thermal inertia requested, performs security tasks to the mechanical and thermal loads belonging its use, can perform an important role for sound insulation to air noise from outside or from the upper and lower levels, distributes internal installations, and realizes the interior finishes; 2.) a layer of thermal insulation, made with one or more materials of adequate characteristics for the intended use, to the dimensional characteristics of the building and to the thermo-hygrometric and acoustic performance desired; 3.) a ventilation layer which, as is known from the relevant literature, must comply with the minimum requirements of the intake air area, of the current airflow area and of the output area, so that the stack effect can be activated, and the rainscreen can be effectively defined "ventilated"; 4.) a support layer, that is a skeleton, normally made of wood or aluminum, which holds the external screen and is supported by the structural base layer by means of metallic shelfs (made in stainless steel, common carpentry steel or galvanized steel, or aluminum) that cross the layer of thermal insulation and thus constitute, or may constitute, punctiform thermal bridges; 5.) and, finally, by the outer coating layer, which forms the protective shield around the envelope, more or less continuous and therefore also more or less impermeable to air and water from rain and more or less efficient for the airborne sound insulation. The simulation hypothesis is that behind the ventilated rainscreen there is a room of 4.00 x 4.00 m, 3.00 m tall.

3. Physical-mathematical modeling of a ventilated rainscreen functioning

The model developed for ventilated rainscreens is directly derived from the one previously studied by the authors to model, simulate and analyse the behaviour of the DSF - Double Skin Façades (Lembo, Marino & Lacava, 2007 [1] and 2009 [2]) and to optimize their design. It is based on the use of MATLAB® Simulink software platform and is organized on the interaction between three subsystems: the thermal model (figure 1a); the airflow model (figure 1b); the wind velocity models (figure 1c, 1d).

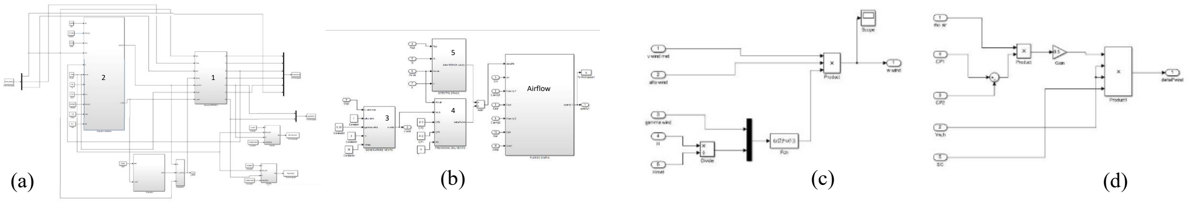

(a) (b) (c) (d)

Figure 1. (a) *Thermal model*: (1) thermal subsystem, (2) airflow subsystem; (b) Airflow model: (3) wind generator, (4) wind pressure, (5) stack effect; *Wind velocity model*: (c) wind generator; (b) wind pressure

3.1. The thermal model

The <u>*thermal model*</u> simulates the thermal exchanges that occur between the different elements of the ventilated rainscreen, by conduction, convection and radiation, under the action of temperature differences. The required inputs are the external climatic conditions, the coefficients of heat transfer and air flow, resulting from the *airflow* model.

The outputs are the temperatures of all the layers that make up the system and the internal ambient and the speed of the air flow in the cavity. In every node acts a dynamic system which can be described in non-stationary conditions resorting to differential equation's solution (from 1 to 5).

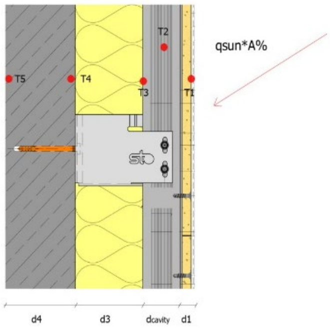
$$\frac{dT_1}{dt}=\left[\frac{\alpha_0\cdot(\partial_0-\partial_1)+\alpha_{c1}\cdot(\partial_2-\partial_1)+\alpha_{r13}\cdot(\partial_3-\partial_1)+A_{\%}\cdot q_{sun}}{(\rho_1\cdot d_1\cdot C_1+\rho_a\cdot d_a\cdot C_a)\cdot 0.5}\right] \tag{1}$$

$$\frac{dT_2}{dt}=\left[\frac{\rho_a\cdot C_a\cdot q_{cavity}\ (\partial_{cavity}-\partial_2)+\alpha_{c2}\cdot(\partial_3-\partial_2)+\alpha_{c1}\cdot(\partial_1-\partial_2)}{\rho_a\cdot d_{cavity}\cdot C_a}\right] \tag{2}$$

$$\frac{dT_3}{dt}=\left[\frac{\alpha_{r13}\cdot(\partial_1-\partial_3)+\alpha_{db}\cdot(\partial_4-\partial_3)+\alpha_{c2}\cdot(\partial_2-\partial_3)}{(\rho_a\cdot d_{cavity}\cdot C_a+\rho_3\cdot d_3\cdot C_3)\cdot 0.5}\right] \tag{3}$$

$$\frac{dT_4}{dt}=\left[\frac{\alpha_{db34}\cdot(\partial_3-\partial_4)+\alpha_{db45}\cdot(\partial_5-\partial_4)}{(\rho_3\cdot d_3\cdot C_3+\rho_4\cdot d_4\cdot C_4)\cdot 0.5}\right] \tag{4}$$

$$\frac{dT_5}{dt}=\left[\frac{\alpha_{db34}\cdot(\partial_5-\partial_6)+\alpha_{in}\ (\partial_{room}-\partial_5)}{\rho_4\cdot d_4\cdot C_4}\right] \tag{5}$$



$A_{\%}$	Part of solar radiation absorbed [-]
q_{sun}	Solar radiation [W/m^2]
α_{in}	Convective heat transfer coefficient between the base layer and the room [W/m^{2}K];
α_0	Convective heat transfer coefficient between the outside panel and the air [W/m^{2}K]
α_{r13}	Radiant heat transfer coefficient between the outside panel and the insulation [W/m^{2}K]
α_r	Radiant heat transfer coefficient between the external layer of the rainscreen and the insulation [W/m^{2}K]
α_{c1}	Convective heat transfer coefficient between the outside panel and the cavity [W/m^{2}K]
α_{c2}	Convective heat transfer coefficient between the cavity and the insulation [W/m^{2}K]
α_{db34}	Heat transfer coefficient (conduction, radiation and convection) of insulation [W/m^{2}K]
α_{db45}	Heat transfer coefficient (conduction, radiation and convection) of base layer [W/m^{2}K]
C_a	Specific heat of the cavity air [J/KgK]
C_1	Specific heat of the given exterior panel/layer of the façade [J/KgK]
C_3	Specific heat of the insulation [J/KgK]
C_4	Specific heat of the base layer [J/KgK]
ρ_a	Density of cavity air [Kg/m^3]
ρ_1	Density of the given exterior panel/layer [Kg/m^3]
ρ_3	Density of the insulation [Kg/m^3]
ρ_4	Density of the base layer [Kg/m^3]
d_1	Thickness of the given exterior panel/layer of the façade [m]
d_3	Thickness of the insulation [m]
d_4	Thickness of the base layer [m]
d_{cavity}	Cavity thickness [m]
θ_{cavity}	Entry air temperature [°C]
θ_0	Temperature of external air [°C]
θ_1	Temperature of the exterior panel/layer [°C]
θ_2	Temperature of the air in the cavity [°C]
θ_3	Temperature of the insulation layer [°C]
θ_4	Temperature of the internal face of insulation [°C]
θ_5	Temperature of the external face of base layer [°C]
θ_6	Temperature of the internal face of base layer [°C]
θ_{room}	Temperature of room [°C]

The air inlet temperature in the cavity is evaluated with the following formula 6; for the windward side, the turbulent flow is calculated according to the formula 7; for the side not exposed to the wind, the turbulent flow is that of the formula 8:

$$\partial_{\text{cavity}} = \frac{q_{\text{stack}}}{q_{\text{stack}} + q_{\text{v turb}}} \cdot \partial_0 + \frac{q_{\text{v turb}}}{q_{\text{stack}} + q_{\text{v turb}}} \cdot \partial_0 \quad (6)$$

$$q_{v_{turb}} = 0.05 \cdot A_{defl} + 0.0035 \cdot v_{Win} \cdot A_{defl} \quad (7)$$

$$q_{v_{turb}} = 0.05 \cdot A_{defl} + 0.009 \cdot v_{Win} \cdot A_{defl}^{0.16} \quad (8)$$

θ_{cavity}	Entry air temperature [°C]
θ_0	Temperature of external air [°C]
A_{defl}	Intake Area [m^2]
q_{cavity}	Airflow in the cavity [m^3/s]
q_{stack}	Airflow generated from stack effect [m^3/s]
$q_{\text{v turb}}$	Airflow generated by wind turbulence [m^3/s]
V_{win}	Wind velocity [m/s]

The heat exchange coefficients, used in the thermal model, were calculated from the general principles of physics and in agreement with the experimental studies by Di Maio & Van Paassen (2001) [4], Stec & Van Paassen (2002) [5], Stec & Van Paassen (2003) [6], Stec (2006) [7] at the University of Technology - T.U. - Delft, The Netherland.

3.2. The airflow model

The *airflow model* consists of four sub-systems:

- the *stack effect generator*, which allows to determine the pressure differences generated by the stack effect or buoyancy, on the basis of the following inputs: external temperature, temperature in the cavity, air density, height of the cavity. The difference in pressure determined by the temperature variation is defined (as in Di Maio & Van Paassen, 2001 [4]) by the equation (9). Through a series of simple further equations, it is possible to determine the trend of the pressure in the ventilated cavity and the position of the medium pressure level, in relation both to the area of the input section than to that of the outlet section (10):

$$\Delta P_s = P_{out} - P_{in} = (\rho_{out} - \rho_{in}) \cdot g \cdot z + P_{z0} - P_{z0} = (\rho_{out} - \rho_{in}) \cdot g \cdot (h_{z0} - h) =$$

$$= \rho_{in} \cdot g \cdot (h_{z0} - h) \cdot \left(\frac{T_{in} - T_{out}}{T_{out}}\right) = \rho_{out} \cdot g \cdot (h_{z0} - h) \cdot \left(\frac{T_{in} - T_{out}}{T_{out}}\right) \quad (9)$$

$$A_1{}^2 \cdot z_1 \cdot \rho_{out} = A_2{}^2 \cdot z_2 \cdot \rho_{in}) = \frac{z_2}{z_1} = \frac{\rho_{in}}{\rho_{out}} \cdot \left(\frac{A_2}{A_1}\right)^2 = \left(\frac{T_{out}}{T_{in}}\right) \cdot \left(\frac{A_2}{A_1}\right)^2 \quad (10)$$

- the *wind effect generator* allows to determine the pressure difference generated by the effect of the wind on the rainscreen, on the basis of the following inputs: air density, pressure coefficient on external surface of the building C_{p1}; pressure coefficient on the building roof C_{p2}, wind speed, local security coefficient. On the basis of known indications of the ASHRAE 1997 [8] and Swami & Chandra (1987) [9], and the tests carried out in the wind tunnel at the T.U. Delft (Stec, 2006) [7], it is possible to calculate the pressure difference due to the action of the wind, through (11) Swami & Chandra (1998) [10].

- the *airflow generator*, which allows to define the value of all the air flows, at the input, in the cavity, and at the outlet, from the following input data: the difference in pressure due to the wind; pressure difference due to the *stack effect* in the cavity; coefficients of admittance, at the input, in the cavity and at the outlet. Starting from the equation which expresses the Bernoulli's Theorem, in the case of an ideal fluid and considering the resistance to motion by friction, due to the distributed and localized load losses and to the nature of motion, laminar or turbulent (see *Reynolds number*), they were adopted the resistance coefficients ξ_{is} experimentally determined in the Laboratory of Refrigeration and Indoor Climate Technology of the TU Delft [11], which have served to calculate (12) the coefficients of admittance *Cij*, as a function of the ventilated rainscreen geometry.

3.3. The wind velocity model

The *wind velocity model* transforms the wind speed measured by the meteorological station in the speed of the wind acting on the surface of the building (13), starting with the following input data: wind speed by the weather station, weather station height, height of the ventilated rainscreen, parameters dependent on the type of ground and the local situation, protected or not (Sherman & Grimsrud, 1980 [12]; Burns & Deru, 2003 [13]).

$$\varDelta P_{wind} = \left(C_{p1} - C_{p2}\right) \cdot \frac{1}{2} \cdot \rho_{out} \cdot {v_w}^2 \qquad (11)$$

$$C_{ij} = \frac{v \cdot A_{ij}}{\sqrt{\frac{1}{2} \cdot \xi_{ij} \cdot \rho_{air} \cdot v^2}} = \sqrt{\frac{2 \cdot v^2 \cdot {A_{ij}}^2}{\xi_{ij} \cdot \rho_{air} \cdot v^2}} = \sqrt{\frac{2 \cdot {A_{ij}}^2}{\xi_{ij} \cdot \rho_{air}}} \qquad (12)$$

$$v_{w,h} = v_{w,met} \cdot \alpha \cdot \left(\frac{H}{H_{met}}\right)^{y} \qquad (13)$$

4. Example of model application

As an example of the studies conducted on the different (by type of materials, stratification, thicknesses and dimensions in height) types of ventilated rainscreens analyzed (as mentioned in paragraph 1), here it is reported only the result of its application to one of the most widespread ventilated rainscreen on a global scale, produced and marketed by StoSE & Co. KGaA in Weizen, Germany: the model StoVentec R (figure 3) is characterized by the outer coating to organic plaster in opera performed on recycled glass slabs 12 mm thick, with the most various finishes, which may be continuous up to an area of 25 x 25 m (625 m^2) without any joint fractionation; the structure consists of a T vertical aluminum, supported by stainless steel shelves.

Several hundred simulations were run, according to section 1, crossing the different planning solutions. The following figures show some of the most significant results of some parameters' simulations regarding the continuous ventilated rainscreen – StoVentec R (figures 2 and 3).

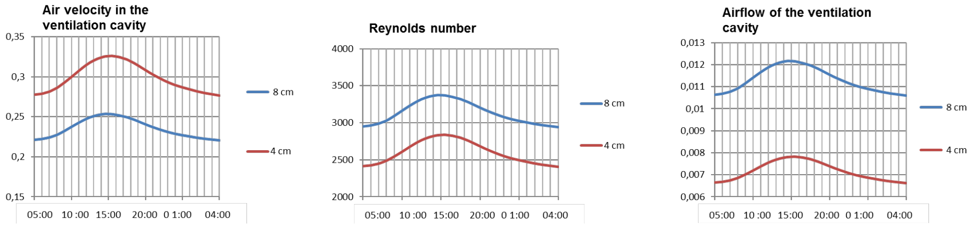


Figure 2. Continuous ventilated rainscreen: ventilation cavity 4 and 8 cm wide, 23.50 m height

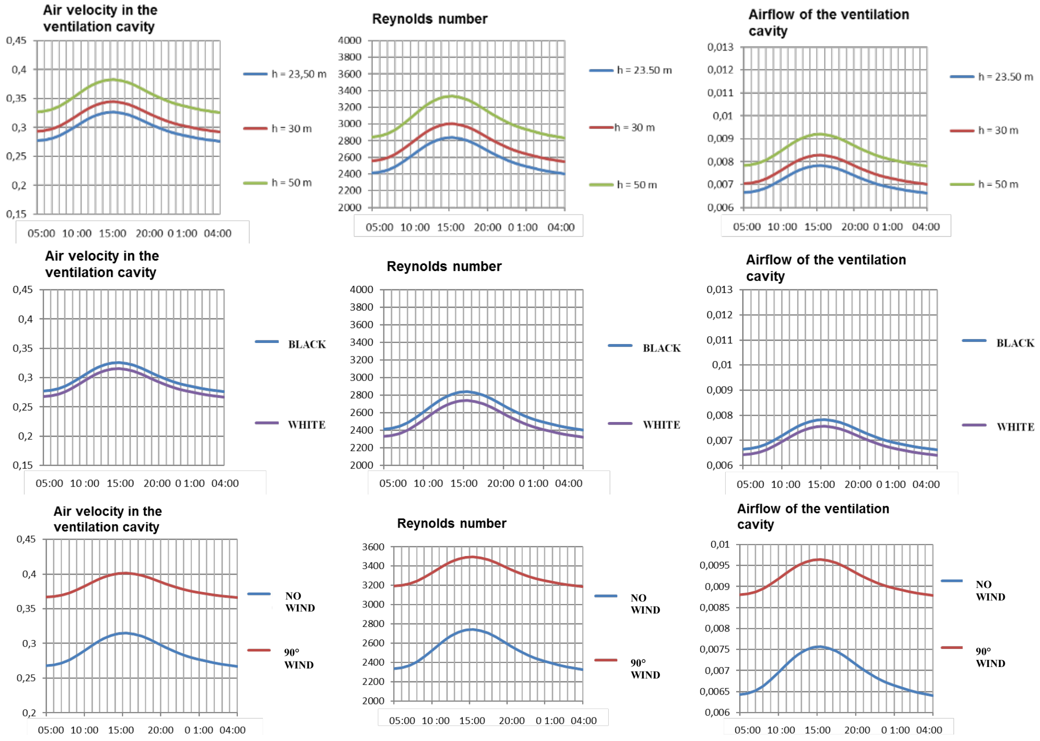


Figure 3. Example of cross-comparing results for continuous ventilated rainscreen: ventilation cavity 4 cm wide; height of 23.50 m, 30 m and 50 m (top); ventilation cavity 4 cm wide, 23.50 m height, black and white exterior finish (middle); ventilation cavity 4 cm wide, 23.50 m height, in the absence and in the presence of wind with incidence angle of 90° (down)

5. Results and conclusions

Overall, the research results of the countless simulations and the analyzes carried out on the different types of ventilated rainscreens shown that the variations of pressure and air flow inside the ventilation cavity are conditioned not only by the height of the ventilated rainscreen but also by the thickness, the temperatures, the material and the color of the external cladding, by the intensity of the wind and its angle of incidence with the external surface of the ventilated rainscreen, as well by the presence of horizontal rafters that determine partial obstruction of the ducts ventilation. Regarding the type of continuous ventilated rainscreen, reported as an example of the model application, in summary it can be stated as follows: the system with 8 cm ventilation cavity presents turbulent flows thus being less efficient than that by 4 cm; the height of the rainscreen of 23.50 m marks the limit of the transition from laminar to turbulent flow; the color of the finishing and the type of the insulating coating do not affect so significant on the thermo-fluid dynamic variations; the simultaneous presence of the stack and the effect of the wind incidence generates limited turbulent flows, also below the height of 23.50 m.

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The authors' contribution in the research and to the editing and writing the text of the paper was equal.

IOP Conference Series: Materials Science and Engineering

Preface to X IAQVEC 2019: nearly Zero Energy Buildings

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Dear Colleagues,

on behalf of the Organizers, it is our great pleasure and an honor to welcome you to the X IAQVEC 2019: nearly Zero Energy Buildings, which will be held on September 5 to 7 in Bari, Italy.

The Conference was hosted by the Politecnico di Bari and co-organized by three universities, the Ryerson University (Ontario, Canada), the Politecnico di Bari (Italy), the Universita del Sannio (Italy).

X IAQVE 2019 focused on the theme "Healthy nearly Zero Energy Buildings" and envisaged the participation of over 450 scientists, researchers and practitioners and the submission of over 300 papers covering a broad range of topics relevant to the main subjects of Building Science.

This conference has been organized around the following five streams: Ventilation and measurement techniques; IAQ and Indoor Environmental Quality; HVAC systems; Smart Technologies for Zero Energy Buildings (ZEBs); and ZEBs: design and energy modeling.

The conference provided a forum for the exchange of knowledge among scientists, researchers, and practitioners from all over the world. It helped to disseminate technical information, new ideas, as well as the latest and future developments of research in the field of building science. Moreover, the conference was expected to create a platform through which stakeholders from various countries could exchange their new knowledge, research outputs, and experiences.

The Conference has attracted over 500 submissions from 81 countries around the world. The final X IAQVEC's technical program consists of over 280 oral presentations and almost 60 poster presentations, including five keynote lectures delivered by prominent scientists and professors, such as Dr. Qingyan Chen, Dr. Philomena Bluyssen, Prof. Mauro Strada, Dr. Xudong Yang, and Dr. Mattheos Santamouris.

Thanks are due to the many people who have freely given their time and goodwill to make X IAQVEC a success. We are grateful to the Politecnico di Bari for the valuable support in the conference.

We would like to thank the members of the International and National Scientific Committees and the additional Reviewers whose help has been essential to ensure the high level of quality of the selected papers. Their names are reported at the end of this introduction.

Important contributors to the conference have been made by the Authors, Presenters, and Delegates, without whom the conference could not take place. We, therefore, offer them our heartfelt thanks.

We hope that you will enjoy the conference program!

Dr. Umberto Berardi
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