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Experimental characterization and implementation of an integrated autoregressive model to predict the thermal performance of vegetal façades

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ABSTRACT

This article presents the results of an experimental study carried out in a vegetal façade situated in a locality close to Madrid.

The objectives of the study are to develop a performance predictive model of a vegetal façade whose independent variables are irradiance, exterior temperature and relative humidity, based on the effect of the vegetation on the environmental conditions of the building, as well as to characterize thermally the vegetal element by comparing two identical enclosures (with a vegetal layer present in one of them being the only difference).

The results of the three-year monitoring period are analyzed by means of statistical data processing and an autoregressive model is fitted. This model estimates the temperature difference between both enclosures. The validation of the model based on the experimental data is done subsequently.

Once the improvements caused by the vegetation on the interior environmental conditions of the building have been quantified, the results show that it is possible to predict with high accuracy the vegetation's performance, being the multiple *R*-squared of the estimated models around 85%.

Furthermore, the application of the model is suitable for other buildings located in a similar climate to the one studied, as the independent variables exclusively depend on climate conditions.

1. Introduction

The growing interest in vegetal surfaces in both architectural and urban environments is reflected in the gradual development of new research about vegetal façades in recent years [1–8].

In most cases, the studies focus on the analysis of the energy performance of this type of envelopes, as well as the effects stemming from their implementation in buildings and environment, from very different points of view: thermal [9–12] reduction of the urban heat island effect [13–15], air quality [16,17] and acoustic comfort [18].

Generally, these researches tend to base their conclusions on experimental data from monitorings and tests [19,20] or on simulation results [21–23].

In addition, the monitoring periods usually taken into account are short and centered on the summer [19,24], making it impossible to extrapolate the analysis of the treated envelope's performance to other seasons of the year, a necessary condition, in turn, for the study of the building's global thermal balance.

Moreover, simulation software mostly bases the case studies in complex mathematical models [20] which in turn require a comprehensive knowledge of the specific characteristics of the substrate and vegetation for their use [25–27]. A knowledge that, in most cases, is not included in the technical formation of the sector's professionals. The complexity and existence of a great variety of simulation software, testing and monitoring methods, is precisely due to the difficulty in being unable to treat the main components of vegetal façades (water, vegetation and substrate) as any other material. This is due to the fact that vegetation is a living element that interacts with the environment and the building in very different ways, depending on the weather and hydrologic conditions, the type of plant used, etc. [28]. Furthermore, the substrate is composed of several materials whose characteristics differ generally in most cases, affecting significantly the ensemble's behavior. In addition,

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This enables these models to be extended to the study of vegetal façades located in places with similar weather conditions to those characteristic of the place of study. It is possible to estimate the behavior of the enclosure and interior environment with only the data for outdoor temperature, relative humidity and irradiance. The verification of the validity of the models is done by comparing the experimental and predicted data

As Section 7 shows, the performance of the predictions is quite similar to that previously observed, being captured abrupt changes and instability of temperature in the prediction. In fact, both the residual standard error and the multiple *R*-squared of the estimated models indicate that the error made in the prediction is very small.

In conclusion and regarding the possibility of using the predictive models in other contexts, the following aspects are worth mentioning:

- the models reproduce the performance of an envelope with vegetal finish type *sedum* facing another with metal finish. For the cases in which the façades analyzed were of a different finish than the ones tested, the necessary adjustments should be done, considering the physical and optical properties of the reference façade, as well as the characteristics of the type of plant used in the vegetal façade.
- The study develops five groups of models grouping the time slots with a similar thermal behavior. When using the models in places characterized by weather conditions different to those studied, it is important to consider if the time slots match with the ones observed in the study case, and if this were not the case, to adapt them to the new conditions.
- The fact that one of the explanatory variables of the models is the irradiance on vertical surface facing south causes that, in the event of studying façades with other orientations, the part of the model relating to the irradiance needs to be adjusted, being more or less influential based on the façade's orientation.
- Finally, in the event of considering the application of the model to enclosures formed of several layers, the models relating to the interior surface temperature should be taken into account and used as a starting point to estimate the thermal performance in the interior of the building. To this end, the effect of the façade's additional layers should be assessed, which would not be a problem since, on one hand, the thermal properties of the conventional materials are known and, on the other hand, there would be no difficulty in rebuilding the thermal gradient in the other layers of the enclosure once the response of the vegetal layer to the exterior weather conditions is known.

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