Thermal and Acoustic Analysis of Innovative Integration of PV Modules in Façade Envelopes

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Introduction

The crucial need of implementing efficient techniques to improve energy performance in building's sector without jeopardizing the indoor comfort levels is more and more widespread.

The aim of the study is to analyze an innovative integration of PV modules inside the cavity of multiple skin glazed façade buildings according to the thermal and acoustics comfort point of view.

Numerical simulation and experimental validation have been applied to evaluate this innovative integration. The analysis include various aspects such as cavity width and different ventilation typologies and its relation to the overall thermal, electrical and acoustical efficiency of the system.

Background

Building Integrated PV (BIPV) is the design and integration of PV technology put into the building envelope, usually replacing conventional building materials [2].

In modern cities, the ratio between roof area and façade area of buildings is high and a vertical arrangment o PV elements can solve a number of installation problems related to soil rates. A vertical PV wall can generate up to 70% of the rooftop array, depending on building shape and façade orientation, and produce relatively more power in winter and less in summer [3]. A strong limit for this application is due to insufficient solar radiation, often caused by obstructions from the surroundings.

Several researches have been recently carried out to investigate building envelope integration of PV modules [1] and photovoltaic cell electrical performance dependence from temperature in a BIPV/T (photovoltaic/thermal) element [5]. Other researches concern the validation of a coupled thermal-aerodynamic model [6][7] and the analysis of indoor conditions of a PV integration in a low energy building façade [4].

Simulation model: thermal, electrical and acoustical analysis of BIPV

In order to investigate interaction between thermal, electrical and acoustic performance of PV modules integrated in a Double Skin Ventilated Façade (DSVF), a numerical study on a portion of an office building was carried out.

For this simulation an open-space plan was considered (Figure 1) and the following geometrical and constructive characteristics have been applied both for thermal and acoustic evaluation:

- room volume = 280 m³;
- façade area for each floor = 70 m²;
- DSVF thickness (min-max) = 100÷500 mm;
- façade shape, $\Delta L_{fs} = 0$;
- two types of façade inner glazed layer (SL, single layer, or DL, double layer);
- two types of cavity ventilation (NV, natural ventilation, or MV, mechanical ventilation).

The study included two main steps:

1) a numerical dynamic thermal model was carried out on TRNSYS [9]. Several comparative parameters have been taken into consideration such as location of PV module, ventilation typologies of the façade cavity, design optimization of inner glazed layer, location and orientation of the building, different weather conditions, etc.. The model was validated against measured data and then it was used to analyse the yearly thermal and electrical energy performances between different comparative cases;
2) considering previous given thermal parameters and the variation of façade thickness, the evaluation of expected sound reduction of the whole façade was obtained with AcouS STIFF 11.0; then calculations according to EN 12354-2 were performed to evaluate façade standardized level difference $D_{2m,nT,w}$.

The results of acoustic simulations show that, varying the parameters that may affect the acoustic performance of the façade (composition of the glass, the thickness of the cavities, etc.), the expected range of standardized level difference $D_{2m,nT,w}$ is enough high to fulfil a large set of requirements of protection from external noise (Figure 2).

However, the estimated range of centrifugal fan sound power level due to the façade cavity ventilation system represents a potential noise generation problem inside the room or in the façade cavity, depending on the ventilation system location.

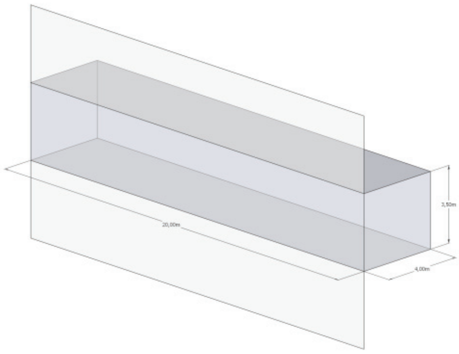

Figure 1: Sketch of the portion of building considered for the acoustic and thermal simulations (w x d x h = 20.0 x 4.0 x 3.5 m).

Table 1: Thermal and acoustic parameters of the simulation model

Façade glazing components (Ext-Int)	Parameter		
	Façade *U* [W/m²K]	Solar Heat Gain Coefficient (SHGC)	Sound Reduction Index (Min-Max) $R_w(C;C_{tr})$ [dB]
SL/cavity/PV/ cavity/SL	1.68	0.29	44 (-3;-6) 48 (-3;-7)
SL/cavity/PV/ cavity/DL	1.23	0.24	48 (-2;-6) 53 (-2;-7)

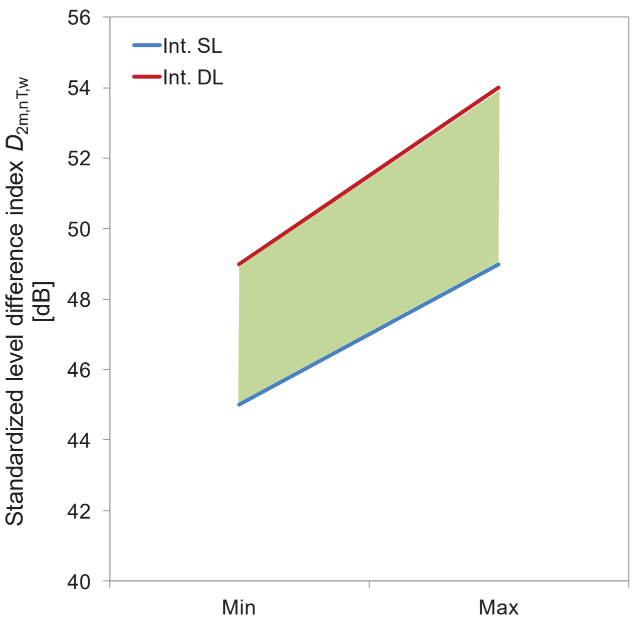

Figure 2: Expected range of standardized level difference $D_{2m,nT,w}$ (Min-Max) for different composition of the analyzed DSVF of the BIPV.

Preliminary conclusions

BIPV façades represent a new challenge for building envelope design but many aspects concerning indoor comfort have to be investigated.

The thermal and electrical improvements within glazed building sector have to be accompanied with an effective evaluation of sound insulation requirements.

The expected noise level in BIPV caused by the cavity mechanical ventilation system may become a problem if the acoustical glazing performances and frame design details (i.e.: junctions, air inlets, etc.) are not specifically evaluated.

Future works

Starting from the results of the latest researches on the optimization of the electricity production of PV modules integrated in ventilated façades [8], a more extended analysis of acoustic performances of DSVF in a BIPV system is in progress, with the aim to consider acoustic problems related to ventilation techniques.

References

[1] Zogou O., Stapountzis H., Experimental validation of an improved concept of building integrated photovoltaic panels, Renew. Energy 36 (12) (2011), 3488-3498

[2] Redweik P., Catita C., M. Brito, Solar energy potential on roofs and facades in an urban landscape, Solar Energy 97 (2013), 332-341

[3] Patterson M., Vaglio J., Noble D., Incremental Façade Retrofits: Curtainwall Technology as a Strategy to Step Existing Buildings toward Zero Net Energy, Energy Procedia 57 (2014), 3150-3159

[4] Polo López C.S., Sangiorgi M., Comparison assessment of BIPV façade semi-transparent modules: further insights on human comfort conditions, Energy Procedia 48 (2014), 1419-1428

[5] Bigailaa E., Rounisa E., Luka P., Athienitisa A., A study of a BIPV/T Collector prototype for Building Façade Applications, Energy Procedia 78 (2015), 1931-1936

[6] Agathokleous R.A., Kalogirou S.A., Double skin facades (DSF) and building integrated photovoltaics (BIPV): A review of configurations and heat transfer characteristics, Renew. Energy 89 (2016), 743-756

[7] Saadon S., Gaillard L., Giroux-Julien S., Ménézo C., Simulation study of a naturally-ventilated building integrated photovoltaic/thermal (BIPV/T) envelope, Renew. Energy 87 (2016), 517-531

[8] Elarga H., DeCarli M., Zarrella. A., Dynamic energy evaluation and glazing layers optimization of façade building with innovative integration of PV module, Energy and Buildings 111 (2016), 468-478

[9] Klein S., Beckman W., Mitchell J., Duffie J., Duffie N., Freeman T. et al., TRNSYS 16 - A transient system simulation program, User manual, University of Wisconsin, Madison, USA, 2004