Scientific Report for the COST Action TU 1403 Adaptive Façades Network

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Beneficiary (institution)	Giulio Cattarin (Politecnico di Milano)
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Host (institution)	Prof. Francesco Goia
	Norwegian University of Science and Technology (NTNU)
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1. Summary

The present document summarizes the research activity carried out at the Norwegian University of Science and Technology (NTNU) by Giulio Cattarin, PhD candidate from end-use Efficiency Research Group - Politecnico di Milano (eERG-Polimi, Milan, IT) and visiting PhD at the Ecole Speciale de Travaux publics (ESTP, Paris, FR). The STSM strengthened the collaboration among the three institutions and laid the foundations for future joint projects.

The first main objective of the experience was to validate the lumped-parameter thermal model developed by Cattarin within his PhD project by means of an experimental campaign. For this purpose, after setting up the necessary instrumentation, one of the ZEB Test Cells has been run in free-floating mode for five days while exposed to external weather conditions. The candidate created a thermal model describing the test cell and ran the simulations using the measured boundary conditions. The thermal model was able to predict the profile of internal temperatures with residuals never exceeding ±1°C and lying most of the time within the measurement uncertainty bands.
Cattarin also investigated which parameters and inputs are most influential on the thermal behaviour of the test cell by means of a local sensitivity analysis. The "highest ranking" variables shall be measured with high accuracy when performing the heat balance of the test cell for e.g. calorimetric tests.
This objective is in line with the fulfilment of the Deliverable 2.4.: Report on the validation of developed simulation tools and models.

The second main objective was to develop guidelines for the experimental determination of the solar factor of transparent façade components under real weather conditions. The guidelines result from the experience gained by the three Institutions in the last years by means of (i) an extensive literature review on test cell and indoor laboratory experiments (Cattarin et al., 2016a), (ii) modelling and simulation activities (e.g. Cattarin et al. (2016b), Goia et al. (2014)) and (iii) the practical experience gained by NTNU and SINTEF during the design, construction and start-up of the ZEB Test Cells.

2. Purpose of the STSM

The STSM strengthened the network among three research groups (eERG, ESTP and NTNU) around the common research topic of the experimental characterisation of building façade components under real weather conditions.

The scientific objectives have been:

- gaining a deeper insight on the potentialities and limits of the ZEB Test Cells Laboratory in comparison with other test cell facilities, in order to identify candidate test components
- developing practical guidelines for the determination of the solar factor of transparent façade components under dynamic weather conditions with a focus, among the different aspects, on the outdoor weather conditions, the heat balance equations, the data post-processing and the uncertainty analysis
- validating a thermal model developed by Cattarin within his PhD project at eERG and ESTP

3. Description of the work carried out during the STSM

Cattarin worked in close collaboration with Francesco Goia (NTNU), Christian Schlemminger (SINTEF) and Steinar Grynning (SINTEF) on the following activities:

Validation activity

- detailed characterisation of the test cell facility (e.g. geometry and materials of the envelope, optical characteristics of the installed transparent component)
- creation of the lumped-parameter thermal model of the ZEB Test Cells
- set-up of the experiment: design of the experimental procedure, positioning of the sensors, initialization of the data acquisition system
- data processing and analysis: gathering, selecting and filtering the raw data, checking data quality
- validation phase: thermal simulations, comparison between measurements and predictions by means of a residual analysis, local sensitivity analysis on 50 parameters of the model

Development of guidelines for the determination of the solar factor in test cell facilities

- operative definition of the solar factor in dynamic test conditions and comparison with standardized steady-state tests
- description of the experimental apparatus and instrumentation necessary to carry out calorimetric tests, focusing on the determination of the extracted cooling power, the monitoring of the weather data and the other boundary conditions experienced by test cell facilities.
- definition of the test procedure: minimum requirements concerning external weather conditions, pre conditioning and start-up of the system, duration of the measurement and data processing
- calculation procedure for the determination of the solar factor and its combined standard uncertainty, with examples

4. Description of the main results obtained

The experimental validation was carried out on a 5-day period between the 9th and the 14th September 2016, under both cloudy and sunny weather conditions. The results show that the model is able to predict the evolution of the internal air temperature and the envelope's surface temperature with good accuracy, with residuals lying always within a range of ± 1°C and lying most of the time within the measurement uncertainty bands.

The validation work has been summarised in a 34-pages report, which presents the main characteristics of the test cell facility, the modelling assumptions, the comparison between simulation results and measurements and a local sensitivity analysis performed over 50 parameters and inputs. On the basis of the sensitivity analysis, suggestions are provided in order to improve the experimental set-up and conduct future experimental campaigns (see Section 7 in the report).

The thermal model in Matlab environment is a fully-customizable thermal simulation tool that could be used by other researchers who want to (i) carry out numerical studies on the interaction between the test cell and an installed component, (ii) fine-tune the *design of experiment* of future experimental campaigns by means of preliminary simulations and (iii) compare experimental results and numerical predictions and carry out residual analyses adopting a diagnostic approach.

The guidelines developed within the STSM aim at offering a practical support to research centres that are either planning to design a new outdoor test cell facility or working to improve the accuracy of calorimetric tests carried out in existing facilities. The guidelines deal with all aspects of calorimetric measurements, from the operative definition of the solar factor under dynamic conditions to its determination using state-of-the-art and new-generation test cell facilities. The guidelines present a rigorous method to implement uncertainty analysis, taking into account the thermal dynamics of the test cell facility.

The guidelines suggest amendments to the American standard proposed by the National Fenestration Rating Council for the measurement of the solar factor in indoor and outdoor solar calorimeters (NFRC, 2010). On a longer term, the guidelines might constitute the base of discussion for the development of a European standard for outdoor test cell calorimetry.

The validation report and a draft version of the guidelines are both available in Appendix.

5. Future collaboration with the host institution

The STSM laid the foundations for future collaborations among eERG-Polimi, ESTP-Paris, NTNU and SINTEF, including the possibility to jointly design and carry out experimental campaigns at the ZEB Test Cells or other facilities.

6. Foreseen publications/articles resulting from the STSM

The guidelines drafted within the STSM are presently undergoing an internal reviewing phase and will soon be presented at the COST Action TU1403 meeting in Lucern (CH), on the 5th - 6th

October 2016. The guidelines will be circulated within the COST network in order to gather feedback and proposals for amendments.

Within the STSM, Cattarin discussed with prof. Goia some aspects of his numerical work, which will be soon submitted for review in the form of a journal paper. The COST Action will be acknowledged for creating the framework for such exchanges.

Finally, the ongoing work will be presented at national and international conferences in 2017.

7. Confirmation by the host institution of the successful execution of the STSM

See attachment.

8. References

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Goia , F., Perino , M., & Serra, V. (2014). Experimental analysis of the energy performance of a full-scale PCM glazing prototype. *Solar Energy, 100*, 217–233.

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