Contents

The experimental assessment of adaptive facades under real outdoor conditions: the case study of ADAPTIWALL (7th FP)

Short-term scientific mission COST TU 1403 Adaptive Facades Network at CEA INES /LOCIE

1 Description of the short term scientific mission

This chapter briefly describes the short term scientific mission as it was proposed.

The proposed short-term scientific mission is focused on experimental procedures for the assessment of adaptive facades under real outdoor conditions

1.1 The host institution

The CEA and French National Solar Energy Institute INES have a solid experience in full scale outdoor testing of innovative and adaptive façade systems. The outdoor testing platform of the institute allows to do test both on solar technologies, innovative building envelope solutions, integrated to the system.
CEA-INES is equipped with four *PASSYS* test cells, roof test benches, 4 detached houses named INCAS to carry out tests on fully instrumented experimental houses with envelopes that have different degrees of inertia.
Recently CEA-INES is setting up a completely new testing facility named FACT. This new versatile tool will be dedicated to building envelope components testing: opaque and transparent elements, light-weight and massive façades, different thickness (from 10 to 60 cm) and heights (up to 8 m) and different geometry of the indoor environment.

1.2 The guest institution

The Institute for Renewable Energies of Eurac Research was founded in 2006 and is developing considerable experience in testing of innovative and multifunctional façade systems.
The scope of Eurac is to expand its testing activities, improve and expand its testing procedures and experimental set-ups as well as to cooperate with industry and research institutions on local and international level.

1.3 Objectives of the short term scientific mission

The objectives and prospected outcomes were defined in the project proposal as follows:

Aims and objectives

- Share experience between guest and visiting institution and the COST TU 1403 community in the field of testing of adaptive façade systems
- Contribute to developing common procedures for testing adaptive façade systems
- Contribute to developing common performance indicators for adaptive façade systems
- Enhance collaboration between CEA- INES and EURAC and create additional future opportunities for exchange and synergies
- Enhance knowledge on experimental evaluation of adaptive façade systems of EURAC, procedures and quality of the testing set-up

Description of the work to be carried out by the visitor at the host institution

- Analysis of the testing facilities of CEA-INES: PASSYS, INCAS and FACT
- Description of the characteristics of the testing facilities for deliverable D 2.5. Report on the developed experimental procedures.
- Data analysis of the ADAPTIVALL tests with ready data of tests undertaken with the PASSYS test cell
- Assessment of the ADAPTWALL with suitable performance indicators developed within WG 2 Task 2.1

Prospected Outcome

- The STSM contributes to the deliverable D 2.5. Report on the developed experimental procedures

The described testing facilities and procedures will be integrated as data sets into the manual and the freemind mindmap. The deliverable will be enriched with an extra data set of the ADAPTIWALL test procedure.

- The STSM will contribute to the application and development of performance indicators developed in Task 2.1
- The definition of the structure of a possible common publication

1.4 The ADAPTIWALL project

Among the different research, the European project ADAPTIWALL (**http://www.adaptiwall.eu/**) is of a particular interest in the framework of the COST ACTION TU1403.

The concept of ADAPTIWALL is based on the consideration that retrofitting attempts by increasing envelope thickness bring negative consequences like too high airtightness, over-heating, poor ventilation and loss of space due to voluminous retrofit units. ADAPTIWALL solves this problem by using nanotechnology to develop a multifunctional and climate adaptive panel for energy-efficient buildings.

This novel panel consists of 3 elements: Lightweight concrete with additives for efficient thermal storage and load bearing capacity. Adaptable polymer materials for switchable thermal resistance. Total heat exchanger with nanostructured membrane for temperature, moisture and anti-bacterial control.

Small-scale prototypes of ADAPTIWALL of 1 m² were tested without the integrated ventilation system at a test site at Algete (Madrid) and monitored from October 2015 to June 2016.

Currently the first real scale prototypes of ADAPTIWALL are under construction and will be installed in two PASSYS test cells at CEA in Chambéry. The installation was planned for the beginning of autumn (2016) and first experimental data from these real scale tests were supposed to be available during the short-term scientific mission. However, due to errors in the construction of the prototypes by a supplier the already installed prototypes had to be partly dismounted and modified. For this reason, no experimental data from the real scale tests are available up to now.

2 Report of the activities during the short term scientific mission

2.1 Short description of STSM activities at CEA /University of Savoie Mont Blanc - LOCIE.

For legal reasons, concerning mainly confidentiality issues, I could not be hosted officially as a guest researcher at CEA. This situation could be solved involving the neighbor institute of CEA, which is the LOCIE institute. LOCIE is member of the COST Action TU 1403 and was able to host me officially. However, these formal changes did not affect the planning of my activities and the supervision of CEA . I had my workplace at the premises of LOCIE for one week before I finally got access to the premises of CEA.

LOCIE is the "Laboratory for the Optimization of the Design and Engineering of Buildings" of the University of Savoie Mont Blanc. CEA is the French "Center for Atomic and Alternative Energy". The branch of CEA at Chambéry is the "Department for Solar Technologies". CEA and LOCIE are grouped together at Chambéry within the "National Institute for Solar Energy" INES.

My main tasks within the short term scientific mission were:

- The description of the building laboratories of CEA in a mindmap for the D. 2.5 of the COST ACTION TU 1403
- Data analysis, definition and calculation of performance indicators for the adaptive façade ADAPTIWALL

Additionally these dissemination and networking activities were performed:

- Oral presentation of EURAC Research its Institute for Renewable Energies and relevant activities at CEA
- Oral presentation of EURAC Research its Institute for Renewable Energies and relevant activities at the annual meeting of FEDESOL hosted by LOCIE.

FEDESOL is an association of French academic research institutions working in the field of solar energy. The event was the annual meeting of the working group on solar buildings and integration on solar systems into the building envelope.

2.2 Performance metrics for adaptive facades and the ADAPTIWALL case study

Data analysis and definition of performance indicators for an adaptive façade

2.2.1 Description

A main objective of this STSM was defining performance indicators for the adaptive façade Adaptiwall with experimental data. Here a short summary of the activities for reaching this goal is given:

Before arrival:

- Review of openly available literature about Adaptiwall
- Literature review on performance indicators for Adaptive Facades

- Pre- selection of performance indicators that could be used or adapted for Adaptiwall

During stay:

- Literature review on building envelope integrated thermal storage, in particular latent heat thermal storage
- Literature review and structuring of performance indicators for adaptive facades in a table
- Literature review of the available project deliverables of Adaptiwall
- Discussion about the preselected performance indicators, definition of strategy to adapt, test and calculate suitable performance indicators for Adaptiwall
- Study of Matlab, which was chosen to be used for the data analysis of Adaptiwall
- Visualization of relevant variables for the definition, verification and calculation of the performance indicators in Matlab plots
- Writing of a matlab code for the calculation and visualization of performance indicators for all prototypes

During and after stay:

- Review of the definitions and calculations of the performance indicators and its results
- Improvement of the visualization of the results

2.2.2 Results

Performance indicators for the adaptive façade Adaptiwall were defined and calculated:

- *Daily energy to the room* $e_{24,inside}$
- *Latent heat thermal energy storage efficiency* $\mu_{Latent\ heat\ thermal\ energy\ storage}$
- *Usable heat efficiency* μ_{usable}
- *Total heat efficiency* μ_{TOTAL}

Due to its extent, a more extensive report about the experimental campaign, the studied prototypes, the definition of performance indicators for Adaptiwall and its results is inserted in the appendix, at the end of the document.

2.2.3 Discussion – next steps

To what extend the goals are met?

As described in appendix experimental data was analyzed and performance indicators were defined and calculated. However further research is needed for getting meaningful results.

The goal is to publish the results, which will be based on the work described in appendix, in a publication. A first proposal for the index of the paper:

1. Introduction
2. Analysis of existing synthetic performance metrics for adaptive facades
3. A case study of a European project: Adaptiwall
4. Methodology: the evaluated metrics

5. Discussion
6. Conclusion

What are the next steps?

- The new experimental campaign on the real scale prototypes should start these days in the beginning of 2017 at CEA in Chambéry.
- To keep collaborating with CEA on the Adaptiwall project.
- The approach presented in Appendix will be applied to the new experimental data and further developed.

2.3 Mapping of test infrastructures and experimental procedures

2.3.1 Description

The COST TU 1403 Adaptive Facades Network is collecting and categorizing testing facilities and testing procedures for adaptive facades in a mind map. During this STMS the testing facilities of CEA were added to this mindmap.

2.3.2 Results

The following testing facilities of CEA were added to the mindmap:

- The four INCAS houses
- The four PASSYS test cells
- The new testing facility FACT

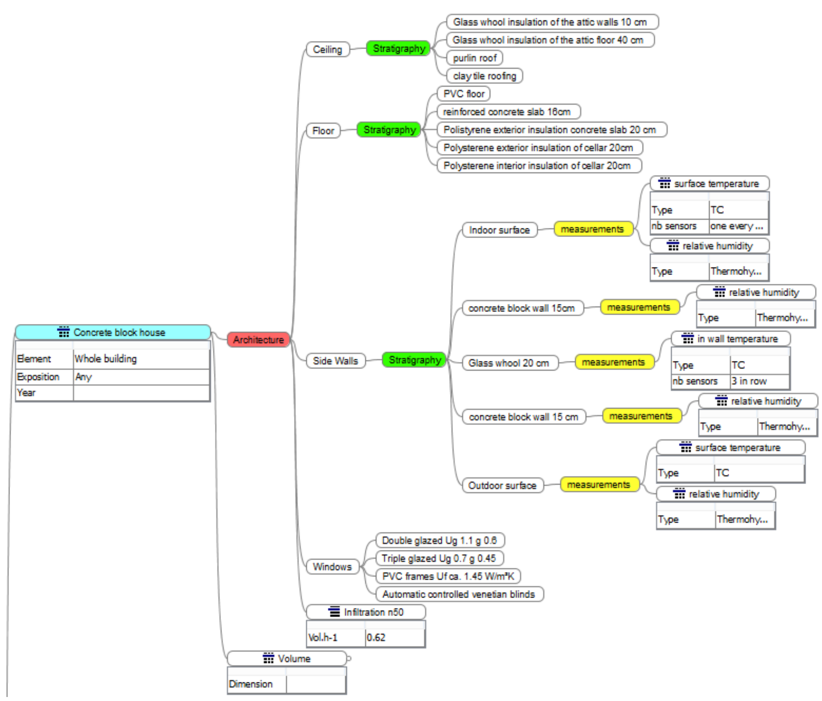

Figure 1 Mindmap mapping testing facilites and procedures for adaptive facades

Figure 1 shows an exemplary part of the mind map: the house made of concrete block of INCAS.

2.3.3 Discussion – next steps

To what extend the goals are met?

The maps of the labs were successfully created. They are currently under revision by CEA and will then be accessible for the COST community.

2.4 Networking, knowledge sharing and personal benefit - a final conclusion

To what extend the goals are met?

The goals are met. The STSM was a great chance to get the now the two institutes LOCIE and CEA, its competences and infrastructure and to present on the other hand EURAC Research. The STSM enabled me to exchange information and create personal contacts that created starting points for new or enhanced collaboration and synergies among the three institutes within the work on adaptive facades and beyond. The whole COST community profits immediately of this STSM by the descriptions of the testing facilities of CEA in the mindmap but also through the ongoing work on performance indicators and procedures developed for the adaptive facade Adaptiwall. Personally, for me it was enriching to see new and different laboratory infrastructure, research projects, working methods, working cultures and share experiences.

3 Acknowledgements

I want to thank Timea Bejat, Lorenza Bianco and Stefano Avesani for their commitment during my supervision and I want to thank Prof. Christophe Menezo, Virginie Renzi and Phillip Tony for they effort for making this STSM possible. Finally, I want to thank all people involved in the COST ACTION 1403 Adaptive Façades Network and in the same way Eurac research for the trust in my work and for giving me this great opportunity.

4 ANNEX: Description of the experimental campaign, the results of the data analysis and of the definition of the performance indicators

The analysis is based on the experimental testing of four small-scale prototypes that have been tested at Algete Demo Park of ACCIONA Infraestructuras in Spain. The four prototype panels have been placed in the same façade facing east of a conditioned container.

4.1 Description of prototypes

It shall be highlighted that for confidentiality reasons the Adaptiwall protoypes are described only to a certain extend.

The prototypes are panels with a dimension of 110 x 110 cm and are composed of two key components: The lightweight concrete thermal buffer and the adaptive insulation. The lightweight thermal buffer is composed of lightweight concrete with incorporated phase change material (PCM) using a vacuum impregnation technique. The prototypes have a cladding made of 4 mm clear float glass leaving a 15 mm cavity.

The differences of the four prototypes are as described below:

A. Prototype 1 and 2 are reference panels that do not contain any PCM. They are identical apart from the overheating protection mechanism. In contrast to all other panels prototype 1 uses a fan for overheating protection instead of a sun screen
B. Prototype 3 is the basic system incorporating PCM in the concrete aggregate. A mortar layer on the surface prevents possible small quantities of PCM leakage at high temperatures.
C. Prototype 4 is an alternative system that uses micro encapsulated PCM in aluminum casings for leakage prevention. The casings were placed in the rebar space and create several small compartments. Therefore, high fluid concrete was used. This resulted in denser concrete, but the final weight remained similar to the other prototypes since due to the casings less concrete was used.

Table 1 summarizes the properties of the four prototypes.

Table 1 Overview prototypes 1-4

	Prototype 1	Prototype 2	Prototype 3	Prototype 4
Concrete type	C20/25, Lightweight concrete	C20/25, Lightweight concrete	C20/25, Lightweight concrete	C20/25, very fluid concrete (Consistency class S5)
Additives	Without PCM	Without PCM	PCM and alumina	PCM and alumina
Thickness of buffer	16 cm	16 cm	16 cm	16 cm
Total thickness	40 cm	40 cm	40 cm	40 cm
Dimension of prototype	110 cm x 110 cm	110 cm x 110 cm	110 cm x 110 cm	110 cm x 110 cm

Approximate weight	160 kg	160 kg	180 kg	170 kg
Cladding	Tempered float glass	Tempered float glass	Tempered float glass	Tempered float glass
Thickness	4 mm	4 mm	4 mm	4 mm
Cavity	15 mm	15 mm	15 mm	15 mm
Solution for avoiding overheating	Fan	Sun screen	Sun screen	Sun screen

4.2 Testing period

The whole test campaign started on 18/11/2015 and ended on 27/6/2016. For the calculation of the performance indicators, a period of ten days was selected starting the 24th of March 2016. This period is characterized by distinct potential charging and discharging periods during the single days. The combination of sunny days with cold nights that reach 0°C as well as cloudy days with mild nights represents a winter or transitional period of the year where the "heating mode" of Adaptiwall can be well studied.

4.3 Results

The defined performance indicators are based on a publication of Favoino et al. [1] and were adapted to suit Adaptiwall. Favoino et al. defined performance indicators for a low inertia opaque and prefabricated adaptive façade named "ACRESS". The latent heat storage of ACTRESS is composed of two very thin layers of PCM material that is charged by a heat foil, electrically driven by façade integrated photovoltaic modules.

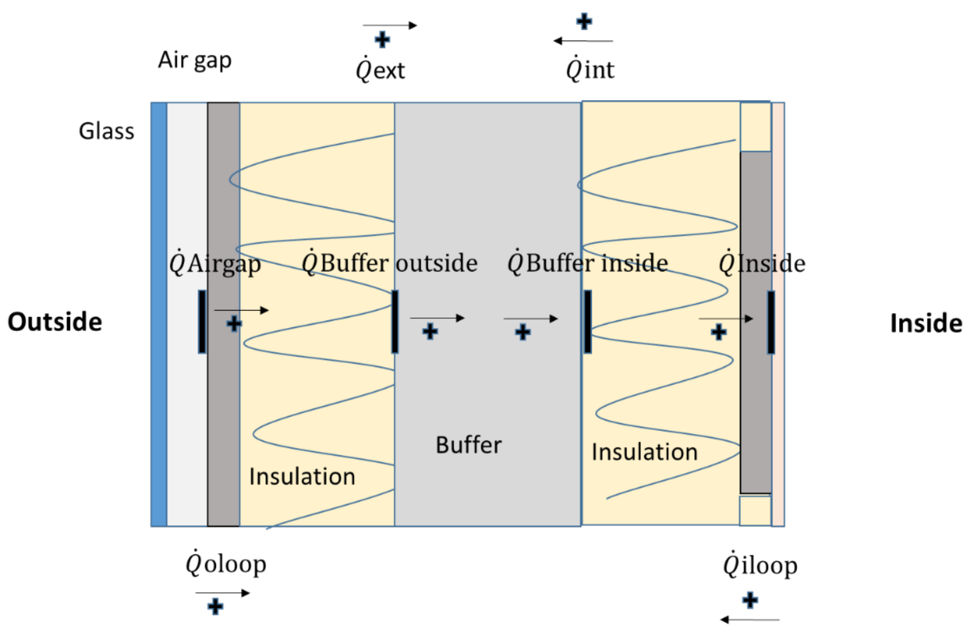

Figure 2 Scheme of the Adaptiwall's, heat flows and the positioning of all heat fluxmeters

Figure 2 visualizes and defines the heat flows within Adaptiwall used for the calculation of the indicators. $\dot{Q}_{EXT}$ and $\dot{Q}_{INT}$ are heat fluxes measured by heat flux meters in W/m² and correspond to $\dot{Q}_{Buffer\ outside}$ and $\dot{Q}_{Buffer\ inside}$ but the signs are defined differently. $\dot{Q}_{OLOOP}$ and $\dot{Q}_{ILOOP}$ are heat fluxes of water loops in W/m² . The energy balance of the buffer is defined as follows:

$$\dot{Q}_{Buffer} = (\dot{Q}_{OLOOP} + \dot{Q}_{EXT} + \dot{Q}_{INT}) \text{ [W/m²]}$$

For the energy charged into the buffer $\dot{Q}^{+}_{Buffer}$ only positive fluxes are considered:

$$\dot{Q}^{+}_{Buffer} = 0 \quad when \quad \dot{Q}_{OLOOP} + \dot{Q}_{EXT} + \dot{Q}_{INT} < 0$$

The performance indicators for Adaptiwall are defined as follows:

4.3.1 Daily energy $e_{24,inside}$ for typical days

$$e_{24,inside} = \int_{6am}^{6am+1\ day} \dot{Q}_{INSIDE}\, dt \text{ [W/m²]}$$

The indicator $e_{24,inside}$ is the cumulated heat flow through the border layer between the wall and the room during 24h. It is an indicator for on the overall performance of the system.

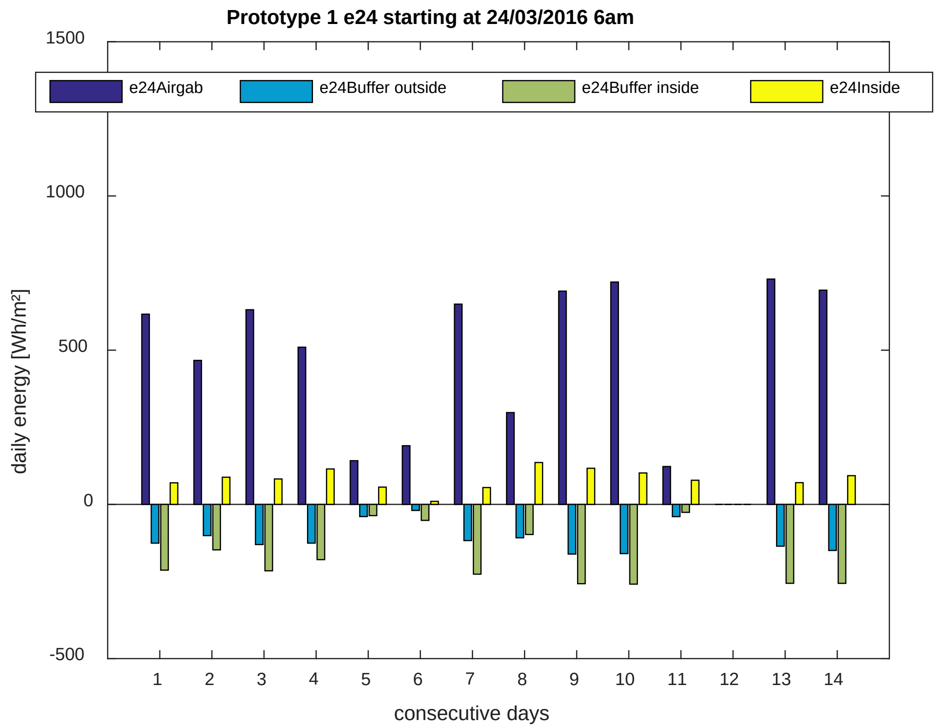

Figure 3 24h fluxes in different positions within the specimen for prototype 1

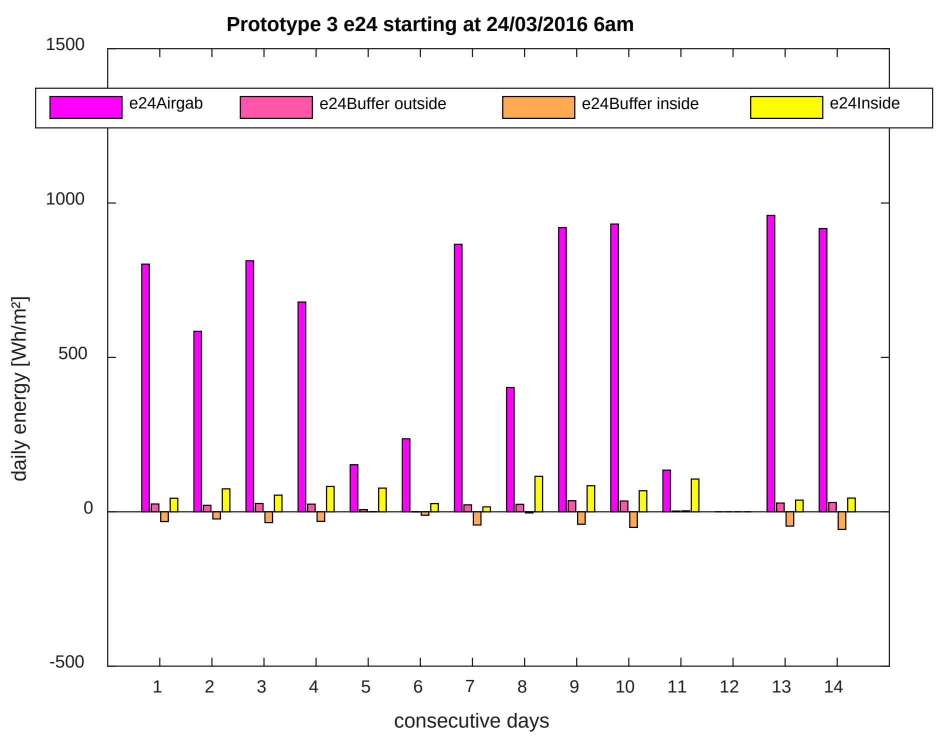

Figure 4 24h fluxes in different positions within the specimen for prototype 3

Figure 3 and Figure 4 show all cumulated fluxes for 24h within the specimen for different positions. The daily energy in the air gap is particularly high since the air gap is heated up by the sun behind the glass. Days with lower daily energy in the airgap (5, 6, 11) are caused by cloudy weather during daytime. For day 12 no data is available.

In this graph a qualitative indication of the trend of $e_{24,inside}$ for the studied period is given. It is interesting that $e_{24,inside}$ is positive (towards the room) for both prototypes for all days. $e_{24,inside}$. This could confirm the functioning of the heating effect of the system. The trend of $e_{24,inside}$ follows the change between presence or absence of sunny weather with about 1 to 2 days of delay. This shows the effect of the thermal mass or thermal storage of the wall. An eye-catching difference between the two prototypes are the significantly negative values of $e_{24\ buffer,inside}$ and $e_{24buffer,\ \ outside}$ of prototype 1, which could not be explained, yet.

4.3.2 Latent heat thermal energy storage efficiency

$$\mu_{Latent\ heat\ thermal\ energy\ storage} = \frac{\int_{6am}^{6am+1} \dot{Q}^{+}_{Buffer}\, dt}{\int_{6am}^{6am+1} \dot{Q}^{+}_{OLoop} dt}$$

The latent heat thermal energy storage efficiency indicates how much heat of the charged heat through the OLOOP is effectively stored during 24 hours.

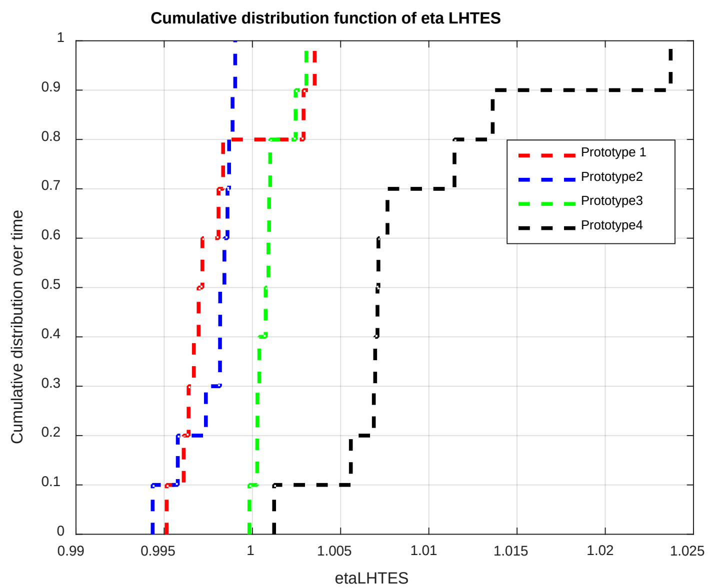

Figure 5 μ_{LHTES} as cumulativ distribution function

Figure 5 shows the cumulated distribution function of μ_{LHTES} for all prototypes. μ_{usable} is a measure about how much of the charged heat is lost by conduction through the insulation layers inside and outside.

X indicates μ_{LHTES} and F(x) the cumulative distribution function which is a frequency distribution over time of the indicator for a period of ten days starting from March 24, 2016. The figure shows that heat losses are negligible. Positive values mean that the buffer even has slight daily energy gains from inside and/or outside instead of losses.

4.3.3 Usable heat efficiency

$$\mu_{usable} = \frac{\int_{start\ discharge}^{end\ discharge} \dot{Q}_{ILOOP}^{-}\, dt}{\int_{6am}^{6am+1\ day} \dot{Q}_{Buffer}^{+} dt}$$

The usable heat efficiency indicates how much heat is discharged to the inside of the room compared to the charged heat inside the buffer during 24h. The discharge period is defined as the period when the ILOOP of the switchable insulation is open.

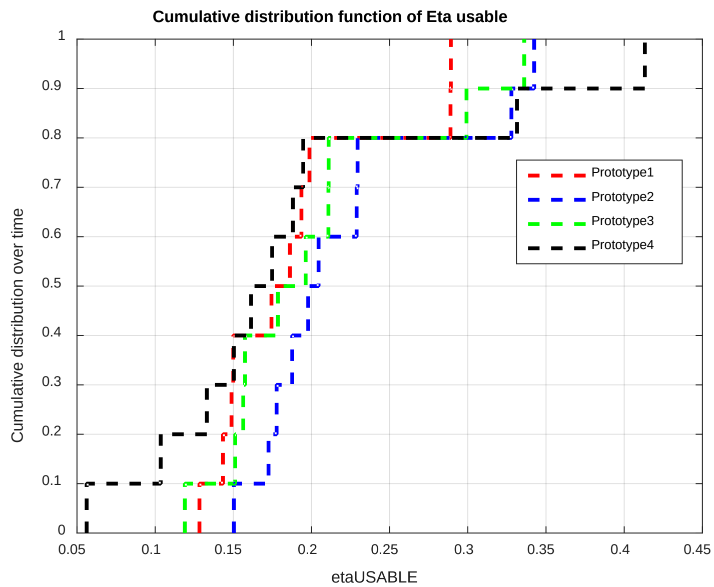

Figure 6 μ_{usable} as cumulativ distribution function

Figure 6 shows the cumulated distribution function of μ_{usable}. μ_{usable} expresses how much heat is made usable by transporting it into the room for single days. X indicates μ_{usable} and F(x) the cumulative distribution function which is a frequency distribution over time of the indicator for a period of ten days starting from March 24, 2016.

The values have a rather linear distribution and range usually between about 0.1 and 0.35 and don't show important differences between the prototypes. Solely protoype 4 shows a wider distribution with a higher number of lower values starting from almost 0 and some values that exceed 0.4.

4.3.4 Total system heat efficiency

$$\mu_{TOTAL} = \frac{\int_{6am}^{6am+1} \dot{Q}_{ILoop}^{-}\, dt}{\int_{6am}^{6am+1\ day} \dot{Q}_{OLOOP}^{+} dt}$$

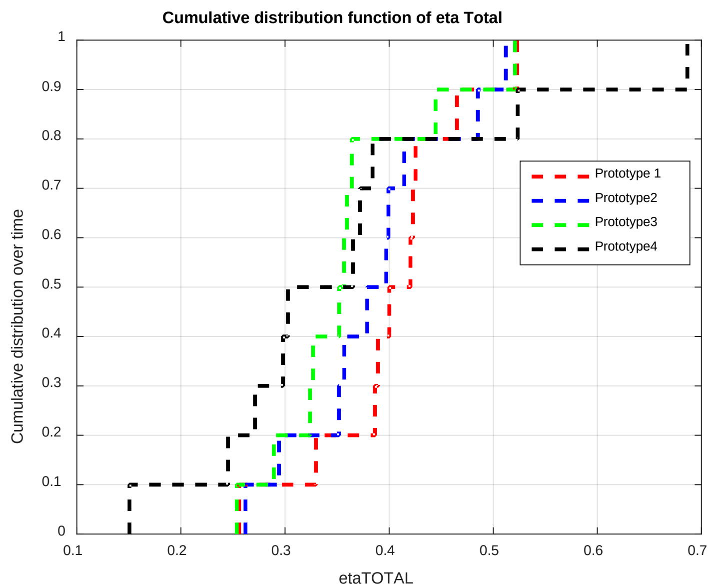

Figure 7 μ_{TOTAL} *as cumulativ distribution function*

Figure 7 shows the cumulated distribution function of μ_{TOTAL}. μ_{TOTAL} expresses the overall efficiency of the system. It is the ratio of the heat supplied to the room by the heat charged into the buffer. X indicates μ_{TOTAL} and F(x) the cumulative distribution function which is a frequency distribution over time of the indicator for a period of ten days starting from March 24, 2016.

Figure 4 shows a similar picture than Figure 3. However, the magnitude of the values is higher reaching 0.5 for the protoypes 1-3 and almost 0.7 for prototype 4.

Generally, the values of μ_{Usable} and μ_{TOTAL} are rather low, staying far away from 1. In the case of μ_{Usable} one reason could be that after the discharge period, as it was defined, the internal radiator is still warm and is further transmitting heat to the inside. Since losses by conduction proved to be very low, further investigations are needed to find out the reasons for the low efficiencies resulting from these preliminary results. Relevant aspect are probably the effect of long term accumulation of heat in the big thermal mass of the storage and of course the uncertainty of the mass flow in the inner and outer water loops.

4.4 Discussion and Conclusion

Experimental data was analyzed and performance indicators were defined and calculated. However, the work is not finished, yet. Some aspects that remain open:

- The calculated indicators are not able to show an improvement of the performance of the system due to the use of phase change material (prototype 3 and 4)
- One important difference to the ACTRESS façade is the massive construction and high thermal mass of Adaptiwall. E.g. for ACTRESS of main importance were the losses of the storage to a ventilated cavity and consecutively to the outside. As μ_{LHTES} shows the losses of the buffer of Adaptiwall are negligible. Further investigations are needed to verify the experimental data and to further adapt the indicators to Adaptiwall.

- A main source of uncertainty of the calculation is the fact that the ILOOP and OLOOP heat flows could only be estimated using temperature measurements. The full-scale prototypes will be equipped with a water flow measurements and provide data that is more reliable. Unfortunately, no experimental data of the full-scale tests was available, yet for technical experimental reasons. With the available data, only a comparison between the prototypes is reasonable to a certain extend

4.5 Bibliography

[1] F. Favoino, F. Goia, M. Perino and V. Serra, "Experimental analysis of the energy performance of an ACTive, RESponsive and Solar (ACTRESS) façade module," *Solar Energy,* vol. 133, pp. 226-248, 2016.