DYNASTEE

Foreword

DYNASTEE informs on dynamic methods for testing, simulation and analysis. So does this newsletter with research progress and results on data gathering and new testing and analysis methods for energy performance of buildings.

In conjunction with the 6th Expert meeting of IEA EBC Annex 71 in Bilbao, DYNASTEE organises a Symposium on 'The Building as the Cornerstone of our Future Energy Infrastructure' (10-11 April 2019). Results of that event will be available soon in an extra issue of this Newsletter, together with the full programmes of the Summer Schools 2019. Two training sessions at different levels will be organised in Denmark (one week in August) and in Granada Spain (two weeks in September). Number 13 will be available within a few weeks from now. Scale up your knowledge and skills in dynamic analysis of energy performance data!

Setup for wall surface temperature/U-value measurement using different types of infrared cameras

CONTENTS

DYNASTEE

Newsletter Editors

Hans Bloem, INIVE

Luk Vandaele, INIVE

Alex Marshall, Salford University

Using UAV-based RGB and thermography images to generate simulation input about envelope geometry and U-values

Philip Gorzalka, Dhruvkumar Patel, Jacob Estevam Schmiedt (Institute of Solar Research, German Aerospace Center (DLR), Jülich/Cologne, Germany)

Before energetic refurbishments are actually performed, performance simulations can deliver valuable insights about the status quo and about possible refurbishment options. However, collecting sufficient input data is often costly, time-consuming, and/or assumption-based. As a possible solution, various remote sensing tools are currently investigated and tested by German Aerospace Center (DLR) for their applicability on energetic building analysis [1]. Unmanned aerial vehicles (UAVs) can be used as a flexible sensor carrier that is able to quickly reach various positions around a building. In the presented project, UAVs have so far been used for mounting RGB, thermal infrared (IR), and hyperspectral cameras. RGB images are used for the digital geometrical reconstruction of the building envelope via photogrammetry as well as for feature recognition, whilst infrared thermography serves for determining U-values of the walls. Hyperspectral analyses reveal the material classes of the outer wall layer [4]. In DLR's approach, digital 3D reconstruction starts with creating a point cloud out of automatically or manually recorded single lens reflex camera images with commercially available software. Afterwards, semantically annotated surface polygons are reconstructed using an internally developed method and windows are recognized in façade textures generated from the initial images [2]. The use of thermography for U-value measurement from the outside is currently limited by several disturbing factors and significant uncertainties [5]. The current project objective is to reach a reasonable uncertainty value in minimal flight time. Measurements on test walls and on an overheated test building were performed in Winter 2018/2019 to investigate different influencing factors: a tent was placed around the test walls to obtain a more controlled environment; repeated images of the same scene were taken over the days to study the dynamics of the thermal radiation; different methods for calculating convection coefficients were compared; at the test building, various types of uncooled microbolometers like those carried by UAVs and many handheld IR cameras as well as a high-precision cooled camera were used to record images with the goal of analyzing varying measurement values; a black body with known temperature was placed in the scene for calibration purposes; different viewing angles and distances between camera and wall were covered. Evaluation will provide insights on the uncertainties connected with the various influencing factors and possibly improve the accuracy of quantitative external infrared thermography for U-value determination.

A wrap-up of the current state of the project was recently presented at the IEA-EBC Annex 71 expert meeting [3]. Further information on the project progress will be presented at Building Simulation 2019 conference, provided final acceptance of the respective contributions, and in future Annex 71 meetings. This includes not only optical sensor systems, but also microwave radar and ultrasound technology which are tested for application on wall structure and air tightness analysis, respectively.

References: [1]Estevam Schmiedt, J., Cerra, D., Dahlke, D. et al. (2017), 'Remote sensing techniques for building models and energy performance studies of buildings'; [2] Frommholz, D., Linkiewicz, M., Meissner, H. et al. (2017), 'Reconstructing Buildings with Discontinuities and Roof Overhangs from Oblique Aerial Imagery';[3] Gorzalka, P., Estevam Schmiedt, J., Dahlke, D. et al. (2018), 'Building Tomograph – From Remote Sensing Data of Existing Buildings to Building Energy Simulation Input'; [4] Jilge, M., Heiden, U., Habermeyer, M. et al. (2017), 'Detecting Unknown Artificial Urban Surface Materials Based on Spectral Dissimilarity Analysis', Sensors; [5]D., Estevam Schmiedt, J., Röger, M. et al. (2018), 'Approach for external measurements of the heat transfer coefficient (U-value) of building envelope components using UAV based infrared thermography'

Estimating occupancy heat gains from CO_2 measurements

T.J.H. Rovers, C. Struck (Saxion University of Applied Sciences, School of Business, Building & Technology, Chair of Sustainable Building Technology & Material)

Besides the direct heating system, solar heat gains and internal gains from appliances, heat gains from occupants are an important source contributing to space heating in domestic buildings. It is necessary to consciously consider all of these heat gains when aiming at accurately estimating the heat loss coefficient (HLC) of a building. Whilst sensor technology and algorithms are available to quantify the contribution of the heating system, solar gains and electrical appliances, the accurate estimation of the sensible heat gain from occupants is challenging due to its stochastic character.

Research of e.g. Calì, Matthes, Huchtemann, Streblow, & Müller (2015) and Szczurek, Maciejewska, & Pietrucha (2017), suggests that occupant presence can be successfully derived from time series of dry bulb temperature, relative humidity and CO2 concentration. Given the availability of data, we propose a three-step process to determine metabolic heat gains: (1) Detecting CO2 emissions, (2) estimating the number of present occupants and (3) determining the metabolic heat gains.

Step 1 makes use of the assumption that the CO2 emission by people is larger than its reduction due to ventilation and infiltration. Based on that assumption, CO2 emission can be related to occupancy when the measured CO2 concentration has a positive gradient. For example, Figure 1 shows measurements of the CO2 concentration in the lounge of a case object (an end-terrace dwelling in Gainsborough, UK) for one winter day.

Step 2 relates the human respiration rate to the number of people present. In case of the example, the number of occupants is estimated using standardized CO2 respiration rates: for 'low activity', the CO2 respiration is 0.02 m3 h-1 per person (The Engineering Toolbox, 2018). Using the ideal gas law, this may be converted to 13.8 mg min-1. Figure 2 shows the CO2 concentration and gradient for the demarcated period in Figure 1. From the data, it can be concluded that three people had been present between 7:50 and 8:20 a.m.

$$\frac{\Delta CO_2 \, [mg]}{t \, [min]} = \frac{1423}{30} = 47 \; mg \; min^{-1}$$

$$\frac{47 \, [mg \; min^{-1}]}{13.8 \, [mg \; min^{-1}]} \approx 3 \; persons$$

In step 3, derived occupancy profiles can be enriched with standardized data for metabolic heat rate (ISO 8996, 2004), i.e. the number of occupants is multiplied with a metabolic heat production of 115 W ('low activity'). See Figure 3. A total metabolic heat production in the lounge of 0.84 kWh is found for this day. Although the pragmatic three-step approach does provide realistic results in case of the presented example, it is linked to a number of uncertainties which could lead to inaccurate results. For example, the operation of the ventilation system (including the opening of windows) and the presence of secondary sources for CO2 emissions, such as cooking or the presence of pets.

References:

Calì, D., Matthes, P., Huchtemann, K., Streblow, R., & Müller, D. (2015). CO_2 based occupancy detection algorithm: Experimental analysis and validation for office and residential buildings. Building and Environment, 86, 39–49. https://doi.org/10.1016/j.buildenv.2014.12.011

ISO. (2004). ISO 8996: Ergonomics of the thermal environment - Determination of metabolic rate.

Szczurek, A., Maciejewska, M., & Pietrucha, T. (2017). Occupancy determination based on time series of CO_2 concentration, temperature and relative humidity. Energy and Buildings, 147, 142–154. https://doi.org/10.1016/j.enbuild.2017.04.080

The Engineering Toolbox. (2018). Carbon Dioxide Emission from People. Retrieved October 3, 2018, from https://www.engineeringtoolbox.com/co2-persons-d_691.html
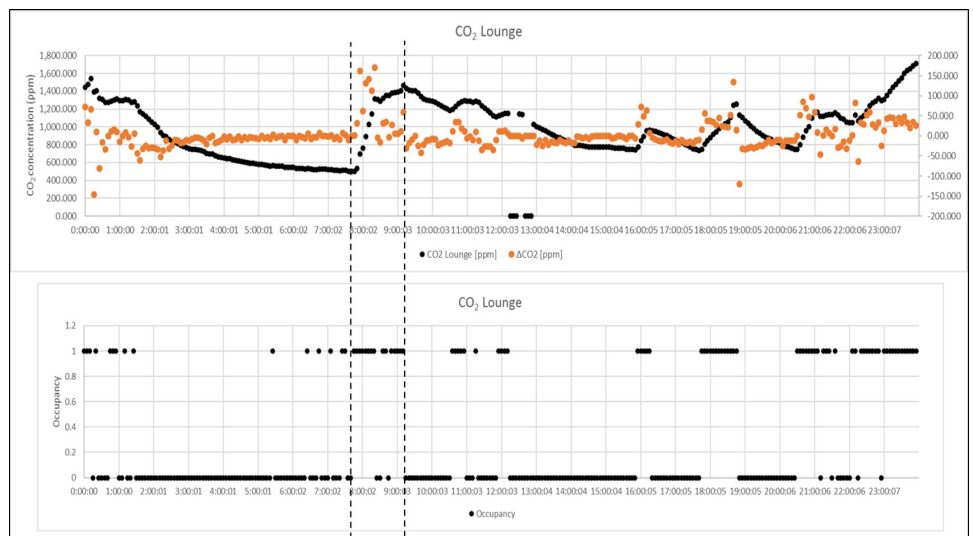
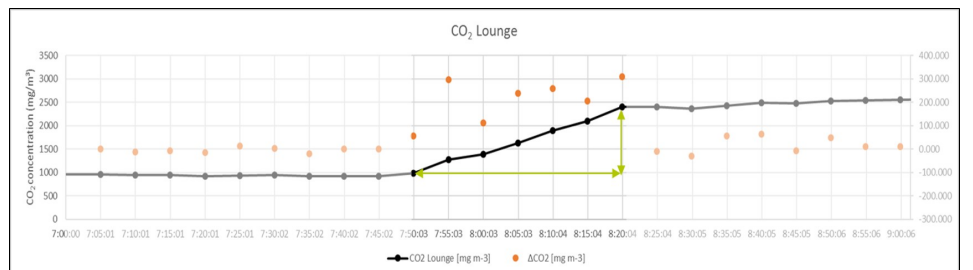*Figure 1: CO2 concentration, gradient and occupancy*

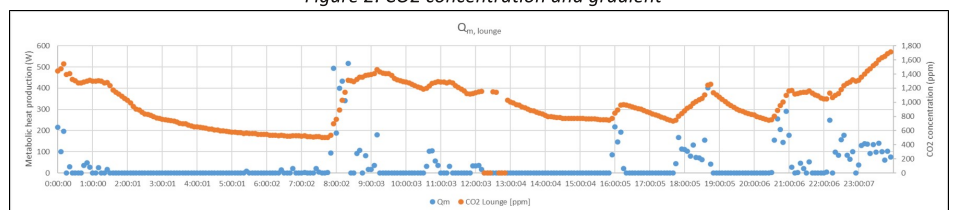*Figure 2: CO2 concentration and gradient*

Figure 3: Metabolic heat production

Pulse Regulation: The Journey Towards Introducing a New Testing Method into the UK Building Regulations

Pulse is a newly available technology to measure the air permeability of buildings at ambient pressure levels. This article describes a series of activities which were undertaken in 2018 to test the repeatability and accuracy of Pulse with the aim of inclusion in the UK's Building Regulations, these included:

• Application of the EU's Environmental Technology Verification program by the UK's Building Research Establishment (BRE)

• A field trial in over 100 homes demonstrating a high level of repeatability and accuracy

• Positive independent assessment by industry experts and the UK's National Physics Laboratory (NPL).

Pulse was invented and developed at the University of Nottingham through UK Government Research Council funding for fundamental research.

Pulse is a compressed air-based system which is used to release a measured amount of air from an air receiver into a building. This generates a flow rate through the gaps and cracks in the building façade. The change of internal pressure of the building due to this flow is seen as a pulse and its representation is characteristic of the building's leakage at low pressure. The Pulse system cites air leakage directly at 4Pa, eliminating the need for unreliable extrapolation required if seeking to use 50Pa blower door test results in energy models.

Build Test Solutions (BTS) is a UK based company that exists to transition new testing and measurement technologies from academia to the market place in the built environment sector, through product development, demonstration and market making. In addition to Pulse, BTS are working on products that measure whole house heat loss and elemental U-values in a less invasive and expensive way than currently available.

The strategy adopted for gaining regulatory acceptance of the Pulse method has been grass-roots based. Confidence in the method has been built up through extensive comparative testing across numerous property types in a wide range of different conditions with a wide range of different stakeholders involved throughout the process. As described, BTS followed a multi-faceted approach including a major field trial carried out by BTS and the University of Nottingham, but also several different third-party assessments methods to provide impartial guidance and verification.

The field trial was carried out in 108 homes, which provided a representative sample of the UK housing stock. A total of six Pulse tests were carried out in each home, which showed an average repeatability of better than 5%. Comparisons were also carried out with the blower door test in all 108 homes, and tracer gas testing in 24 homes. The comparison showed a close correlation between the results of Pulse and blower door tests (r2 of 0.9 across all homes, and 93% of all measurements falling within a 95% confidence interval of a simple linear regression between the two sets of measurements). The comparison between the Pulse, blower door and the tracer gas testing showed less clear relationships, with much more variation between the results of the tests. This shows the difficulties inherent in tracer gas testing, with its greater dependence on external weather conditions. One interesting observation was that on average the airtightness as measured by tracer gas testing was 44 times lower than that measured by the blower door test, and the minimum difference was 30 times lower. This is markedly different to the 1/20 conversion factor often used between airtightness at 50Pa and ambient pressure difference.

Recognising the significant time and costs associated with producing a completely new International Standard test method, the EU's Environmental Technology Verification (ETV) is a new tool designed to help innovative environmental technologies reach the market. It provides a standardised process for performance claims to be verified as credible and scientifically sound by qualified third parties. In the case of Pulse this was the BRE and the ETV verification included observed testing in homes, laboratory testing and a review of testing procedures. Pulse was formally granted the ETV in December 2018.

In addition to the ETV, BTS commissioned NPL to carry out a review of the fundamental physics which underpins Pulse. These strands come together to form an evidence base to support the inclusion of Pulse in Building Regulations, reaching from the fundamental physics, through laboratory testing in a controlled environment, and finally to widespread application in the field. As a final step, BTS commissioned an independent review of the whole evidence base by Cambridge Architectural Research Ltd to consider the suitability of inclusion of Pulse testing within Building Regulations and make recommendations to the UK Government.

The evidence base and independent review were submitted to the Government in December 2018, and will now be reviewed with a view to possible inclusion in a revision of the Building Regulations scheduled to come into force in late 2020. Hopefully it's clear from the description that gathering this sort of evidence is a complex and time-consuming process, with a rather long and uncertain lead time before eventual inclusion within established standards and regulations. To date, regulatory pressure has proved by far the most effective driver for mass uptake of a testing method though, so the justification for carrying out the process is clear.

The process of gathering the evidence has also been fantastic for the ongoing product development and refinement that BTS are carrying out. Qualitative data has been collected from users in addition to the quantitative data, which is being used to make the product more robust and user friendly which will be key in making Pulse attractive to future users.

Pulse is available to buy now, and is already in use with early adopters in the UK, the rest of Europe and further afield in Asia and Australia. The evidence base generated for inclusion in the UK's Building Regulations is not specific to the UK, and Build Test Solutions would be delighted to work with other authorities to facilitate inclusion in their regulations. To find out more visit buildtestsolutions.com, or get in touch via email or Twitter, enquiries@buildtestsolutions.com and @BuildTestUK.

Data-Driven Retrofit

A research team at the Chair of Architecture and Building Systems at ETH Zurich is working on a Data-Driven Retrofit (DDR) project. The aim of this project is to accurately predict cost-optimal retrofit strategies for buildings by using in-situ measurement data. The data is gathered using a wireless sensor network (WSN), designed and developed at the Chair. The WSN, as seen in Figure 1 is an open-source, modular design that is easy to deploy without much expertise*. It is capable of measuring indoor and outdoor air temperature, relative humidity, supply and return temperature of hot water from the heating system, heat flux through wall and window, luminosity, oil flow, electricity, window opening times and CO_2-concentration. In collaboration with the Office of Water and Energy, Canton St. Gallen, the WSN has been deployed in ten single-family houses in St. Gallen, Switzerland. The time series data is recorded at an interval of 5-minute and streamed to an online database. The gathered data is used to train and develop prediction models using two data-driven techniques. These are the Resistance-Capacitance (RC) models and machine learning models. The research team have also consolidated a retrofit matrix comprising of all popular retrofit measures. This matrix includes the investment cost of the element, workmanship cost as well as maintenance and disposal cost. In the course of the project, the trained models will analyze each of the retrofit strategies and their combinations to predict their impact on final energy consumption, cost-optimality and CO_2 emissions.

The gathered data is also used to infer interesting traits in the building operation using clustering and rule-mining. We study the influence of outdoor weather, occupant-induced changes and heating systems on the prevailing indoor air temperature. This juxtaposes well with the IEA Annex-71 objective that states to 'disaggregate the building energy use to its three main sources: building fabric, systems and users.' The research team has also developed an automated load disaggregation methodology for residences with electrical resistance heating. This process can instantly provide energy consumed by the electrical heating system for space as well as domestic hot water heating. So far, the WSN has been well received by occupants and has generated equal interest in the industry. The measurement campaigns have provided crucial experience to the research team with respect to WSN installations and analytical methods.

The Chair is headed by Prof. Dr. Arno Schlueter. The researchers involved in this project include Dr. Chirag Deb, who works on data analysis and machine learning; Mario Frei, who has developed the WSN and is working on his PhD with RC models; And also student researchers, Diego Sigrist and Zhonghao Dai who are working on their Master thesis in line with this project.

This project is also part of the Swiss Competence Center for Energy Research – Future Energy Efficient Buildings and Districts (SCCER-FEEB&D) and aims to accelerate the energy efficiency in the Swiss building sector as proclaimed in the Swiss Energy Strategy 2050.

For more information on the project, please contact Chirag Deb: deb@arch.ethz.ch

* github.com/architecture-building-systems/Wireless-Sensor-Network

Ψ Deb C, Frei M, Hofer J, Schlueter A. Automated load disaggregation for residences with electrical resistance heating. Energy and Buildings (2019) 182:61-74.
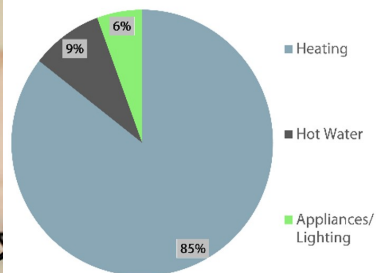

Figure 1 a. Wireless Sensor Network developed at the Chair of Architecture and Building Systems, ETH Zurich; b. Results for load disaggregation for a residence with electrical resistance heating^Ψ

ABOUT DYNASTEE

DYNASTEE stands for: "DYNamic Analysis, Simulation and Testing applied to the Energy and Environmental performance of buildings". DYNASTEE is a platform for exchange of knowledge and information on the application of tools and methodologies for the assessment of the energy performance of buildings. DYNASTEE functions under the auspices of the INIVE EEIG and it is open to all researchers, industrial developers and designers, involved in these items. The EU energy research projects PASSYS (1985-1992) COMPASS and PASLINK created the initial European network of outdoor test facilities, developed test methods, analysis methodologies and simulation techniques. It resulted eventually into the PASLINK EEIG network (1994). The grouping profiled itself as a scientific community of experts on Testing, Analysis and Modelling. In 1998, PASLINK EEIG started a new project PV-HYBRID-PAS on the overall performance assessment of photovoltaic technologies integrated in the building envelope. The use of the outdoor test facilities in several Member States situated in different climates, together with the available expertise on analysis and simulation techniques, offered the ingredients for more successful projects: IQ-TEST (2001), focussing on quality assurance in testing andanalysis under outdoor test conditions as well as evaluation techniques of collected in-situ data. The expertise of the grouping was also offered to other European projects, such as DAME-BC, ROOFSOL, PRESCRIPT, IMPACT and PV-ROOF. In 2005 the EEIG was converted into an informal network that today is known as DYNASTEE. It is offering a network of excellence and should be considered as an open platform for sharing knowledge with industry, decision makers and researchers. It has been very active in supporting projects such as the IEA-EBC Annex 58 and recently the new project IEA-EBC Annex 71 'Building energy performance assessment based on in-situ measurements'.