Building Simulation 2017: "Determination of heat flux coefficient inquiry methods for city district simulation"

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Abstract

This paper deals with work within the RWTH Aachen University "EnEff: Campus - RoadMap RWTH Aachen" (EnEff:Campus) project aiming at developing a systematic road map towards a cost-effective reduction of the primary energy consumption of the complete campus. The project follows a systematic approach for deriving low-order dynamic building and distribution network energy performance models from a geo-information data base. Since the thermal transmittance of the buildings' enveloping surfaces is barely known, various methods for U-value determinations are applied and refined due to insufficiencies of current approaches. One developed approach builds on the fact that the surface appearance of a building allows conclusions about the U-value. Another one works with heat flux sensors and derives physical quantities of a wall from temperature gradients. The goal of this paper is to combine these methods for enabling a more precise determination of heat transfer coefficients.

Introduction

Thermal building performance simulation, especially with a low-order approach, requires, inter alia, information about the envelope surface construction, such as U-values or heat capacities. Up to now, there are basically two ways of determining the U-value, either by calculation based on the known or assessed wall construction, or by measurements of heat fluxes and temperatures.

With regard to the calculation method, it is necessary to know the thickness of each layer of the construction as well as their thermal conductivities. However, especially in case of historical buildings, the required data are scarce or distorted by non-documented reconstruction measures. Hence, the identification of the wall construction requires expensive or destructive examinations. To avoid time-consuming estimations for assessing wall constructions, a statistical approach was developed by the IWU Institute (Loga et al. 2005). This approach allows for the determination of U-values of residential buildings (Loga et al. 2005) and is applied in the tool TEASER (Tool for Energy Analysis and Simulation for Efficient Retrofit), which is an open source Python-based software, developed by the Institute for Energy Efficient Buildings and Indoor Climate of the RWTH Aachen University (TEASER 2016). It uses the IWU approach to determine wall construction parameters, such as heat conduction or specific heat capacity of layers for estimating parameters to implement them into low order performance building models.

While applying this approach for non-residential buildings, high inaccuracies may occur. To reduce this deviation, an update of the model was developed in the EnEff:Campus project. For the rest of this paper, the model is called "Photo-documented approach (pda-method)". It offers the opportunity to characterize the envelope surface and type of facade construction, based on a picture taken from a street view perspective. The first version of the pda provides average U-values of the whole facade (merging outer wall and window U-values). In further investigations, the pda-method will be updated to recommend specific heat capacity or rather parameters for a lumped parameter building performance model. Therefore, a new low cost building physics measuring method (HBM-method) is developed and integrated into the enrichment and evaluation of the statistical approach of the pda-method. In the future, the combination of methods can be used to determine well-established wall types with their initial heat-flux signature.

Common methods for the determination of wall construction are mostly offering estimates of the heat resistance but not of the heat capacity. While the influence of the heat capacity in case of annual or static simulations is negligible, the heat capacity can have a great impact on the cooling load calculation during dynamic simulations. Especially when the heat-capacity is under-estimated this leads to over-dimension of cooling devices. Valid information about effective heat-capacities can therefore help to produce tailored solutions for cooling and heating. Furthermore, detailed day-to-day observations of individual buildings, for example regarding the expected room temperatures, can be performed.

At present, there is no measurement method which can determine both physical parameters in an acceptable time or with appropriate accuracy. This difficulty is resolved using the HBM-Method.

Methodology

Often, there is no information about the wall construction available. Therefore, the IWU Institute developed a statistical approach (Loga et al. 2005) which will be described in this paper. Furthermore, an update to the approach will be presented.

IWU method: General U-value method

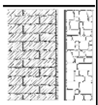
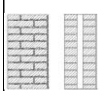
The "Institut Wohnen und Umwelt GmbH (IWU)" developed a method to assess the U-value of envelope surfaces, especially to quantify the quality of the thermal

https://doi.org/10.26868/25222708.2017.310

characteristics of facade elements. The input data is the year of construction and the building type, as illustrated in table 1. To avoid damaging the wall for estimating the construction information, this approach minimizes the necessary input data for an adequate U-value approximation. It builds on the fact that all buildings are constructed in a certain period of time and, thus, also have similar U-values pertaining to a certain range. As one might expect, heat transmission coefficients from one hundred years ago are significantly worse than those from today. Due to extensive examinations, averaged values for whole decades were determined, which should only be considered as recommended values.

This method provides several tables with U-values for different building components. Table 1 illustrates two examples.

Table 1: Two examples out of the table "Pauschal-U-Werte für Außenwände im Bestand" given in the "general U-value method" by the IWU Institute (Loga 2005)

	Original state				
	Year of cons-truc-tion	**Construction Style monocoque construction and double skin facade**			**General U-value [W/m^2K]**
Outer walls	**until 1918**	ma-sonry	brick or quarry wall (thickness 40 cm)		2.2
		timber frame	timber framing with loam		2.0
	until 1948	ma-sonry	brick wall 25 - 38 cm		1.7
		ma-sonry better quality	monocoque or double skin 38– 51 cm		1.4

These values are statistically determined and apply to residential buildings. Each table treats another component such as outer walls, windows, ceilings, ground floors or roofs.

Coefficients for opaque components are subdivided into the year of construction. Furthermore, each period provides at least two different U-values belonging to typical building categories from these times. In order to simplify the classification, each building category is briefly described and pictured in a rough sketch. Since a categorization is not always possible and the year of construction is the only known information, the most common U-value from each period of time is written in bold print.

However, coefficients for windows are not based on the year of construction. They are sorted according to the number of panes (ranging from one to three) and according to the frame material. Thus, nine different coefficients for windows can be chosen (see Loga et al., 2005, chapter 8).

In the course of the EnEff:Campus - RoadMap project, the accuracy of the IWU-method: "General U-Value" was analysed by applying the "Tool for Energy Analysis and Simulation for Efficient Retrofit" (TEASER 2016) for selected buildings. This tool utilizes the method mentioned above and provides a graphical user interface to enter the relevant information.

As mentioned above, this IWU approach is developed for residential buildings. It has to be evaluated if this method can be applied to estimate U-values for non-residential buildings. Therefore, the approximated U-values of ten representative buildings were compared to the actual values (determined by estimating the wall construction). The analysis resulted in an average deviation of 72 % for walls and 58 % for windows concerning the actual heat transfer coefficient, while the U-values were mostly overestimated by TEASER. In this examination, only outer walls and windows were considered, while ceilings, floors and roofs were neglected. The main reason for this huge deviation emerges from the fact that TEASER initially assumes U-values for a solid construction in each age group if no further information is given and the material properties are not changed manually.

Photo-documented approach

While the IWU-method focuses on the building's year of construction and two possibilities of wall structures types for the U-Value, visual features of the real facade are ignored. Hence, already implemented restructuring measures during the life cycle may have no influence on the selected U-value as the wall structure is only chosen based on the year of construction. Even though the method also provides U-values for reconstructed building parts, only state of the art measures are listed. For this reason, another method for U-value determination is required, based on photo documentations of the buildings. Thus, this new approach represents an update or extension of the IWU-method. The main application is the evaluation of the construction type, which leads to a better estimation of the facade U-Value contrary to the IWU-Approach.

By analysing the whole campus, an update is currently developed within the Aachen EnEff:Campus project, including over 300 buildings such as auditoria, laboratories, offices, testing halls and others.

Therefore, the actual heat transfer coefficients of all buildings are determined. However, many buildings of the campus are historical buildings and, there is little information about specific construction-styles and materials; thus, their U-values are largely unobtainable.

Hence, most of the coefficients are approximated after on-site inspections, e.g. by closer examination of imperfections and structural damages. Consequently, these approximations cannot perfectly comply with the actual U-values and, thus, should be treated with certain reservation.

For evaluating this approach, the collected data is divided into two quantities for creating a test set and a trial set to evaluate the proposed method.

For creating the model, buildings are assigned to a facade type by visual inspection of the front side. In fact, this step is rather subjective, since the method differs between insulated and not insulated outer walls, which are (if impossible to estimate) chosen by signs of aging. However, each person may assess the building's age differently and apart from that, the actual age of a building does not constantly emerge from its appearance, due to renovation measures.

In the last step, an average U-value for each wall type of half of the building stock is calculated. This list of heat transfer coefficients can be transferred on other buildings (here the other half of the building stock), by, in turn, assigning the observed buildings to a wall type. Table 2 shows 15 groups of assessed wall structure categories.

Table 2: Facade categories of the pda-method regarding to the RWTH Aachen University building (build before 1994).

Group number	Specific construction style	number of stories
1	Brick masonry	1
2	Brick masonry	>1
3	Lightweight construction with thermal insulation	-
4	Lightweight construction without thermal insulation	-
5	Limestone	-
6	Concrete with thermal insulation	-
7	Concrete without thermal insulation	1-4 or halls
8	Concrete without thermal insulation	>4
9	Plaster with thermal insulation	-
10	Plater without thermal insulation	-
11	Banner facade with thermal insulation	-
12	Banner facade without thermal insulation	-
13	Curtain facade with thermal insulation	-
14	Curtain facade without thermal insulation	-
15	Sandwich elements	-

Figure 1 describes the process for estimating the U-value of a wall with regard to a front facade picture. The first steps are to choose and specify a construction type. Next, possible thermal insulations and number of stories (which affects the wall thickness and, thus, the U-value and heat capacity) have to be chosen.

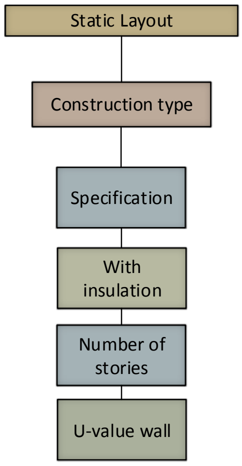


Figure 1: Five necessary steps to estimate the U-value of walls or windows by the pda.

Figure 2 illustrates an extract of the model by an example. If the static layout is a load-carrying construction, like a masonry brick wall and the building has more than one story, the wall construction enhances the U-value to 1.6 W/(m²·K).

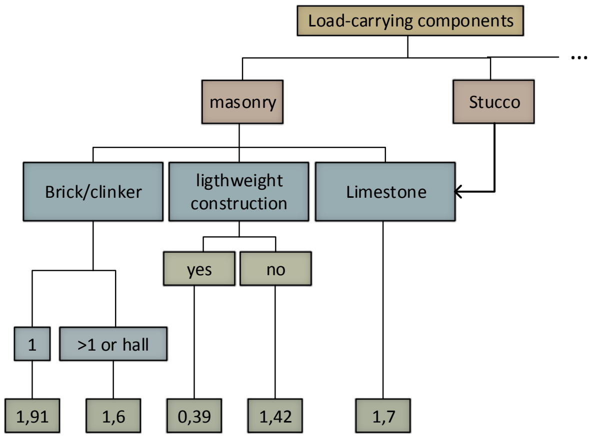


Figure 2: An extract of the process structure of the photo document approach to estimate the U-value of walls or windows, as an example of a masonry.

If this method is applied, errors will occur and have to be taken in account. Therefore, it has to be mentioned that this approach is more suitable for building groups where the deviations between actual and assumed heat transfer coefficients or capacities may cancel each other out. If the pda-method is applied to single buildings, it is necessary to determine the possible deviation, which will be elaborated in the next paragraph.

Heat-flux-balance Method (HBM-Method)

It is desirable to gain accurate information through direct measurements in the building itself. The thermal transmittance can be determined by measuring at least three temperatures around the structure, including the internal and external air temperatures and either the internal or external surface temperature. As the heat transfer resistances between air and surfaces are assumed to be constant,

$$R_{si} = 0.13\ m^2K/W;\ R_{se} = 0.04\ m^2K/W$$

the U-value of the regarded structure can be calculated by allocation of three resistances. This approach allows to correct distorted data generated by undocumented reconstruction measures. Furthermore, it offers the possibility to gain data in case of a complete lack of information. The greatest problem using this approach is to achieve a steady state equilibrium, because the external temperature constantly changes (Desogus, G., Mura, S. and Ricciu, R. 2011).

Testcase

In order to compare the accuracy of the Pda-method with the precision of the IWU-method, a testcase is performed. To ensure the comparability between the different approaches, a representative selection of buildings from the RWTH stock has to be chosen. This is achieved by neglecting all buildings having the following characteristics:

- Used for the creation of the Pda-method
- Unknown year of construction
- Buildings, build or refurbished after 1994
- Retrofit measures are known.

With respect to these constraints, 36 buildings remain for this investigation. An extract of these buildings with corresponding U-values of walls is listed in table 3. These U-values were calculated from information about construction type and wall thickness derived by on-site visits.

Table 3: Facade U-values of RWTH Aachen University buildings (build before 1994) calculated by on-site visit.

Building name	Year of construction	U-value of the wall [W/(m²K)]
Building_001	1874	1.44
...		
Building_023	1976	1.76
Building_024	1976	1.76
Building_025	1977	1.97
Building_026	1977	2.58
…	…	…
Building_036	1994	0.43

For all these listed buildings, the facades are photo documented, so that the pda-method could be tested using these pictures.

Results

Table 4 illustrates the results of the outer wall U-value estimation with pda-method and the IWU-method. The results are compared to the calculated U-values by data acquisition.

Table 4: Comparison of facade U-value estimated with the pda-method and IWU-method and their derivation concerning to the (calculated) U-value of the wall.

Building name	U-value pda-method [W/(m²K)]	U-value IWU-method [W/(m²K)]	deviation of the pda-method	deviation of the IWU-method
Building _001	1.54	2.2	7%	53%
...	1.48	1.7	16%	3%
Building _023	1.98	1	12%	43%
Building _024	1.98	1	12%	43%
Building _025	1.54	1	22%	49%
Building _026	2.86	1	11%	61%
…	…	…	…	…
Building _036	0.38	0.6	12%	40%

Table 4 shows among others the percentage deviation of the approximated U-values compared to the actual ones. As one can see, the photo documented approach delivers better results than the IWU approaches. The average deviations of all 36 buildings amounts to 30.3 % for the pda-method and to 47.5 % for the IWU-method.

Heat-flux-balance Method (HBM-Method)

In order to enhance the accuracy of the U-value determination, attempts are made to gain information through temperature measurement. Due to the dynamic behaviour of the walls, the heat capacity may not be neglected as in the approximation approach described before.

Heat resistance and capacity are the two characteristic parameters for the thermal-energetic consideration of building shells. To determine these values for a monolithic and layered construction, material parameters and thickness of each compound are needed. Unfortunately, this information is often hard to obtain. Additionally, for most low-order building models, the information of a U-value and a C-value are sufficient.
In simplified simulations for example, the wall construction is often approximated by so-called RC-elements. The R-components are functioning as (thermal) resistances while the C-components are acting as capacitances. In the simplest case, an equivalent wall structure consists of one RC-element, hence, one R-component and one C-component. In addition, there exist

also multilayer constructions, which consist of several RC-elements. Therefore, the physical material parameters of the wall construction are split in components. Thus, a simplified representation of the thermal properties results in terms of an electrical replacement system.

The thermal storage capacity as well as density are temperature-dependent, although, in the presented context of building physics, these values are being regarded as constant in the temperature spectrum of -20 to 40°C (ISO 6946). To measure these two variables in building components, a temperature difference on opposite surfaces is required and the resulting temperature ratio must be non-stationary.

Building walls as exterior components are subject to the daily temperature fluctuations as the interior temperature is relatively constant, whereas the outside temperature usually varies greatly between noon and midnight. If the interior temperature is higher than the average outside temperature, a heat flow from the building interior flows outwards. However, the charge and discharge cycles induced by the day-to-day fluctuations superimpose current heat flows.

Short measuring intervals, however, lead to a falsification of the U-value measurement based on surface temperatures. If the observation period is chosen large enough, the charging and discharging components add up to zero and it is possible to deduce the correct U-value by averaging.

The charging and discharging cycles of building walls are very large and can therefore only be measured over a longer period of time. Particularly in the case of a high-density component, the day-cycle-based fluctuations become superimposed and, thus, the required measuring time is further increased. A measurement method which enables a determination of large heavy components regarding U-value and storage mass in an acceptable time would be desirable.

In the described electrical replacement system of the low-order models, references from electrical engineering are used for the thermal parameters. The amount of heat corresponds to the electrical charge and the voltage corresponds to the thermal potential, i.e. to the temperature difference.

A heat flux always results from a temperature difference between two layers. This can either be calculated with the aid of the storage capacity, the U-value and the temperatures, or it can be directly measured with heat flux sensors. Since the physical parameters should be determined, the latter is used below.

$$Q_i = (T_1 - T_2) * U_j$$

Heat flux sensors are used to determine the heat flux flowing through them, with the help of thermo-electric components which consist of p- and n-doped semiconductor elements made of silicon and germanium. These heat flux sensors are glued to both sides of the wall surface and are thermally coupled to the component.

This enables a direct measurement of the energy input into the wall as well as the energy released from the wall. In order to reduce the cost of such measurement-devices, open-source and open-hardware standards are applied (Raspberry Pi). A calorimetric measurement of the wall can now be performed. For this purpose, the differences of the heat fluxes (in- and output of the wall) are computed and integrated over time.

$$Q_{Charge} = Q_{warm} - Q_{cold}$$

$$\frac{\dot{Q}}{\Delta T_m} = C$$

Currently, this is approximated by summing up the mean values between two time steps. The amount of energy calculated is standardised to watt-hours and describes the energy stored in the wall.

As shown, this amount of energy is depending on the feed-in-time and the amount of driving potential difference. In addition, the storage process is slow compared to the change in temperature and requires a characteristic time for a full loading. At the beginning of a potential rise, the charge occurs faster and decreases continuously in intensity until the end of the charging process. Thus, the storage charging can be represented by an electrical replacement system of RC-elements as well. The charging curve has a logarithmic behaviour, like a capacitor charge and can never be considered as complete. Therefore, in case of a thermal system, a special focus must also be laid on the definition of the charging period.

For this purpose, the description of the time constant τ is utilized. One τ is defined as the state when 66.3% of the charging process is completed. In the logarithmic context, one can additionally conclude that 5 τ corresponds to a charge of 99.7% of the total storage volume. In this case, the completion of charging is defined as 5 τ （Liebscher & Held 1968).

Measurements:

In order to obtain measurement data to verify the relation between heat-flux-balances, heat-storage-capacity and u-values, the thermal model house is used (Jänicke 2011). As shown in figure 3 and figure 4 the model-house is basically a wooden box, which is insulated and can be split into two chambers using an exchangeable wall section.

Figure 3: Thermal-Model-House

These two chambers can either be heated or cooled by means of electric coils and electric chillers in the chambers.

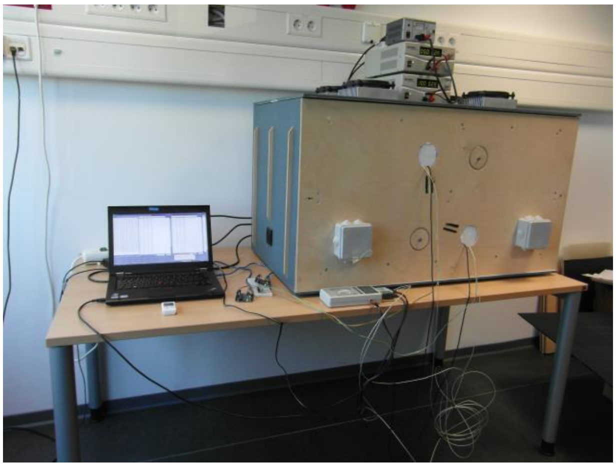


Figure 4: Thermal-Model-House and measurement equipment

It is possible to bring the chambers to different temperature levels and measure temperatures and heat-fluxes inside the model-house. Furthermore, dynamic tests can be carried out, by changing the power-settings of the coils. Because of removable intermediate and outer walls, different partition wall types can be inserted between the chambers. Thus, the thermal properties of various wall structures can be investigated in detail.

An intermediate wall with a variable layer construction was prepared for an easier assembly of the measuring equipment. A carrier plate and up to four plates of an insulating material are clamped between two laminated boards of 9 mm thickness. This allows a variation of properties of the wall in a wide spectrum, and the measurement equipment can be firmly attached to the outer panels.

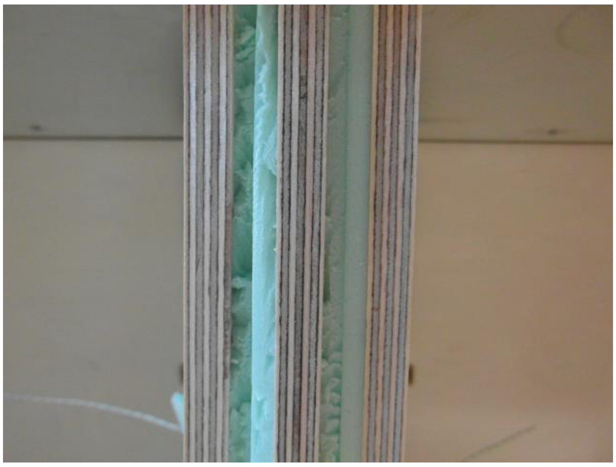


Figure 4: flexible Wall-section

Table 5: Wall construction from material parameters

Layer:	Material:	Thickness [m]:	Density [kg/m³]:	spec. Cap. [Wh/m³]:	Lamba [W/mK]:	R-Value [(m²*K)/W]
1	Multiplex	0,009	600	0,5	0,15	0,06
2	Insulation	0,01	35	0,4	0,04	0,286
3	Multiplex	0,009	600	0,5	0,15	0,06
4	Insulation	0,01	35	0,4	0,04	0,286
5	Multiplex	0,009	600	0,5	0,15	0,06
A	Rsi					0,13
B	Rse					0,13
	U-Value [W/m²K]:					0,974
	C [Wh]:					7,52

The material properties of the wall-section used in this survey are outlined in table 5. In the folloeing test, a wallsection with these properties is used to determine the C-value in patricular with means of heat-flux differentials.

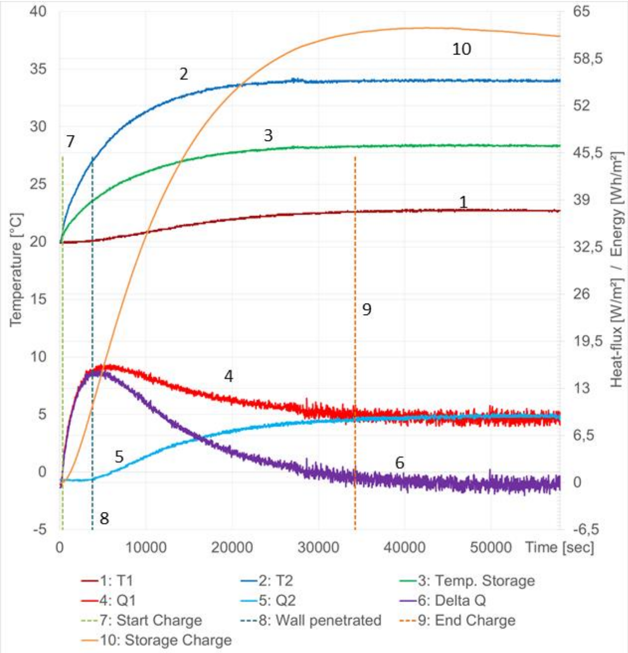


Figure 6: one-sided heating from room-temperature

Figure 6 shows temperature and heat-fluxes obtained from an experiment with one chamber beeing heated while the other one remaines at room-temperature-level. The temperature on the warm side (2:T2) rises as expected, but at first, the cold side (1:T1) does not get warmer. There is a heat-flux on the warm side (4:Q1) that peakes after about 3500 seconds. At this point of time, the heat-flux on the cold side (5:Q2) starts to rise. Comparing the difference (6:Delta Q) shows the actual heatflux into the thermal store of the wall. The charging (10:Storage Charge) starts nearly linear and decreases with time, as observable in the orange line. After about 35000 seconds charging is nearly completed, as the purple differential-graph (6:Delta Q) approaches zero. After 35000sec the heat-fluxes and temperatures can be labeled as stationary.

As the heat-flux sensors measure the heat flux of a squaremeter, the total amount of stored energy divided by the average-temperature difference is a sufficent approximation of the material-constant:

$$\rho * C_{spec} * d = C$$

The second test describes a situation where a temperature difference is already implemented in the beginning of the experiment. In an in-situ-test scenario, a temperature diffenerce between inside and outside is nearly always given. This test shows the impact of varying temperature potentials rather than absolute temperatures. In the beginning of this test, a stationary situation is established at around 10.8K of temperature difference.

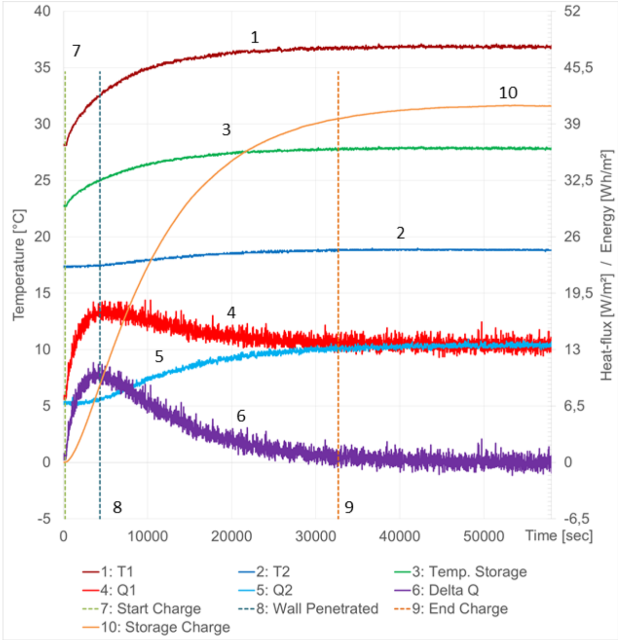


Figure 7: one-sided-heating from existing temperature-difference

As a result, there are two existing corresponding heat-fluxes with the same magnitude exiting the wall. As an additional potential is activated, the overall trend resembels the graphs in figure 6, but at an offset for temperatures and heatfluxes. It takes approximately 35.000sec to for the heatfluxes and temperatures to be stationary in the new equilibrium, is about 35.000sec, although the total temperature difference now is 18K instead of 11.5K as in the previous test.

Table 6 shows the comparison between the two test scenarios. Although the setting is very different, the C-Value can be estimated as in both cases:

$$\frac{\dot{Q}_{Charge}}{\Delta T_m} = C$$

with a derivation of about 5 % from the value calculated from the material-parameters. In addition, values for τ and the time needed to permeate the wall are very similar.

Table 6: Results

Test:	C [Wh/(m²K)]:	Derivation [%]:	Tau [h]:	T1 [h]:	dT (Start) [K]:	dT (End) [h]:
23.11. - 24.11.16	7,83	-3,542	5,70	1,04	10,8	18
29.11. - 30.11.16	7,85	-3,762	5,95	0,94	0,2	11,5

If the storage capacity can be determined depending on the wall thickness and an estimated density, conclusions about the classification of the wall construction in the façade can be drawn. In addition, the measurement could provide an approximation for the amount of available thermal storage mass in the outer wall.

If τ is correctly determined, conclusions about the U-value can be made (via storage capacity) as well.

The relation:

$$\tau = R * C$$

can be used to infer the thermally relevant factors of the exterior wall construction (VDI -6007, 2012) (Liebscher & Held 1968).

During the storage process (at an existing temperature gradient), it is possible either to measure a natural charging and discharging cycle or to apply an artificial, additional potential difference and to consider an additional charging process. Therefore, the method is suitable for a flexible use in different (seasonal) initial situations.

The preliminary study shows, that a higher accuracy of the measured values can be achieved with increasing measuring time.

Potentially, a significant higher accurancy can be expected, with regard to simple and favourably surface temperature measurements, especially for the U-value.

$$U_m = \frac{C}{\tau}$$

Limitations

Currently, the measurement method is only tested within laboratory environments. Therefore, test results can vary from actual on-site measurements. It has to be expected that actual measurements may take up to several days due to large thermal masses. To tackle this problem, the goal is to concurrently do a simulation which can be fed continuously with the obtained data. As the qualitative behavior of wall segments can be seen in the context of thermal storage, estimations can be concluded from measurements of reasonable time. Characteristic initial heat-flux-signatures can be used in conjunction with the pda-method to further improve measurement-times, especially if accuracy is secondary.
The suggested U-values of the “pda-method” are only valid for the RWTH-Aachen Campus buildings or similar facade construction types.

Discussion

As the pda-method is a statistical approach, it has to be mentioned that results are affected by fundamental knowledge of the user about building physics or rather wall constructions. Furthermore, the current statistic is based on half of the available wall structure data from the RWTH Aachen facilities. As the available building stock provides buildings, which have been constructed over the last 100 years with typical German construction types, one of the next steps is to merge the other half of the data into the statistical model. This has to be evaluated by a completely different dataset. Thus, further evaluation should lead to even higher accuracy, as the validity rises due to a higher amount of data. In conjunction with this additional data, uncertainty of the datasets can be further evaluated and eliminated. Currently the pda-method provides the possibility to assess window U-values. This method could be used to identify the allocation of energy consumptions from single buildings if information is scarce and losses have to be elicited for retrofit measures.

For the heat-balance methode (HBM), measurement intervals are still very long for a measurement cycle within a thermal phase (for example, one night) on a real façade. Therefore, the method has to be optimized, so that the values from the beginning of the measurement are continiously being used to establish an estimation, for describing the qualitive evaluation of the heat fluxes.

An extended approach would be to measure only until the heat flux has passed the wall completely (blue line), as there is a relation between τ and the penetration speed.

In order to investigate whether the method is suitable for field studies, the next step would be to transfer the test arrangement to a real exterior wall of an existing building.

The expected transverse conduction has to be compensated by a suitable, extensive heating of the inner wall side.

Conclusion

The pda-method is still under development and has to be updated with more information and further decision steps, such as the year of construction, have to be included into the model. It can be summarized, that errors occur while using the pda-method caused by the statistical nature of the method. In future publications, the deviation of occurring errors will be presented and discussed. Nevertheless, this approach leads to better results than the current IWU-method, which is based on statistical data using residential building wall structures.

Currently the pda-method provides collected information, like heat transfer coefficients, from on-site inspection, that other methods could make available. After further updates and evaluations, the HBM-method will help to provide the estimation of specific heat capacities, so that, low order building performance models can be parametrized more precisely. Thus, the results of cooling load calculations lead to better accuracy.

As a complement to the pda-method, a direct measurement method utilizing heat-flux balances is being developed (HBM). The goal is to advance the method in cost-reduction and implementation on an open-source platform. In conjunction with the pda-method, statistical- and empirical data can be joint to meet varying accuracy/time demands.

It can therefore be used to verify results from the pda-method as well as to enrich the statistical database used in pda-method.

Acknowledgement

We gratefully acknowledge the financial support of this work by the German Federal Ministry of Economics and Energy (BMWi) as per resolution of the German Parliament under the funding code 03ET1260A.

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