ENERGY AND MATERIALS TECHNOLOGY

Precise U-value measurement of installed windows

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Abstract

Renewable energy is today the world's fastest growing energy source limiting the negative consequences of energy use. The commercial and residential buildings stands together for about 40 % of the total energy usage. Residential buildings alone stands for 20 % of the total world delivered energy consumption by end-use sector. In EU the average residential energy use amounts to 25 % and for individual countries like Sweden and Finland it is 21 %.

The revised energy efficiency directive from year 2019 have an energy efficiency target for 2030 of at least 32, 5%, following on from the existing 20% target by 2020.

Finland's energy efficiency law for buildings from 2017 reduces the minimum energy usage allowed for new buildings. New buildings need to be close to zero energy buildings.

As part of the global goal to increase buildings energy efficiency, this work focus on the ability to measure U-values of windows in an effective way. To be more precise the investigation focuses on 5 different sized windows, while the window type remain the same. This is done by measuring the window glazing from different points using Rapid U-value meter. The instrument works by adding thermal insulation on a part of the window. Due to the insulation the temperature under it starts to decrease. This is compensated by a system with temperature sensors and electrical heaters to keep the temperatures identical under and beside the instrument. The required power to keep the temperature under the insulation at same level with the undisturbed surface gives the heat flux. The measurements is taken mainly during night time to limit the exposure to solar radiation. Based on the measurement on the glazing, a method to approximately calculate the U-value for whole window including frame is investigated and the accuracy estimated. The method is tested on 7 other windows not part of the initial testing, making the total amount of windows tested to 12.

The results, based on totally 796 measurements, are promising with relatively good accuracy. The results are discussed and it is concluded that the method can already be used in field work, however a better accuracy can be achieved by securing the validity of calibration of the U-value meter and measuring the U-value for a longer time.

Keywords: U-value instrument, U-value of windows, housing energy efficiency,

PREFACE

This master thesis have been done for Arcada Masters Program in *Real Estate Energy*. The extent of the project is 30 credit units, corresponding to 20 weeks of full time work.

I want to thank Pihla windows, Timo Nissinen for providing me with the windows to use and perform the tests on.

16th. September 2020, Vantaa, Finland
Ossian Pekkala

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1 INTRODUCTION

This MSc thesis consist of six chapters with the focus on finding the answers to the research questions in Chapter 1. After the theoretical framework (Chapter 2) and methodology (Chapter 3) the measurement results and conclusions are given in Chapter 4. The results are based on 796 U-value measurements and based on the conclusions answers to the research questions are given in Chapter 5.

1.1 Outline

In this MSc thesis five different sized windows are installed in a room built for this purpose. The windows are analyzed with U-value meters, thermal imaging camera and temperature loggers. The main goal is to determine if the U-values of whole window elements can be measured in field and to define precision of respective measurements. For the purpose of accuracy and to limit disturbing factors the measurements are done with a limited disturbance created by occupants. The measurements are mainly limited to night times, expect for measurements taken during evenings and late mornings for the purpose to investigate the reliability of the current correction factor of solar radiation. All measurements have been taken during times with wind speeds less than 2 m/s.

In Chapter 1 the introduction to the project is given with the outline (1.1), the background (1.2), global perspective (1.3), research focus (1.4) and research questions (1.5).

Chapter 2 consist of the theoretical framework with history about windows (2.1), earlier and current instruments allowing U-value metering (2.2) and principles of heat transfer (2.3).

Chapter 3 focuses on the methodology with method and system setup (3.1), instruments used for this project (3.2), measured windows for this project (3.3) and measuring setup (3.4).

In Chapter 4 the measurement results and conclusions of these are given from verification of the instruments (4.1), temperature measurements (4.2), thermal images (4.3-4), interference from solar radiation (4.5), different U-value measurements (4.6-8), linear heat transmission coefficient (4.9) and the measured U-value (4.10).

Chapter 5 gives answers to the research questions in Chapter 1 based on the conclusions in Chapter 4.

1.2 Background

The author of this MSc thesis have been working more than 7 years as an authorized person to sign energy performance certificates. Based on the real work experienced situation it can be concluded that quite often it is impossible to precisely determine the U-value of windows; even estimation can be hard. For new windows the U-values is given by manufacturer and normally confirmed by independent calculations by experts or alternatively, similar elements have been analyzed in a laboratory.
Reality can bring significant changes between the nominal and real U-values of windows. Changes in the construction and materials, construction defect and aging will most often if not always have an effect on the U-values. For example, windows with argon or other insulating gas will have some leakage and be replaced with air as time goes by. This have raised the question how to reliably measure real U-values of windows. Currently the only practical method is to look at the window and then based on the year of installation and how the window is built make a rough estimation of the U-value based on similar looking windows with known U-values.
There is a growing need to measure the U-value more precise on the field. True U-values would give better value to the energy certificate, making the energy efficiency suggestion more reliable to the customer. There is also a great value to be able to measure installed windows as a way for the customer to determine if the windows that have been delivered and installed does perform as well as promised by the provider. The possibility as a third impartial inspector to be able to measure the true U-values does have great value in resolving disputes at early stage.

1.3 Global perspective

The global energy usage have been growing and is expected to grow by 1.4 % yearly in the forthcoming years (EIA, 2016). The negative effects of increased energy use are greatly depending on the type of base raw materials required for producing the energy and the negative consequences those have on the environment. From the energy used, fossil fuels stands for the largest part. Excess use of fossil fuels have been shown to have negative effects on the environment, including, but not limited to global warming.

Renewable energy is today the world’s fastest growing energy source, with a yearly increase of 2.6 %, limiting the negative consequences of growing energy use. The residential and commercial buildings together amount to about 40 % of the total energy usage. From total world delivered, the residential buildings amounts to 20 % of the delivered energy usage by end-use sector. In EU the average residential energy use amounts to 25 % and for individual countries like Sweden and Finland it is 21 % (EIA, 2016).

The revised energy efficiency directive from year 2019 have an energy efficiency target for 2030 of at least 32, 5%, following on from the existing 20% target by 2020 (European Commission, 2019). To reach the goals, improved energy efficiency use are required in all sectors

Finland’s energy efficiency law for buildings from 2017 reduces the minimum energy usage allowed for new buildings. New buildings are practically required to be close to zero energy buildings. This is defined by the Ministry of the Environment as buildings that have very high energy efficiency, where the already greatly reduced energy demand is satisfied extensively by renewable energy. (Ministry of the Environment, 2017)

1.4 Research Focus

The aim with this report is to investigate how to conduct in field measurements of the U-values and to do estimations on precision of respective measurements. Different methods which are available will be investigated, with the aspect to determine the U-value of the whole window including the frame. The interference from different weather conditions are also inspected. The overwhelming purpose is that the measurements can be repeated and practically implemented during field work.

1.5 Research questions

The aim is partitioned into following research questions (see Chapter 6 for answer):

1) How to measure U-value for a complete window element which is already mounted in a wall construction?

2) How reliable is the measuring method?

3) How precise is the U-value measurement and how long measurement times are typically required?

4) Can windows U-value be measured when under the influence of indirect solar radiation?

2 THEORETICAL FRAMEWORK

The theoretical framework in Chapter 2 gives a brief history about windows (2.1), earlier and current instruments used for U-value metering (2.2) and principle of heat transfer (2.3).

2.1 Windows

The main purpose of a window is to bring in light into a home. Before the use of glass the holes were covered with animal hide, cloth or wood. During the medieval period most of the windows were unglazed. They were simply openings in the structural frame. Fabric, vertical wood or iron bars were insert to keep out intruders and keep heat inside. Glass was expensive and rare. From 16th century glass started to become cheaper and more common. The windows were one glazed at best and the main purpose was to prevent draft while letting the daylight in. (English Heritage, 2014)

Between the years of 1800 and 1930 the most common windows started to have 2 glasses in separate frames (Neuvonen, et al., 2002).

Figure 1 shows a cutting of a double glassed window.

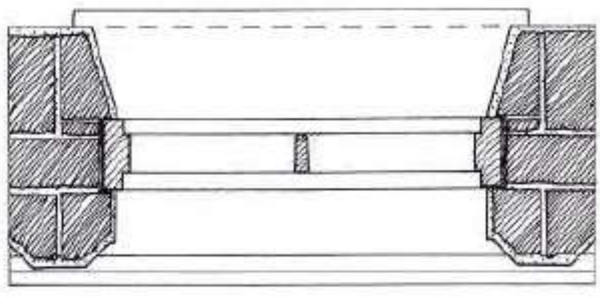


Figure 1. *Double glassed window (Neuvonen, et al., 2002)*

Until beginning of 1970 the windows were usually double glazed with separate wooden frames. After the energy crisis the government set new building regulations 1973 and triple glazed windows started to be used for new buildings. The alternatives were either triple glazed windows in separate frames or alternatively 2 or 3 glazing in the same frame forming an insulating window element. Starting from 1990 wooden-aluminum frames became the most common construction for frames with more than one glazing. (Neuvonen, 2015).

Figure 2 shows a cross section of a triple glazed window. The left one have 3 glazing all in separate frames. In the right window 2 of the glasses are in the same air tight frame forming and insulating element.

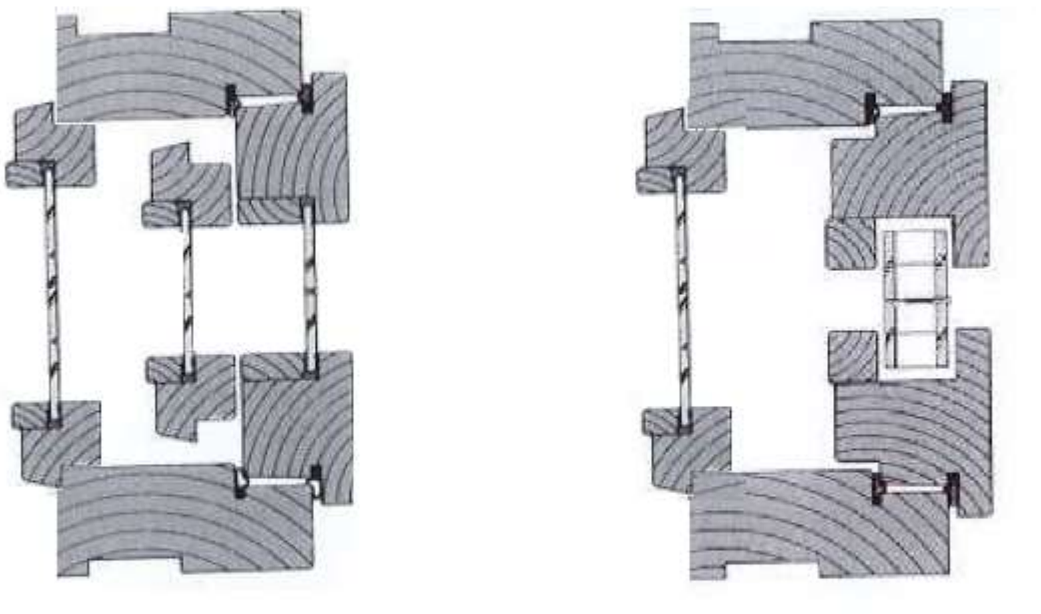


Figure 2. *Triple glazed windows (Neuvonen, 2015).*

2.2 Earlier and current instruments allowing U-value metering

2.2.1 Techniques for measuring U-values

Rapid U-value meters have been developed since 2010. The concept of the instrument is to locally add thermal insulation to the interior side of the outer envelope. If the interior temperature is colder than the exterior temperature then the temperature starts to decrease under the added insulation. When the temperature under the instrument decreases, heat is applied to keep the thermal inertia at equilibrium. The required heat energy is measured and this can be used to calculate the U-value, assuming other parameters are known.

Previously Fredrik Svensk (2017) have investigated Rapid U-value meters on thick brick walls to see the effects of thermal inertia. Figure 3 shows an older version of the Rapid U-value meter when mounted at wall.

Figure 3. *Rapid U-value meter (Svensk, 2017)*

The main method to define U-values of windows are by theoretical calculations. This is mainly applicable for new windows and during window production (Pihla). For example in Finland VTT defines the U-values of windows using the standards EN 10077-2 /3/, EN 10077-1 /2/ and EN 673 /1/ using various heat loss simulation programs. It is to be noted that calculated values are correct only for such new window elements which are constructed exactly according to the drawings with low tolerances as well of materials with precisely defined physical properties.

Sørensen (2010) investigated the possibility for measuring heat losses on field from building facades and windows using the Danish U-value meter with patent granted 2009. He also took into account the limitations of the U-value measurements on real house walls and concluded that they never operate in perfect steady state conditions. The long term weather conditions have to be taken into account and the impact estimated. See also Sørensen (2013). Figure 4 shows the Danish U-value meter on the wall.

Figure 4. *Danish U-value meter (Sørensen,, 2010)*

Green TEG (2015) shows a case study and gives guidelines of how to get reliable U-values from windows using the gSKIN heat flux sensor. They propose that reliable U-values can only be obtained if the measurement is conducted after sunset and stopped before sunrise and that all artificial lights are turned off.

Klems and Keller (1987) makes an interesting study using a mobile windows thermal test facility. Five commercial windows are measured in outdoor weather conditions.

McCabe, M. E. and Goss, W. P. (1987) reviewed the sources of information about U-values and describes the state of thermal tests methods used for windows.

Varshney et al. (2012) investigated a technique to diagnose window failures by simply measuring the temperature on window with an IR meter. The goal is to be able to detect loss of insulating gases, leaky or cracked windows and localize air leakage.

Huizenga et al. (2006) investigated nearly 200 papers, articles and books about human thermal comfort related to windows and summarizes the most important conclusions. The major factors is concluded to be window surface temperature and solar radiation.

Karlsson (2001) treats angle-resolved optical properties and the energy efficiency of windows when using glazing.

From the previous studies the most important for this project is firstly the standards EN 10077-2 /3/, EN 10077-1 /2/ and EN 673 /1/. These are standards that can be used to calculate the U-value of windows and have an important role in this MSc thesis.

Varshney reported about using an IR meter to determine faulty windows is valuable to give further insights about the uses and importance of being able to accurately measure the U-value. This also gives a good comparison to when using the Rapid U-value meter compared to plain IR camera.

Huizenga et al. investigation about human thermal comfort related to windows will also be looked closely in this project, as this is one key application for this project results.

Klems and Kellers mobile window test lab study is a bit old (1987), but it has clear similarities with my own project and can give valuable insights to improve my own work. Also Sørensen and green TEG are doing tests with different U-value meters which is worth to pay some attention to.

2.3 Principles of heat transfer

2.3.1 Theory

Heat transfers spontaneously from a hotter substance to a colder substance. The heat can transfer with convection, radiation and conduction.

Convection means that heat transfers within a fluid or gas with flows. The hotter fluid or gas moves faster than respective colder ones and therefore leading to balancing of heat contents. The heat transfers almost only by conduction within solid materials.

The heat transferred per unit time [W] through convection is:

$$q = \mathrm{h} * \mathrm{A} * \Delta T \tag{1}$$

Where h is the convective heat transfer coefficient [W/m^2 K] of the process, A the heat transfer surface area [m^2] and ΔT the temperature [K] difference between the surface of the bulk fluid.

Heat transfer through radiation means that heat is transferred by radiation without the need of matter in-between the hotter and colder substance. Radiation occurs to both directions, but the colder substance receives more radiation from the hotter substance resulting it to heat up while the hotter substance cools down. Distance does not limit radiation, our sun heating the earth, is a good example of it.

The radiation energy q per unit time [W] from a blackbody is:

$$q = \sigma * T^4 * A \tag{2}$$

Where σ is the Stefan-Boltzmann Constant 5.6703 x 10-8 [W/m^{2}K^4], T is the absolute temperature [K] of the emitting body and A the area [m^2] of the emitting surface.

Conduction means that heat transfers inside a solid substance, from hotter to colder. The thermal conductivity varies between different substances and are high for metals and low for insulating materials like expanded polystyrene.

Heat flux, q, through conduction is the heat transferred per unit time [W]. For conduction through a material it can be described following:

$$q = \frac{k * A * \Delta T}{l}$$

(3)

Where k is the thermal conductivity [W/m K] of the material, A the heat transfer area [m^2], ΔT the temperature [K] difference and l the material thickness [m]. (Incropera, et al., 2011)

2.3.2 Determining the U-value from heat flux

Heat is transferred inside a solid material by conduction. The speed of this heat transfer is called thermal conductivity and varies greatly between different materials. Thermal conductivity unit is [W/m K]. (Incropera, et al., 2011)

The U-value is a structures total thermal transmittance and it is the reciprocal of the total thermal insulance (R_T). The units are [W/(m^2 K)] for the U-value and [m^2 K/W] for the thermal insulance. The relationship between U and R_T can be written as:

$$U = \frac{1}{R_T}$$

(4)

The total thermal insulance (R_T) consist of the constructions total thermal insulance (R_1 + R_2 +...+ R_n) and to this is added the internal (R_{si}) and external R_{se}) heat transfer coefficients.

$$U = \frac{1}{R_{si} + R_1 + R_2 + \cdots + R_n + R_{se}}$$

(5)

Where

R_{si} is the internal surface heat transfer coefficient. R_{si} = 0,13 can be used for vertical building envelope (see 2.3.2.2).

R_{se} is the external surface heat transfer coefficient. This is depending on the air convection (wind speed) at the external surface (see 2.3.2.1).

The thermal insulance through a wall segment can be calculated by its thickness, l, and the thermal conductivity, k:

$$R = \frac{l}{k}$$

(6)

Placing equation 6 in 3 we get:

$$q = \frac{A * \Delta T}{R}$$

(7)

During steady state conditions, the heat flux remains constant throughout the construction. The heat flux, q, is the same for all the thermal insulance parts as long the interior and exterior conditions remain constant and the construction have reached its thermal balance. The relationship between heat flux, q, and thermal insulance for the wall $R_w = R_1 + R_2 + \cdots + R_n$ can now be described as following:

$$R_w = \frac{A * \Delta T}{q}$$

(8)

Placing equation 8 in equation 5 we get following equation for the U-value:

$$U = \frac{1}{R_{si} + \frac{A * \Delta T}{q} + R_{se}}$$

(9)

This equation is the basic equation used with Rapid U-value meters. A more detailed instrument specific formula used for this project and the used instrument is available in 2.4.1.4

2.3.2.1 External heat transfer coefficient, R_{se}

The heat transfer rate is depending on the wind speed. The exterior surface resistance coefficient R_{se}, decreases with increased wind speed. For the U-value the standard R_{se} = 0,04 is used. To compensate for this for in site measurements a correction constant factor depending on the actual wind speed during the measurement needs to be used. (ISO 9869, 2018) and (Paronen, et al., 2020)

Table 1. Vertical wind dependent surface resistance coefficient

Wind speed m/s	R_{se}-wind convection m^2*K/W	R_{sec}-wind corr wind speed related correction constant m^2*K/W
0	0.13	0.09
0.5	0.11	0.07
1	0.08	0.04
2	0.06	0.01
3	0.05	0.01
4	0.04	0
5	0.04	0
7	0.03	-0.01
10	0.02	-0.02

2.3.2.2 Internal heat transfer coefficient, R_{si}

The principle for internal heat transfer coefficient is the same as for the external heat transfer coefficient. (ISO 6946, 2017)

For the U-value a wind speed of 0 is assumed indoors and R_{si} = 0,13 (C4, 2012).

2.3.2.3 G-value

The G-value gives the total solar energy transmittance from outside to the inside. The value is given between 0 and 1. Where 1 represents total transmittance of the solar radiation (open window) and 0 no transmittance through (wall). (D3, 2012)

2.3.2.4 *Spectrally Selective Glazing*

The optical properties for the glazing part consist of transmittance, reflectance and absorption. When light travels through a glass a part of it is absorbed into heat. These properties are dependent on the wave length of the radiation. The spectral behavior of the glazing can be changed by applying a thin coating on the surface. For heating purposes the interest is to transmit as much of the solar radiation as possible and limit the thermal emittance. (Karlsson, 2001)

2.3.2.5 *Insulating gas fills in the windows*

The insulated glazing units have at least a double layer of glazing with a sealed space in between. The spaces are filled with argon or other gasses to reduce the heat transfer through the window. The drawbacks of using natural air is that it contains moisture that can condensate on the inside of the glass unit. Other gases also have better thermal insulating properties. Most thermal windows have Argon or Krypton fills, but also other alternatives exist.

Common for all gas filled windows are that even a small gap in the seal will lead to the gas to escape and lead to air to leak in. This can be noticed by condensation. Gas will even leak from windows with intact seal with a leakage rate of about 1% per year. (Knorr, et al., 2016)

2.3.3 The principle of heat flux for windows

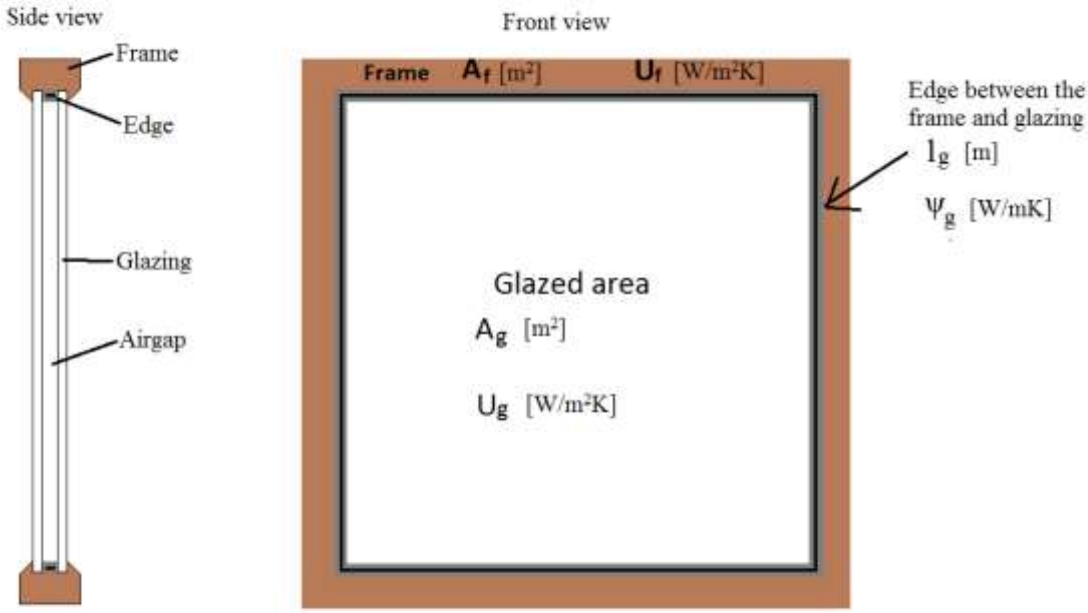


Figure 5. Side view and front view of window (Karlsson, 2001)

Figure 5 shows that a window consist of several parts that all affect its thermal properties. The major part is the glazing that can consist from one to several layers of glass separated by well-sealed gas spaces.

The thermal performance of windows (U-value) can be calculated with the following simplified equation based on the standards EN 10077 part 1 and 2.

$$U_w = \frac{A_g U_g + A_f U_f + l_g \psi_g}{A_g + A_f} \tag{10}$$

Where:

$U_w$is the whole window, including frame and glass.

U_g is the glass surface (transparent) U-value [W/m^{2}K]

$U_f$is the frame (all parts that surrounds the glass) U-value [W/m^{2}K]

$\psi_g$is the linear heat transmission coefficient that takes the edge losses between the frame and glass into account [W/mK]

A_g is the area of the glass surface [m^2]

A_f is the frame surface [m^2]

l_g is the surrounding length of the glass [m]

The linear heat transmission coefficient takes into account that the U-value of the glazing frame is only partly included in the glazing U-value. The list in the frame that keeps the double-glazing's insulating gas sealed does have a higher U-value. This transmission cannot be described as 2 dimensional, but it's transmitted through convection to the sides including the glazing. This is why the edge between the glazing and glazing frame can be considered as linearly surrounding the glazing part.

2.3.4 Measuring the linear heat transmission coefficient

There is no way using the measuring instruments available for this project to directly measure the linear heat transmission coefficient reliably. For this reason we have to measure it indirectly based on the fundamental principles of heat transfer (see 2.3.1). We know that the actual linear heat transmission coefficient, ψ_g, have greatest effect on the window glazing closest to the frame. This would be the local U-value of the window glazing close to the frame, U_{gf}. Here we can make the assumptions that measured U-values close to the frame increases with increased linear heat transmission coefficient values. The effect from linear heat transmission coefficient is reduced further away from the frame, to the center of the window. At the center we can make the assumption that for large windows U-value measurements in the middle of the glazing gives the windows U-value for the glazing part, U_g. The difference between the U-value at the center of the glazing and near to the frame is related to the linear heat transmission coefficient. Assuming this relationship is constant, C, we can make a hypothesis where the U-value differences between U_{gf} and U_g is multiplied with the constant to get the linear heat transmission coefficient.

We get following equation from the hypothesis for the heat transmission coefficient, ψ_{gC}:

$$\psi_{gC} = C * (U_{gf} - U_g)$$

(11)

Where:

C is the constant that gives the relationship between the U-value difference U_{gf}-U_g and ψ_{gC}.

U_g is the measured U-value at the measurement position in the middle of the window.

U_{gf} is the measured U-value at the measuring point on the window glazing next to the frame

The constant, C, can now be calculated from measured values from a reference window with known heat transmission coefficient:

$$C = \frac{\psi_g}{U_{gf} - Ug}$$

(12)

2.3.5 Energy class for windows

Windows have a significant impact on both energy consumption and thermal comfort of a building. In cold climates, with warm summers, a well insulating window that lets the solar radiation through the glazing have benefits during the heating period as it saves energy. Same properties might have the opposite effect during warmer periods, if the heat gain due to radiation from the window causes a cooling need (see 2.3.2.3 and 2.3.2.4).

Energy rating, ER, is a method to compare the energy performance of windows with consideration to both heating and cooling needs. Here a simple U-value is not sufficient due to effect of solar heat gain and thermal radiation losses and gains through the window. The ISO 18929 Energy performance of fenestration system for residential buildings provides an international standard method for calculating the ER for a window.

(Hanam, et al., 2013)

2.3.6 Glazing surface temperature variations

The temperature difference in the window surface compared to the interior wall surface causes heat flows since colder air moves downwards and warmer upwards. The window surface also usually provides less resistance to heat flows than other elements. Due to colder air moving downwards and warmer air upwards, the double glazed windows have their minimum interior surface temperature at the bottom of the window glass. The air flows causes the temperature to rise from bottom and up. (Wilson & Brown, 1964)

For insulated window elements the coldest parts is closest to the frame with higher heat transfer due to conduction across the framing of glazing. The most noticeable change of temperature occurs from the frame and 100-150mm towards the center of the window. (de Abreu, et al., 1996)

3 EXPERIMENTAL METHODOLOGY

Chapter 3 describes how the testing and measurements have been executed (3.1), measuring instruments used for this project (3.2), the measured windows for this project (3.3) and the different measuring positons for Rapid U-value instruments and temperature loggers (3.4)

3.1 Method and system setup

In this report the ability to make precise U-value measurements for windows are investigated. The used U-value meters are known as Rapid U-value meter (see 3.2.1). The U-values are also calculated using logged temperatures (see 3.2.3). The windows have been installed on an actual home. During the measurements access to the respective room is limited. All measurements have been done during Mars-June 2020.

The windows are described in tables 2, 3 and 4. The measurement instruments are described in 3.2. The windows used for the measurements are 5 different sized Pihla Varma windows manufactured on 2018 (3.3.1), 6 older windows from an earlier installation 2011 (3.3.2) and a new Piklas window manufactured and installed 2019 (3.3.3).

3.2 Instruments used for this project

Figure 6. Rapid U-value meter case with instrument

Figure 6 shows the Rapid U-value meter case with the instruments. All of the following instruments fits in the case and have been used during this project:

- Heat flux meter, 6 Rapid U-value meter
- Temperature loggers, Airwits R2
- Wind speed meter, Trotec BA06
- Solar power meter, Tenmars TM-208
- Thermal imaging camera, Flir One Pro

3.2.1 Rapid U-value meter method

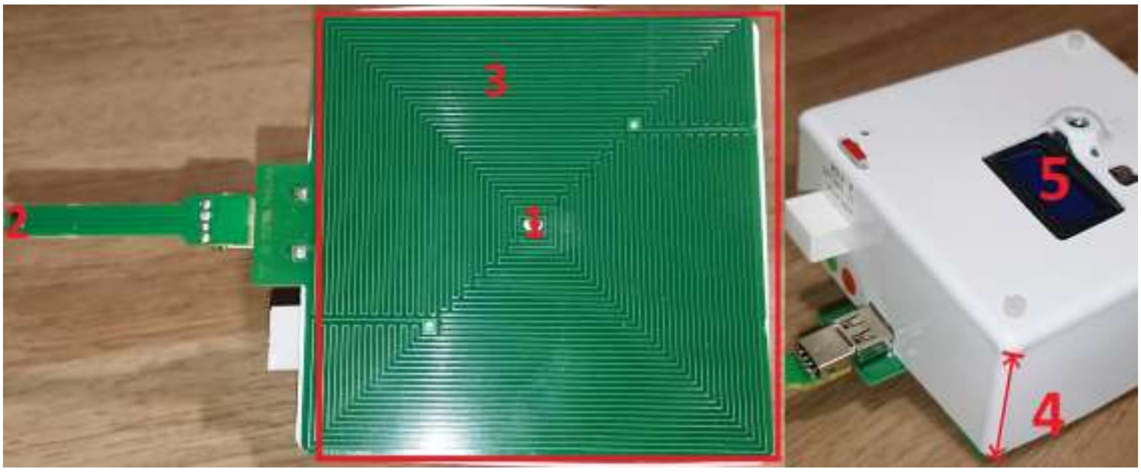


Figure 7. Rapid U-value meter from bottom and top

The key principle of Rapid U-value meter consist of following.

See figure 7 for the pointed out numbers.

1. Temperature sensor in the middle at the bottom surface of the instrument to measure disturbed surface temperature under the instrument.
2. Temperature sensor outside of the instrument to measure undisturbed surface temperature.
3. Electrical heater consisting of the whole area under the instrument.
4. Thermal insulation, about 4cm thick.
5. Electronics to control the system and display that shows the results after a successful measurement.

The basic principle is to place the instrument on the interior surface on the measuring spot. Temperature sensor under the instrument (1) that is covered with thermal insulation (4) starts to measures temperature. At the same time the undisturbed temperature sensor (2) measures temperature. The insulation (4) causes the temperature to decrease at the point of the temperature sensor (1) that is under the insulation. The control system (5) starts to adjust the electrical heater (3) and tries to find the right amount of power required to keep both temperature sensors (1 and 2) at the same temperature. The power required to keep the temperature sensors at equilibrium gives the heat flux. Once the control system have found the right amount of power, the instrument stops all activities and displays the results. The results are measuring time in minutes, power output in milliwatt (mW) and undisturbed surface temperatures in degrees Celsius (^{o}C).

Based on the displayed heating power and inner surface temperature together with outside air temperature the U-value can be calculated. This also including a few other parameters that affects the heat flux including wind speed. (Paronen & Skön, 2015)

3.2.1.1 Field measuring instructions

Temperature loggers should be delivered to the site that is to be measured at least one day before measurements. When arriving to the measuring site the measuring instrument first needs to reach thermal equilibrium with the room temperature. The time it takes depends on the temperature difference between the instrument and the measurement position. Also the room temperature of the measuring place needs to be stable for at least 12 hours for light constructions and longer for heavy constructions. The measuring spots for walls need to be cleared from obstacles at least 12 hours before measurements. Any changes to ventilation needs to be done 12 hours before measurements. To ensure that the steady state conditions are not changed during measurements, all doors and windows should be kept in same position 12 hours before measurement and during measurement. Doors can be temporally opened for a short time to pass through if it is required for measurement. When arriving at the site, any interior doors that is open should be left open. Closing them can cause a change of air movements and disrupt the indoor stead state balance. A sufficient detailed thermal imaging is required to detect anomalies at the measuring spot. Extra care needs to be taken to detect electric cables, any cold bridges like metal structures, supporting structures, single spikes and screws. The instrument is attached to the measuring spot with tape or a monopod. It is important to ensure a close fitting to the wall for the instrument for the successfulness of the measurements. (Paronen, et al., 2020)

3.2.1.2 Fundamental issues related to measurements

The measurement position surface can have a minor or significant effect on the precision of the measuring results. For highly conductive surface materials the heat transfer effect from the sides can have an effect on the results. For such situations it is recommended to place copy paper (80 g/m^2) on the heating element so that it will cover the whole heating element.

A good physical contact between the building envelope surface and U-value is essential for precise measurements. If the measurement position is uneven, then a close fitting is impossible. In these cases the situation have to be accessed individually, case by case and additional actions are required to make a close fitting. Successful measurements on uneven surfaces requires that a close fitting can be arranged, otherwise the measuring results would not have any value.

Variations in the wall constructions can cause significant uncertainties. The key factor is to use thermal imaging camera or by other means ensure that the whole area of the measurement position has only minor detectable temperature variations. It is essential that the instruments is placed so that both of the temperature sensors is positioned at same surface temperature areas (figure 8 in 2.4.1).

When measuring the heat flux it is required that the measurement position and surrounding area is in thermal balance. This means not to add or remove heat sources right before or during the measurement. The instruments temperature needs to be close to the measurement positions surface temperature to limit the heat transfer between the instrument and measuring position. (Paronen, et al., 2020)

3.2.1.3 Calibration validation test of Rapid U-value meter

Rapid U-value meters used in this project have been validated in a cold box test system with variable front walls, test wall 1 and test wall 2.
Test wall 1: A window frame with double glazing with U-value of 2,8 W/Km^2
Test wall 2: EPS wall tested by VTT expert services to have a U-value of 0,31 W/Km^2 (Paronen, 2019).

3.2.1.4 Determining the instrument specific equation for Rapid U-value meter

Equation 9 can be used as the basic equation to calculate the U-value from the measured heat flux when using Rapid U-value meters.

Equation 9:

$$U = \frac{1}{R_{si} + \frac{A * \Delta T}{q} + R_{se}} \tag{13}$$

The Rapid U-value meter have the area A = 0,01m^2 and power (heat flux, q_{mW}) given in milliwatt (mW). The temperature difference ΔT is the difference between the interior surface temperature, T_{is} and exterior air temperature, T_e.

$$\Delta T = T_e - T_{is}$$

(14)

$$U = \frac{1}{R_{si} + \frac{10m^2 * (T_e - T_{is})}{q_{\ mW}} + R_{se}}$$

(15)

Also there is additional heat caused by the electronics that is not measured. Based on laboratory tests, the resulting effect on the measurements is 5mW. When measuring windows there is also a possibility for solar radiation, q_{solar}. The solar power meter is used to determine this radiation and the value is given in [W/m^2], making it [1000mW/m^2] and adding this to the instrument area 0,01 m2. Makes the final equation following:

$$U = \frac{1}{R_{si} + \frac{10m^2 * (T_e - T_{is})}{(q_{mW} + 5 + q_{solar} \ * 10)} + R_{se}}$$

(16)

3.2.2 Thermal imaging camera method

Figure 8. Thermal imaging camera, Flir one pro

Figure 8 shows The Flir One Pro thermal image camera used for this project. The camera resolution is 160x120. This is the minimum resolution for professional use according to the Finnish building information recommendations for thermal cameras (RT 14-11239, 2016). The camera is connected to the iPhone through USB-C connection. The purpose of choosing this thermal camera for the thermal images here is due to its practicality for in site field measurements. For rapid measurements the mobility is essential and equipment size plays a role.

Before taking thermal images from the windows, the window glass was covered with thin painters tape. This since the window surface act like a mirror and the IR images would have been a reflection of something else (see 2.4.1.1). The images are taken during night time so that the tape on the window surface is not affected by solar radiation.

3.2.2.1 Thermal imaging

Visible light have wave lengths from 380 to 780nm. Starting from 780nm up to 1mm is usually called infrared (IR). IR radiation have a behavior that is similar to visible light. It reflects from smooth surfaces like mirrors and have a diffuse reflection for rough surfaces. An example of a diffuse reflection is a normally painted wall, where everything blurs together and reflected objects in practice cannot be seen. The difference is that since the IR wave length is longer, some surfaces like metals can act rough to the visible light and smoothly and comparable to a mirror for IR light. During practical measurement with IR camera, an object emits radiation in the direction of the camera, where the radiation is measured quantitatively. (Vollmer & Möllmann, 2018)

Thermal imaging of an object means that the IR radiation that is emitted from the surface is measured. The intensity of the IR radiation is depending on the surface temperature. Here comes the thermal imaging cameras resolution in. Each pixel corresponds to one measurement. The image appears from the temperature differences at the surface. Also the emissivity of the surface does affect the radiation. A surface with higher emissivity sends more IR Radiation compared to one with lower, when both have same temperature. The emissivity must always be accounted for in a thermal image, expect for cases when the purpose is to compare temperature differences between surfaces with same emissivity. Other important aspect is the surfaces reflectivity and that part of the measured IR radiation is a reflected from another source. Especially care needs to be taken to radiators and other heat sources. This also includes the person taking the images, great care needs to be taken so that the photographers own heat image does not interfere with the thermal images. (Kauppinen, 2012)

When measuring objects close to windows it’s important to keep in mind that the window is not transparent for IR radiation, but act like a mirror. Therefore when taking a thermal image of the window glass, it is instead a reflection of something else, depending on the angle. (Flir Systems, 2016)

3.2.3 Temperature loggers, solar and wind meters method

Figure 9. Temperature logger (1), Solar meter (2) and wind meter (3)

3.2.3.1 Airwits R2 temperature logger

For this project 4 pieces of Airwits R2 with internal temperature and moisture loggers have been used (pointed out as 1 in figure 9). For surface temperature measurements a similar temperature logger is used with an internal temperature sensor, but also two outgoing 2 meter long cables with temperature sensors at the end. The temperature loggers takes measurements hourly and the data is available at the manufacturer's server where the data is available through a user specific account.

3.2.3.2 Tenmars TM-208 Solar power meter

The Tenmars TM-208 (pointed out as 2 in figure 9) solar power meter is used to measure the intensity of solar radiation from windows. The measured intensity is used to correct the measured power output from the Rapid U-value meter during heat flux measurements at times when solar radiation can be expected. The measurement is taken by turning on the device and by pointing the front part outside window, at a close range.

3.2.3.3 Trotec BA06 wind meter

The wind speed meter Trotec BA06 (pointed out as 3 in figure 9) is used to measure wind speeds outdoor to determine the wind correction coefficient. The measurement is taken by turning on the device and holding the measurement up at the exterior location for the measurements.

3.3 Measured windows for this project

The five Pihla windows described in 2.5.1 are used for the testing and to determine the measuring method. The six Pilkington older windows (2.5.2) and Piklas window (2.5.3) will be used for additional test measurement to determine the viability of the measuring method on other windows.

3.3.1 Windows 1-5, Pihla windows

Five of the windows used in the measurements are Pihla Varma windows with product specification for the inner glass 2K4/4Se-16 AR TGI and outer glass float 4 (see figure 10). This means the inner part have argon gas in between the glasses. The glass thickness is 4mm. The thickness of the window outer frame is 170mm and color on both sides are white. The detailed product description from Pihla is attached in Appendix. The windows have been manufactured on October 2018 and installed on April 2020.

Figure 10. Section of Pihla Varma window (Pihla 2017)

3.3.1.1 Theoretical U-value calculation of the windows

Table 2 have the windows 1-5 used in the measurements listed with their dimensions and U-value. The U-value for window 1 were calculated by VTT to 0,97 with a margin of error by +/- 5%. The margin of error is based on experience from calculations and testing of windows with the heat box method (Sipari & Kukkonen, 2017).

The values for U_g, U_f and ψ_g for these Pihla Varma windows have been calculated by VTT based on specifications given by the manufacturer (Sipari & Kukkonen, 2017).The values are following:

$$U_g = 0{,}81$$

$$U_f = 1{,}13$$

$$\psi_g = 0{,}033$$

Using the given values for U_g, U_f and ψ_g and the windows dimensions from table 2 the whole U-value (U_w) for windows 1-5 have been calculated using equation 10.
Where equation 10:

$$U_w = \frac{A_g U_g + A_f U_f + l_g \psi_g}{A_g + A_f} \qquad (17)$$

For table 2 the U-values are theoretical with an accuracy of +/- 5 %. The expected U-value is inside of the +/- 5% range from the theoretically calculated value for windows 1-5.

Table 2. Specifications of the Pihla windows.

Structure	Outer dimensions mm	Inner glass dimensions (mm	Inner glass surface area A_g m²	Window frame area A_f m²	Surrounding length of the glass, l_g m	U-value, including glass and frame, U_w (W/m²K)
Window 1	1480x1230	1310x1060	1,3886	0,4318	4,74	0,972
Window 2	900x900	730x730	0,5329	0,2771	2,92	1,038
Window 3	450x900	280x730	0,2044	0,2006	2,02	1,133
Window 4	300x900	13x730	0,0949	0,1751	1,72	1,228
Window 5	450x450	280x280	0,0784	0,1241	1,12	1,189

3.3.2 Windows 6-11, Pilkington older windows

Six of the windows used in the measurements are older Pilkington windows from an earlier installation 2011. These windows with different specifications will be used to test and verify the results. Dimensions of these windows are available in table 3.

For windows 6 to 9 following specifications are available from the frame:

Pilkington Insulight Therm TM 4-16AR-4 + outer glass, frame 170mm.

This means the inner part have 16mm argon gas in between the glasses. The glass thickness is 4mm. The thickness of the window outer frame is 170mm. Based on the frame thickness, U_f = 1,13 W/Km^2. The given U-value is 1,0 W/Km^2 given in the house drawings. The U-value usually only holds true for bigger standard sized windows like window 1 in table 2. For windows 6-8 the expected U-value would be between 1 and 1,2 W/Km^2. Window 9 being even smaller in size the U-value can be expected to be between 1 and 1,3 W/Km^2.

For windows 10 to 11 following specifications are available from the frame:

Pilkington Piteå 4-12-40T + outer glass, frame 90mm.

This means the inner part have 12mm air between the glasses. The glass thickness is 4mm. The thickness of the window outer frame is 90mm. Based on the frame thickness the U_f = 1,28 W/Km^2. According to the house drawings the U-value is 1 W/Km^2, but this would require an insulating gas like Argon. The construction type with an compact frame suggest the U-value is between 1,2 and 1,6 W/Km^2.

Table 3. Expected and estimated U-value for the older Pilkington windows.

Structure	Outer dimensions mm	Inner glass dimensions mm	Inner glass surface area, A_g m^2	Window frame area, A_f m^2	Surrounding length of the glass, l_g m	U-value, including glass and frame, U_w W/m^{2}K
Window 6	600x1200	430x1030	0,4429	0,2771	2,92	1-1,2
Window 7	600x1200	430x1030	0,4429	0,2771	2,92	1-1,2
Window 8	1000x500	830x330	0,2739	0,2261	2,32	1-1,2
Window 9	600x300	430x130	0,0559	0,1241	1,12	1-1,3
Window 10	1050x1290	880x1120	0,9856	0,3689	4	1,2-1,6
Window 11	1050x1290	880x1120	0,9856	0,3689	4	1,2-1,6

3.3.3 Window 12, Piklas window

In table 4 is window 12. The window is located in other town house that have been built 2020. The window is measured as part of in site measurement to test the developed method in practice. The window were manufactured and installed 2019. The outer frame thickness is 170mm. Based on the frame thickness, U_f = 1,13W/Km^2. The U-value is given following the EN 14351 -1:2006+A1 standard.

Since the window is new and the U-value is given based on the standard, we can assume the accuracy is +/- 5%, similar to Pihla windows. The product description is available in Annex 3

Table 4. Theoretical U-value for Piklas window

Structure	Outer dimensions mm	Inner glass dimensions mm	Inner glass surface area, A_g m^2	Window frame area, A_f m^2	Surrounding length of the glass, l_g m	U-value, including glass and frame, U_w W/m^{2}K
Window 12	920x2010	750x1840	1,38	0,4692	5,18	0,98

3.4 Measuring setup

The windows from 1 to 5 were installed in a 10 m^2 room. The placement of the windows and measurement positions can be seen in figure 11 and more details are given in table 5. A list of all temperature loggers and their locations are given in table 6.

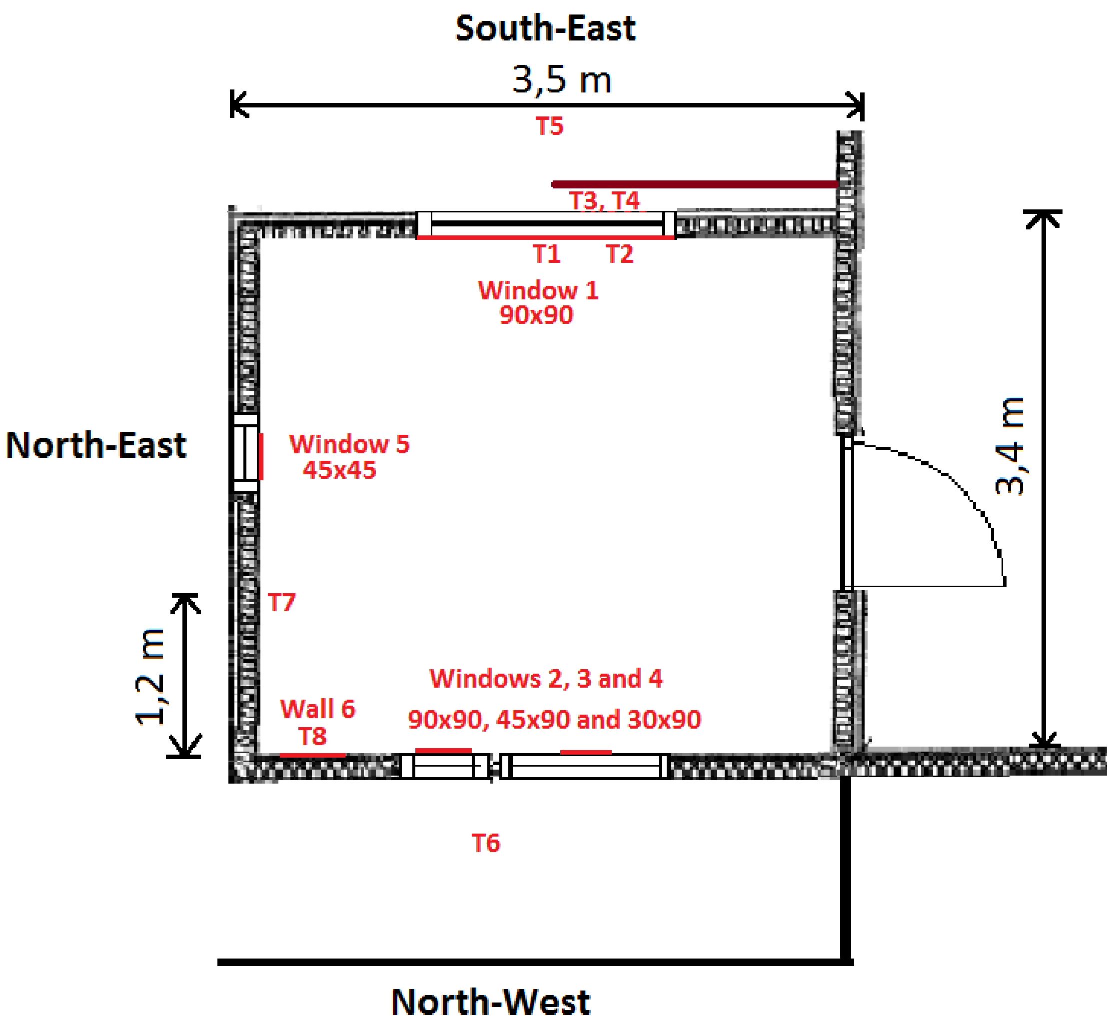


Figure 11. Drawing with the location of temperature loggers and measurement positions

3.4.1 The measurement positions

Table 5 have the measurement positions used for windows 1-5. The position is given for the horizontal height (x,) and the vertical height (, y). The origin for the coordinate system for each window is pointed out for each window in 3.2.3-6.

Table 5. List of all measurement positions used for the measurements

measurement position	The location is given in the (x, y) coordinate system with the Origin (0, 0) in the left bottom corner	Surface
1a	Window 1 (35, 88)	Window glass
1b	Window 1 (35, 56)	Window glass
1c	Window 1 (35, 25)	Window glass
1d	Window 1 (102, 88)	Window glass
1e	Window 1 (102, 56)	Window glass
1f	Window 1 (102, 25)	Window glass
1g	Window 1 (69, 56)	Window glass
1h	Window 1 (35, 112)	Window frame
1i	Window 1 (102, 112)	Window frame
1j	Window 1 (137, 83)	Window frame
1k	Window 1 (137, 30)	Window frame
1l	Window 1 (0, 83)	Window frame
1m	Window 1 (0, 30)	Window frame
1n	Window 1 (5, 83)	Window glass
1o	Window 1 (5, 30)	Window glass
2a	Window 2 (40, 40)	Window glass
2b	Window 2 (5, 40)	Window glass
2c	Window 2 (35, 40)	Window glass
3a	Window 3 (17, 53)	Window glass
3b	Window 3 (17, 40)	Window glass
3c	Window 3 (17, 25)	Window glass
4a	Window 4 (10, 53)	Window glass
4b	Window 4 (10, 40)	Window glass
4c	Window 4 (10, 25)	Window glass
5	Window 5 (17, 17)	Window glass

3.4.2 The temperature loggers

Table 6 have a list of the location of all temperature loggers inside and outside the measuring room for windows 1 to 5.

Table 6. List of all temperature loggers used for the measurements

Temp. logger, T	The location is given in the (x, y) coordinate system with the Origin (0, 0) in the left bottom corner. cm	Description
T1	Window 1 (68, 130), see T1 in Figure 1 and 2	Hourly temperature logger with a sensor in the device and with outgoing surface temperature sensors T2 and T3
T2	Window 1 (92, 68), indoor surface of window, see T2 in Figure 1 and 2	Temperature surface sensor for device T1
T3	Window 1 (92, 68), outer surface of window, see T3 in Figure 1 and 2	Temperature surface sensor for device T1
T4	Window 1 (95, 25), located outside the Window 1 at 7cm distance, see T4 in Figure 1 and 2	R-306. Hourly temperature logger
T5	Window 1 (45, -20), located outside the Window 1 at 1m distance, see T5 in Figure 1 and 2	R-294. Hourly temperature logger
T6	Window 2 (70, 10), located outside the Window 2 at 1m distance, see T6 in Figure 1 and 3	R-317. Hourly temperature logger
T7	At the height of 150cm from the floor and 120cm from the left corner (see T7 in Figure 1)	R-213. Hourly temperature logger
T8	At the height of 180cm from the floor and 40cm from the right corner (see T8 in Figure 1 and Figure 7)	R-316. Hourly temperature logger

3.4.3 Window 1

The measurement position for Window 1 can be seen in figure 12. Half of the window is covered with a wooden panel with an open airspace of 10 cm. The purpose of this is to limit solar and other radiation for this part so that the effect of radiation can be compared.

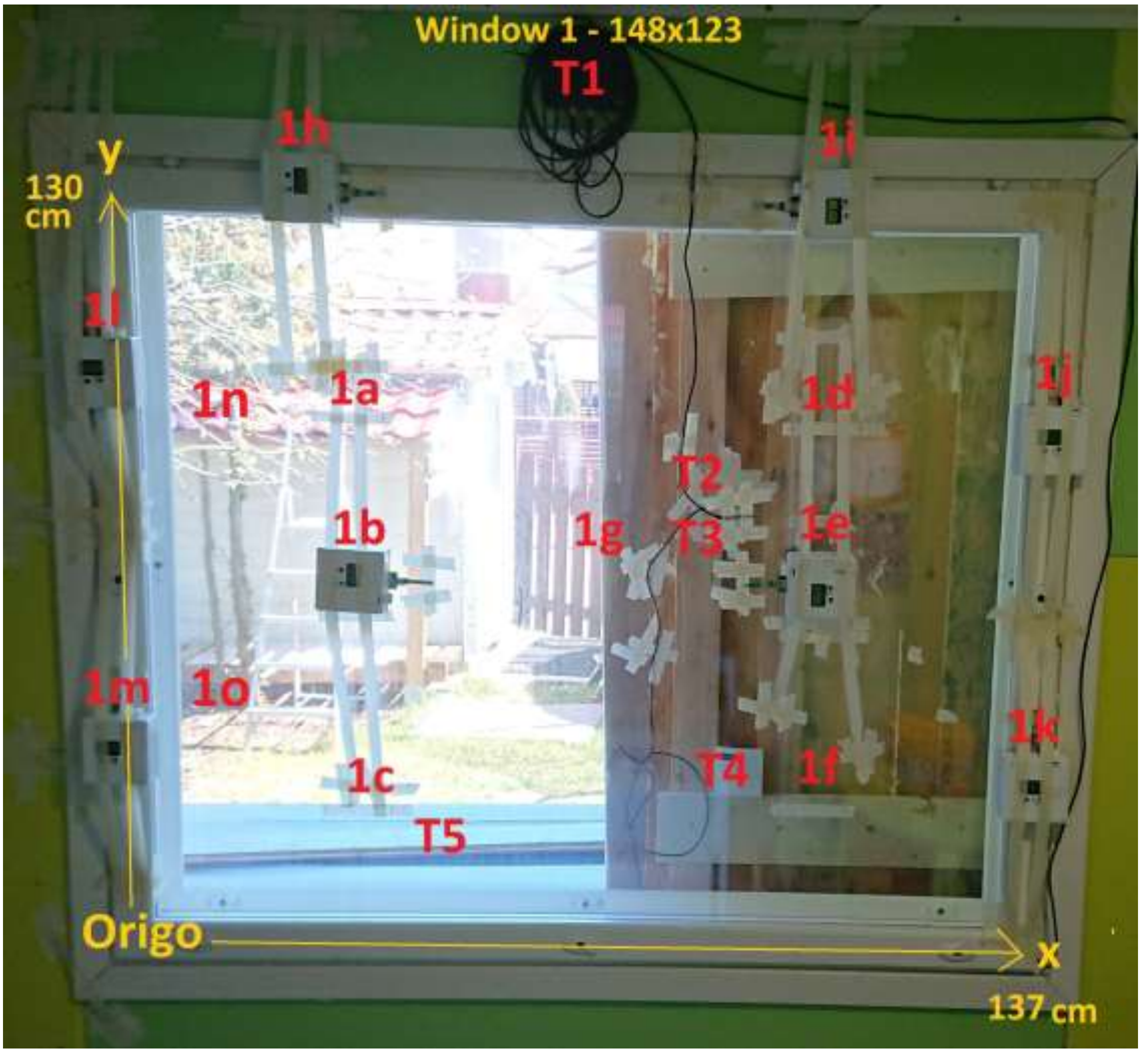


Figure 12. The measurement position for window 1

3.4.4 Window 2

The measurement position for Window 2 can be seen in figure 13. At the measuring spot 2a the direction of the outgoing temperature sensor is tried while pointing upwards, rightward and downward.

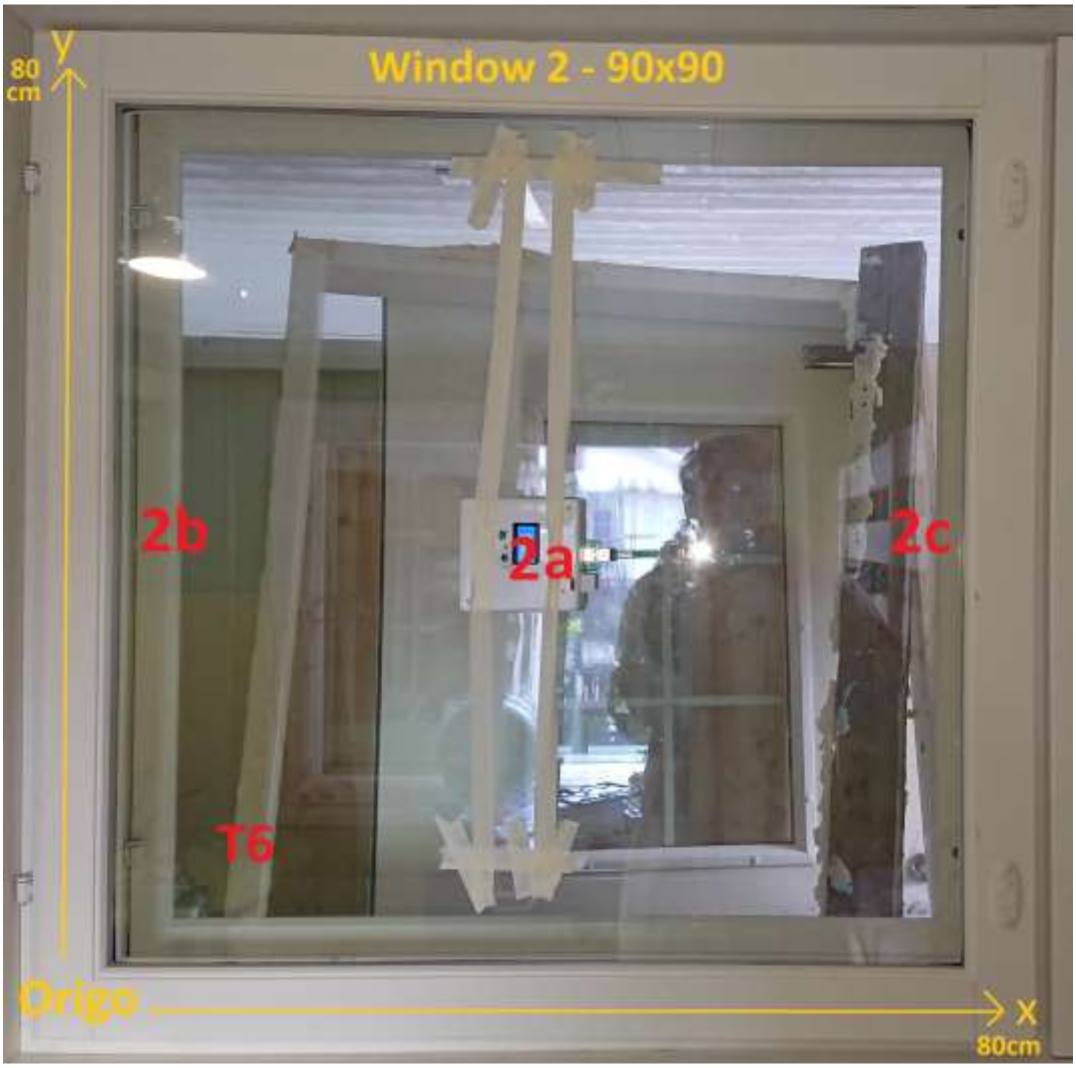


Figure 13. The measurement position for window 2

3.4.5 Window 3 and 4

The measurement position for Window 3 and 4 can be seen in figure 14.

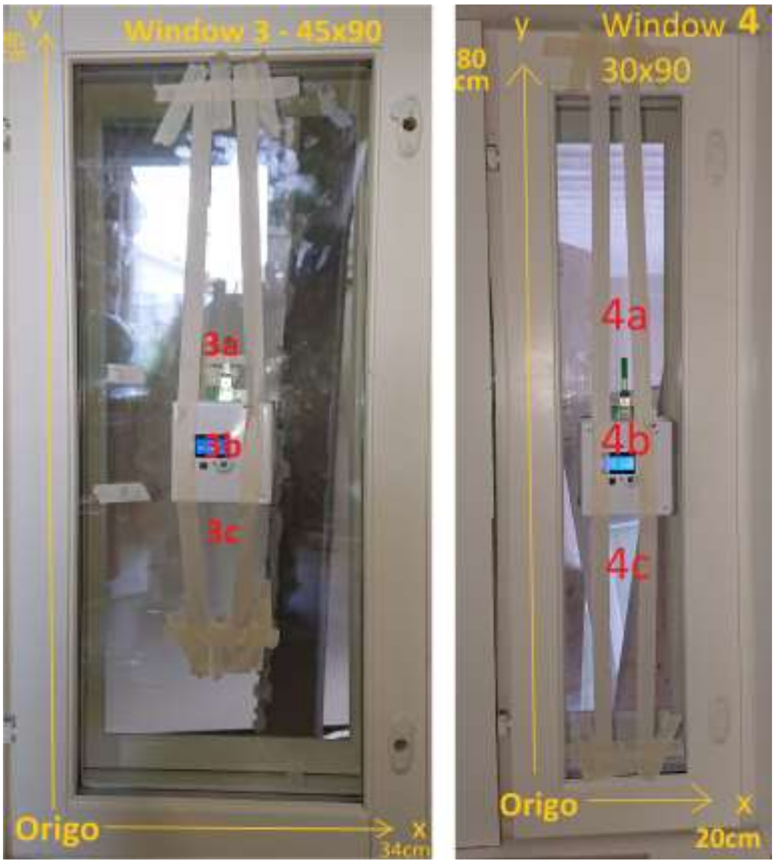


Figure 14. The measurement position for window 3 and 4

3.4.6 Window 5

The measurement position for Window 5 can be seen in figure 15.

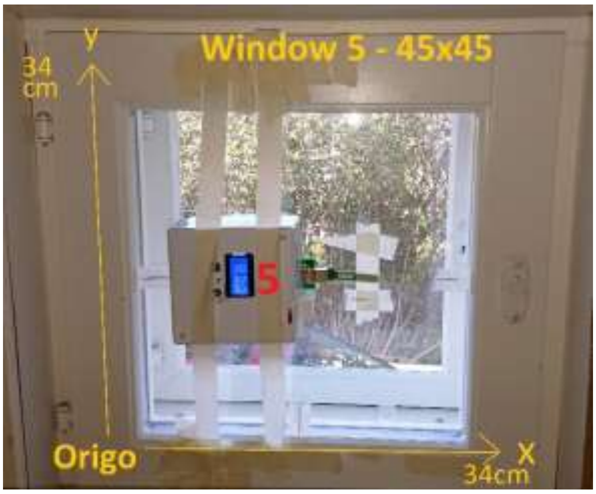


Figure 15. The measurement position for window 5

3.4.7 Location of measurement execution

The place of the measurements located in Vantaa, Finland. For the purpose of the measurements an extension to a private house were built. The location is pointed out in the map, figure 16. The measurements was taken during Mars-June 2020. The measurements was taken using temperature loggers and Rapid U-value meter.

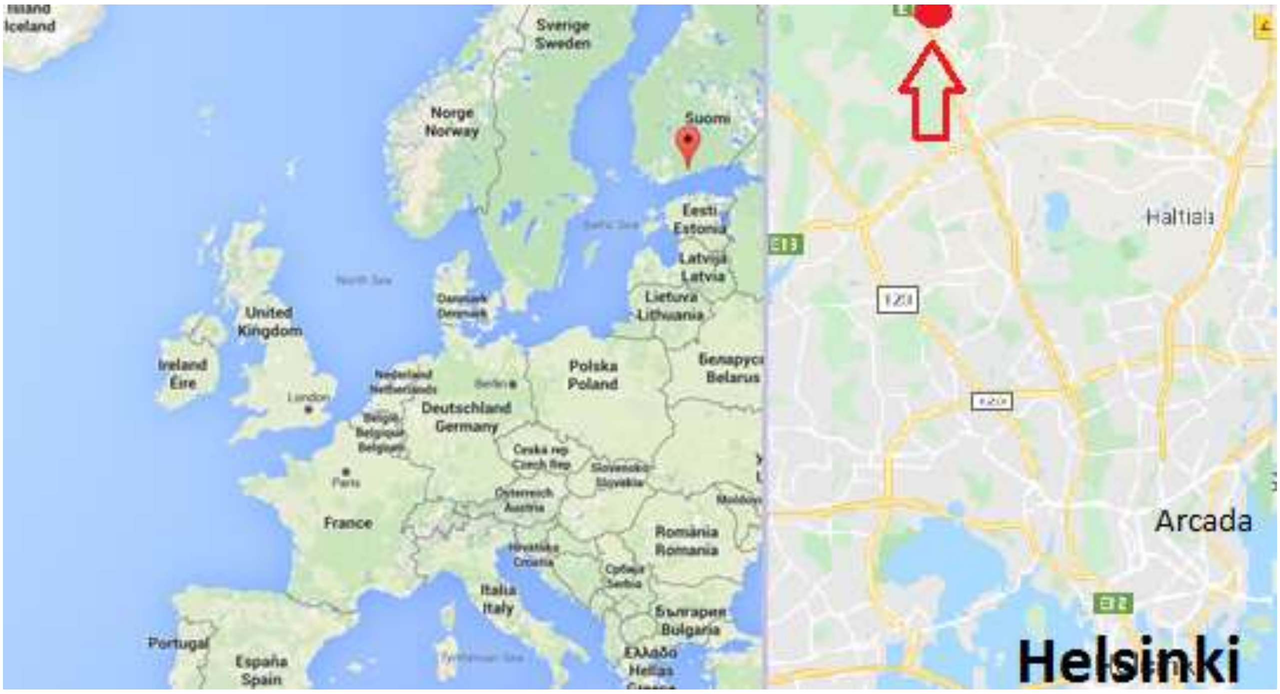


Figure 16. Location of the measurement execution pointed in the map.

4 RESULTS AND CONCLUSIONS

In Chapter 4 the measurements and the results of these are given together with the conclusions after each result. These are shown in the figures from 17 to 25 and in tables from 7 to 10.

4.1 Verification of the instruments

The instruments have been tested with standard walls in 2019 (Annex 2).

The verification were done on a EPS wall with U-value of 0,31 W/Km^2 and a window with U-value 2,8 W/Km^2.

For the purpose of ensuring that the instruments are still properly calibrated the validation measurements have been conducted on window 1 and 2. The U-value of the glazing part of the window 1 and 2 have been theoretically calculated to 0,81 W/Km^2 with an accuracy of +/- 5% (see 2.5.1.1). Here the assumption is that the interference from the frame and gas movement due to temperature difference at the frame is negligible. The evidence for this can also be seen from the thermal images, figure 18, 19 and 20.

Table 7 shows a verification of the used instruments. Here the expected value of 0,81 W/Km^2 is used for the window 1 and 2 glass at the middle of the windows. Singular measurements that differ 35% or above from the expected value will be disregarded from the average and considered failed (see table 10 in annex 5 for detailed information). The failed and total amount of measurements have been listed for the individual instruments in table 7. Measurements that can be related to weather disturbance or temporary instrument failure have been disregarded altogether from this table.

Table 7. Verification of instruments based on Table 10 in annex 5.

Instr. No	Instrument average differing from expected	Single measurements with above 35% difference from expected	Total amount of measurements	Successful measurements	Comment
112	-2%	0	18	100%	OK
114	2%	1	21	95%	OK
115	-5%	2	29	93%	OK
116	5%	0	8	100%	OK
118	1%	1	28	96%	OK
119	-3%	0	16	100%	OK

4.1.1 Conclusions

The verification test of the instrument in 4.1 indicates that there might be minor differences between the instruments when looking at average values for a large quantity of measurements. This would explain the difference of the average values from table 7 when measuring on the same spot for each instrument. For the purpose of this project the instruments accuracy is good and the conclusion is that the results are reliable.

4.2 Temperature measurements of window 1

Figure 17 shows a graph over the logged temperatures for window 1. Temperature logger T1 measures the interior room temperature, T_i. Temperature logger T2 measures the interior surface temperature, T_{si} of window 1. Temperature logger T3 measures the exterior surface temperature, T_{se} of window 1. Temperature logger T4 measures the exterior air temperature, T_e. The measurement period from 13th April to 22th April. The graph shows how the temperature changes during the measuring period from day to night. During this period the exterior temperature gets about 15 °C degrees colder during night time compared to day time maximum. Measurements is possible starting after 10 PM until 4 AM. The temperature changes during this period is 2-3 degrees making successful measurements still possible for windows. This can be seen more clearly from the zoomed in temperature measuring period from 20th to 21st April that is available in annex 4.

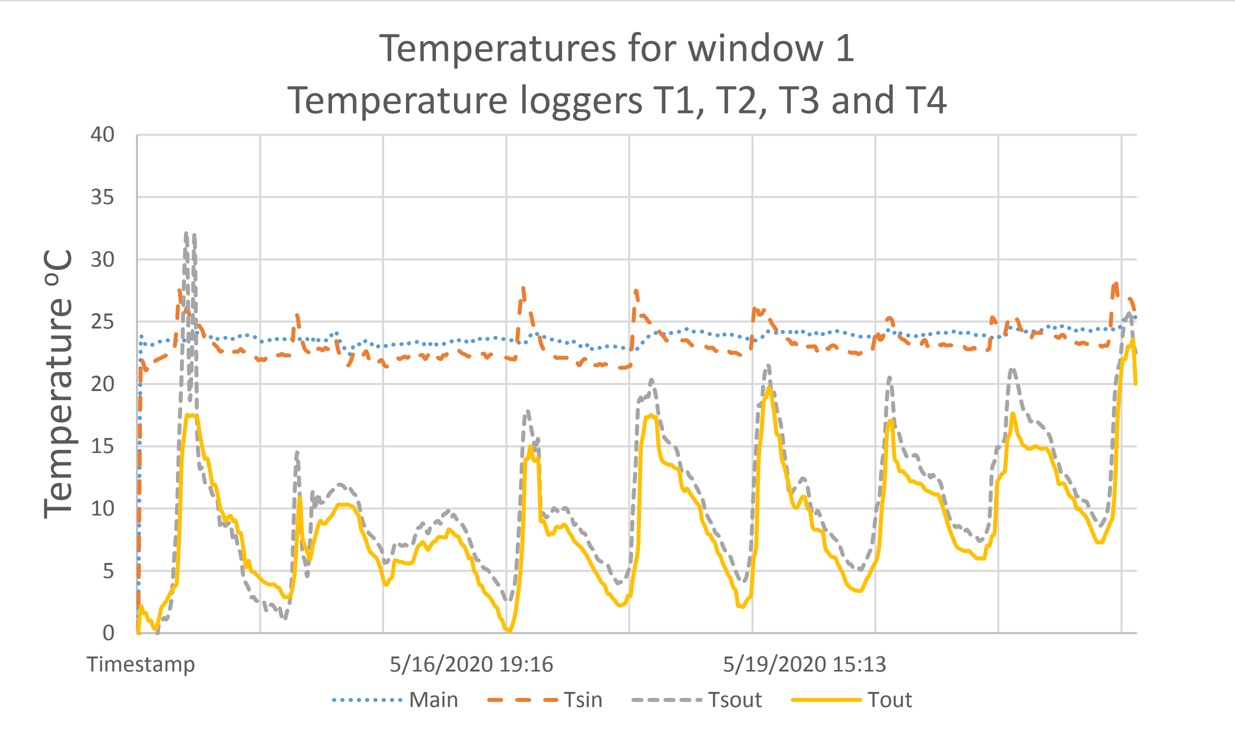


Figure 17. Graph over the logged surface and air temperatures for window 1.

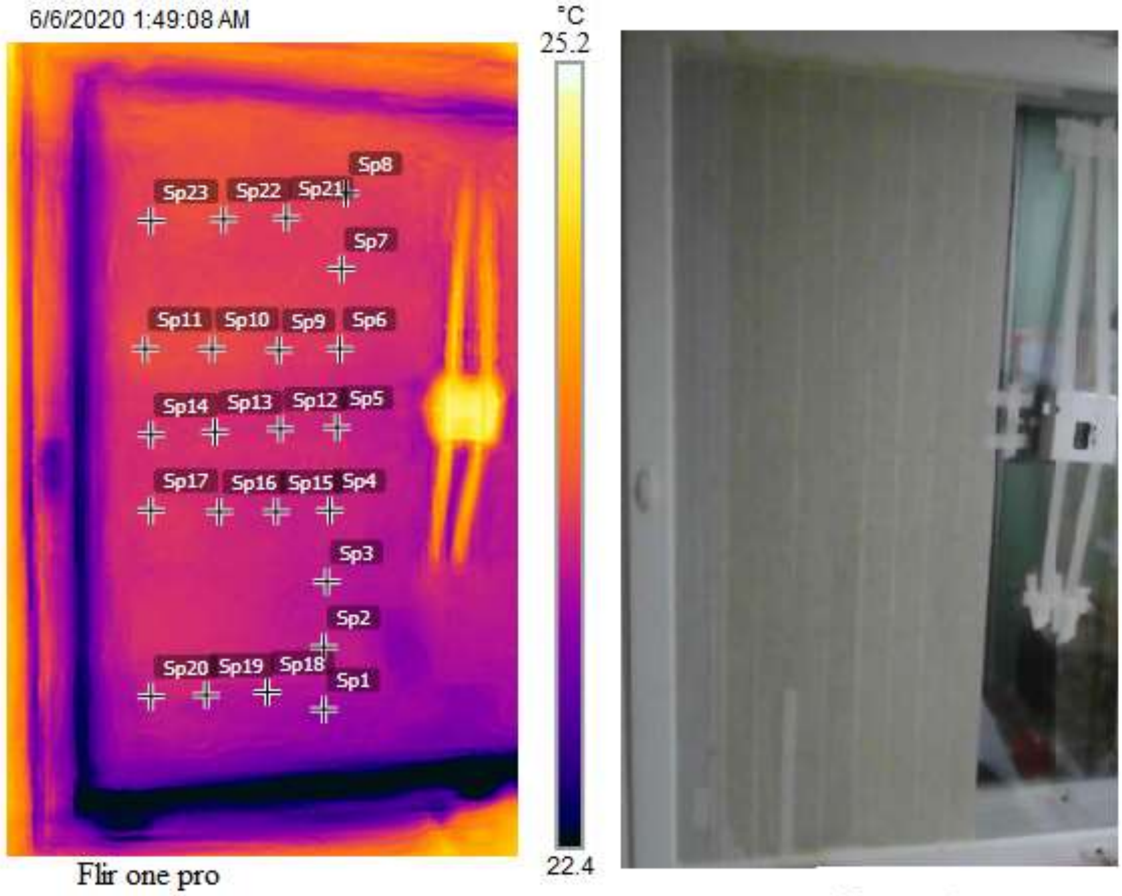
4.2.1 Conclusions

From the temperature graph in 4.2 we can see the logged temperatures during April. The outside temperature fluctuates with about 20 degrees between day time and night time. This is caused by the intensive solar radiation during day time, while still remaining relatively cold during night. These conditions are normally challenging for U-value measurements due to the difficulty to determine the resulting effect of the solar radiation to the structure that is measured. For night time the change in temperature between sunset and sunrise is about 2-4 degrees Celsius, making this the favorable U-value measurement period. This can be seen more clearly from Annex 4 with the logged temperatures in a graph zoomed in on one measuring period starting from sunset until sunrise.

The conclusion from the graph in Figure 17is that the conditions for U-value measurements are most favorable after sunset and remain favorable until sunrise.

4.3 Thermal images from window 1 and 4

In figure 18 the horizontal surface temperatures are constant and the vertical slightly increasing from bottom and up. The thermal images of the window have been taken during night time. The window have been taped with 0,15 mm thick painters tape and the temperatures are from the tape surface.



Measurements	
Sp1	23.3 °C
Sp2	23.4 °C
Sp3	23.4 °C
Sp4	23.5 °C
Sp5	23.5 °C
Sp6	23.5 °C
Sp7	23.6 °C
Sp8	23.6 °C
Sp9	23.6 °C
Sp10	23.6 °C
Sp11	23.6 °C
Sp12	23.5 °C

Measurements	
Sp13	23.5 °C
Sp14	23.5 °C
Sp15	23.5 °C
Sp16	23.5 °C
Sp17	23.5 °C
Sp18	23.4 °C
Sp19	23.4 °C
Sp20	23.4 °C
Sp21	23.6 °C
Sp22	23.6 °C
Sp23	23.6 °C

Parameters	
Emissivity	0.9
Refl. temp.	22 °C
Distance	2 m
Atmospheric temp.	20 °C
Ext. optics temp.	25 °C
Ext. optics trans.	0.8
Relative humidity	50 %

Temperature outside 12.6 °C
Relative humidity outside 85 %
Temperature inside 25 °C
Relative humidity inside 43 %

Figure 18. Thermal image of window 1

In figure 19 the vertical surface temperatures are increasing from bottom and up. The thermal image of the window have been taken during night time. The window have been taped and the temperatures are from the tape surface.

Measurements	
Sp1	25.0 °C
Sp2	25.2 °C
Sp3	25.3 °C
Sp4	25.4 °C
Sp5	25.3 °C
Sp6	25.5 °C

Parameters	
Emissivity	0.9
Refl. temp.	22 °C
Distance	3 m
Atmospheric temp.	20 °C
Ext. optics temp.	25 °C
Ext. optics trans.	0.8
Relative humidity	50 %

Temperature outside 25 °C
Relative humidity outside 85 %
Temperature inside 25 °C
Relative humidity inside 43 %

Figure 19. Thermal image of window 4

4.3.1 Conclusions

To analyze the windows glazing surface temperature variations thermal images were taken from window 1 and 4 (4.3). The interior surface of the glazing were first taped using thin painters tape. This to make a thermal image of the surface temperature possible. The images are taken during night time to ensure there is no solar radiation interfering with the results. Here the effect of the painters tape to the temperature of the glazing surface is negligible at night time. The goal is not to get precise temperatures, but to get precise temperature differences of the surface.

From the thermal imaging of window 1 we can see that the horizontal measurements marked with Sp from 9 to 23 are constant for a broad length of the window to an accuracy of 0,1 °C. The vertical measurements marked with Sp from 1 to 8 have a rise of temperature from the bottom to the top after the initial effect of the frame. The temperature difference is barely noticeable, but can still give some interference to the results if the outgoing temperature sensor is placed upwards or downwards. This interference can be seen from figure 24 in 4.8. For window 1 and 2 measurements were taken from the middle of window having the undisturbed reference sensor pointed vertically and upwards during different measurement times. From graph 24 we can see that when the outgoing temperature sensor is pointed upwards it shows a slightly higher average temperature compared to the rightwards pointed. This is to be expected based on the thermal images, due to the fact that if the outgoing reference temperature sensor is placed on an area with higher temperature the instrument will compensate this by heating extra, resulting in higher measured heat flux. According to Fredik Svensk (2017) there is a possibility that the electrical heater under the Arcada instrument might cause a noticeable flow of heated air upwards the instrument. This would then interfere with and upwards pointing temperature sensor. However, no such noticeable interference were detected and the instruments main purpose is not to change the surface temperature and a successful measurement is depending on that.

For window 4 the thermal image shows a clear overall rise of the temperature from bottom and up. For this window there is only space to place the sensor upwards alternatively downwards. Due to the narrowness of the window element the resulting effect of the frame is higher. For narrow and small windows there might not be optimal measuring positions. In these cases it is important to know how the temperature difference will affect the measurement.

The recommendation is to keep the outgoing temperature sensor directed horizontally for windows since the temperature difference at bottom and top frame results in natural gas flows as the density changes with temperature. Although this movement is barely noticeable for bigger insulated glass units due to the limited gas space between the separating glass units.

4.4 Thermal images from windows 1-11

In figure 20 thermal images have been taken from windows 1-11. The thermal image has been taken from the frame and the window glazing next to it. This part of the glazing have been taped. From the images the glazing temperatures have been determined 2, 5, 7 and 10 cm next to the frame. Also the linear surface temperature in between the frame and glazing. Infrared reflection always occurs from the surroundings and the angle from which picture is taken from have been taken with consideration to this.

Temperature outside 10 °C

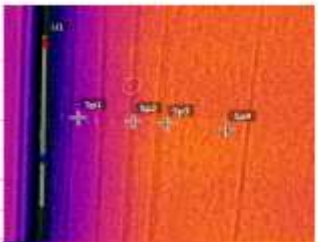
Relative humidity outside 80 %

Temperature inside 26-27 °C

Relative humidity inside 56 %

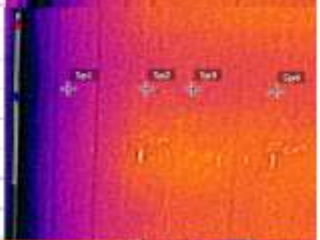
Window 1

Sp1	2cm	25.3 °C
Sp2	5cm	25.9 °C
Sp3	7cm	26.0 °C
Sp4	10cm	26.0 °C
Li1	Max	24.3 °C
	Min	24.1 °C
	Average	24.2 °C



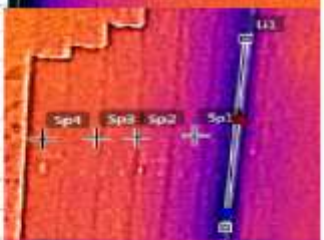
Window 2

Sp1	2cm	26.6 °C
Sp2	5cm	27.1 °C
Sp3	7cm	27.1 °C
Sp4	10cm	27.1 °C
Li1	Max	25.9 °C
	Min	25.7 °C
	Average	25.8 °C



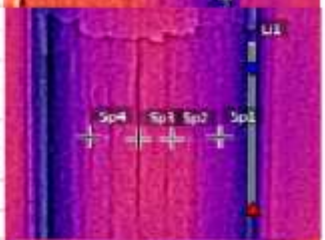
Window 3

Sp1	2cm	26.2 °C
Sp2	5cm	26.7 °C
Sp3	7cm	26.8 °C
Sp4	10cm	26.8 °C
Li1	Max	25.5 °C
	Min	25.0 °C
	Average	25.2 °C



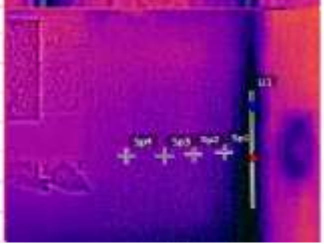
Window 4

Sp1	2cm	26.6 °C
Sp2	5cm	27.0 °C
Sp3	7cm	27.0 °C
Sp4	10cm	26.8 °C
Li1	Max	26.2 °C
	Min	26.0 °C
	Average	26.1 °C



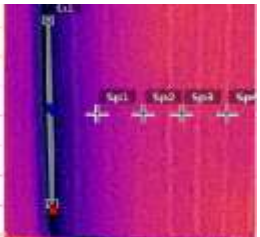
Window 5

Sp1		24.9 °C
Sp2		25.1 °C
Sp3		25.1 °C
Sp4		25.1 °C
Li1	Max	24.3 °C
	Min	24.1 °C
	Average	24.2 °C



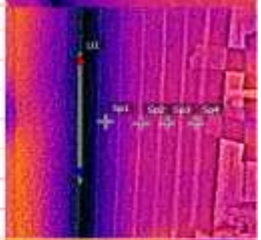
Window 6

Sp1	2cm	26.8 °C
Sp2	5cm	27.2 °C
Sp3	7cm	27.3 °C
Sp4	10cm	27.3 °C
Li1	Max	25.7 °C
	Min	25.4 °C
	Average	25.5 °C



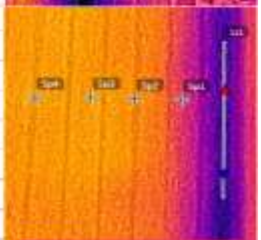
Window 7

Sp1	2cm	27.0 °C
Sp2	5cm	27.6 °C
Sp3	7cm	27.7 °C
Sp4	10cm	27.7 °C
Li1	Max	26.0 °C
	Min	25.9 °C
	Average	26.0 °C



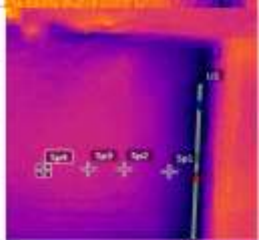
Window 8

Sp1	2cm	24.7 °C
Sp2	5cm	25.1 °C
Sp3	7cm	25.2 °C
Sp4	10cm	25.2 °C
Li1	Max	23.9 °C
	Min	23.7 °C
	Average	23.8 °C



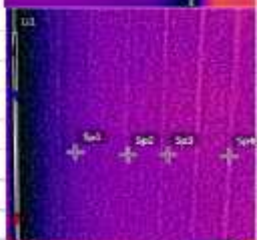
Window 9

Sp1	2cm	25.0 °C
Sp2	5cm	25.4 °C
Sp3	7cm	25.4 °C
Sp4	10cm	25.4 °C
Li1	Max	24.6 °C
	Min	24.5 °C
	Average	24.5 °C



Window 10

Sp1	2cm	27.2 °C
Sp2	5cm	27.5 °C
Sp3	7cm	27.6 °C
Sp4	10cm	27.6 °C
Li1	Max	26.1 °C
	Min	25.9 °C
	Average	25.9 °C



Window 11

Sp1	2cm	26.0 °C
Sp2	5cm	26.2 °C
Sp3	7cm	26.3 °C
Sp4	10cm	26.3 °C
Li1	Max	25.2 °C
	Min	24.6 °C
	Average	24.9 °C

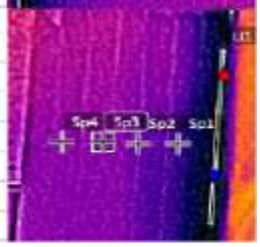


Figure 20. Thermal image of windows 1-11.

4.4.1 Conclusions

In 4.4 figure 20 thermal images were taken from windows 1 to 11. The images were taken from the windows glazing next to the frame, approximately at the vertical center of the window. The temperature were determined from the thermal images at the linear heat transmission point, the edge where the glazing and frame meets. Measurements were also taken 2, 5, 7 and 10 centimeters in horizontal direction from the frame. For all windows recorded thermal images shows that the temperature remains constant from 7 to 10 centimeters in horizontal direction. This gives a strong indication that the heat transmission from the vertical frame becomes negligible with longer distance than 7 centimeters. The thermal image from the window 1 in 4.2 also indicates that this is true from any position along the frame. Possible temperature differences at the surface were no longer measurable with 0,1 ^{o}C accuracy after 7 centimeters distance from the frame.

The conclusion is that the horizontal surface temperature remains relatively constant with longer than 7 centimeters distance from the frame. However it is important to point out that these thermal images are limited to windows with good insulation and practically no leakage from the joints. For in site field measurements the first hand measuring position should always be from the window glazing vertical and horizontal center position. Secondary alternatives should only be considered if the first obvious option is unavailable.

4.5 Interference from solar radiation

In figure 21 the U-value have been plotted as a function of the measured solar radiation intensity. Here the x-axis stands for solar radiation and y-axis for U-value. This means that for measurements taken during solar radiation, the value is set to depend on the solar radiation. The measurements have been taken normally during the sunset while solar radiation were still measurable. The measured solar radiation have been added to the U-value equation to compensate for the heat gain. The temperature difference have been at least 10 ºC for all measurements. The measurements have been taken from window 1 and 2 at the center parts of the window. These values are in the figure as yellow dots. The theoretically expected U-value is 0,81 W/Km^2 and drawn as the green line. The individual measurements are available in Annex 6 with all measurements.

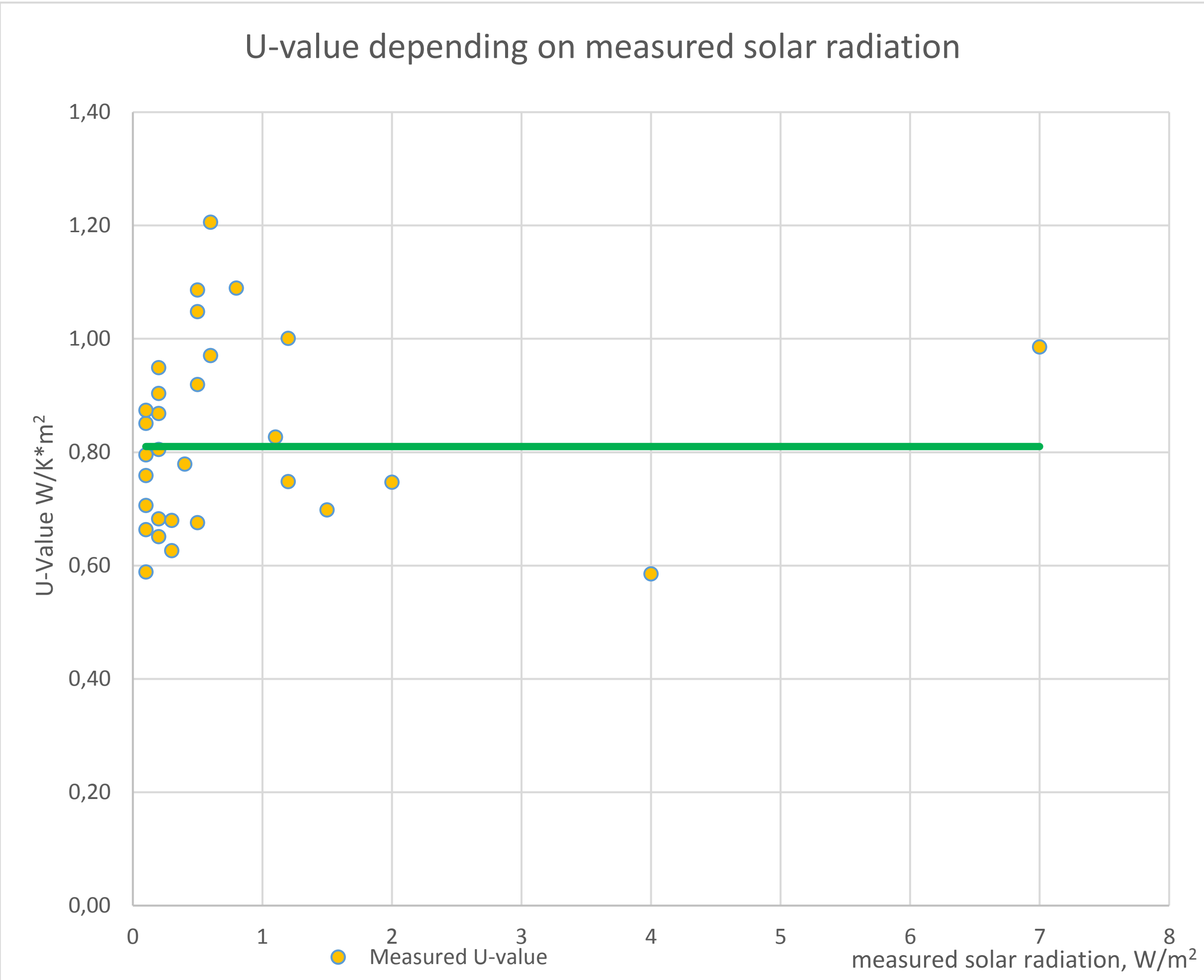


Figure 21. U-value measurements during solar radiation

4.5.1 Conclusions

From 4.5 figure 21 we can see how the U-value is depending on the solar radiation. The theoretically expected U-value for the measuring positions are 0,81 W/Km^2. Overall the main divergence seems to be +/- 20% with a few exceptions. The measured average U-value for 30 measurements are 0,83 W/Km^2. These measurements were taken during sunset with rapidly decreasing exterior temperature. Figure 17 in 4.2 shows a graph over the logged temperatures. A focused graph over the exterior temperatures are also available in Annex 4. The graphs shows that during sunset the temperature is decreasing more rapidly making the measuring conditions more challenging compared to after sunset. This means that any interference and divergence cannot be directly related to the measured solar radiation, but that there is other factors involved as well.

The main issue when measuring during solar radiation is that the radiation requires to be stable during the measuring period. Small changes in intensity can lead to noticeable temperature rise or decrease during the measurement making the measurement to fail. The measurements have also been taken during sunset with solar radiation still available. During sunset the conditions are also more challenging with rapid temperature change. For the measurements in figure 21 the conditions did stay stable long enough for the instrument to finish measurement and give result. Measurements that failed are not included here, but those did occur more often. When interpreting the results one must take into account that the conditions were also challenging due to a more rapid temperature change at sunset.

The recommendation is to avoid places and times when solar radiation might occur. The optimal measuring period during this time of year with aspect to temperature difference is between sunset and sunrise. For the point of measuring the U-value during solar radiation these measurements were taken close to sunset and during the sunset when the temperature difference allowed this. During the time of sunset the temperature change is also more rapid making the conditions for measurements more challenging. Still, based on 30 measurements, the average measured U-value did come close to the theoretically expected U-value.

The conclusion is that measuring U-values during indirect solar radiation is reasonable reliable for at least radiation up to 2 W/m^2. The main noticed issue here were that more measurements are required for successful measurements as the instrument will not give a result if the conditions changes too rapidly.

4.6 U-value measurements from window 1 glazing frame.

The purpose of measuring the window 1 glazing frame here is to determine if the glazing frame U-value can be measured directly and if the same U-value can be obtained between different measurement periods. In figure 22 is listed U-value measurements from window 1 glazing frame from measuring spots 1h, 1i, 1j and 1k. For other windows the glazing frame is inwards the wall making similar measurements impossible with the Rapid U-value meter.

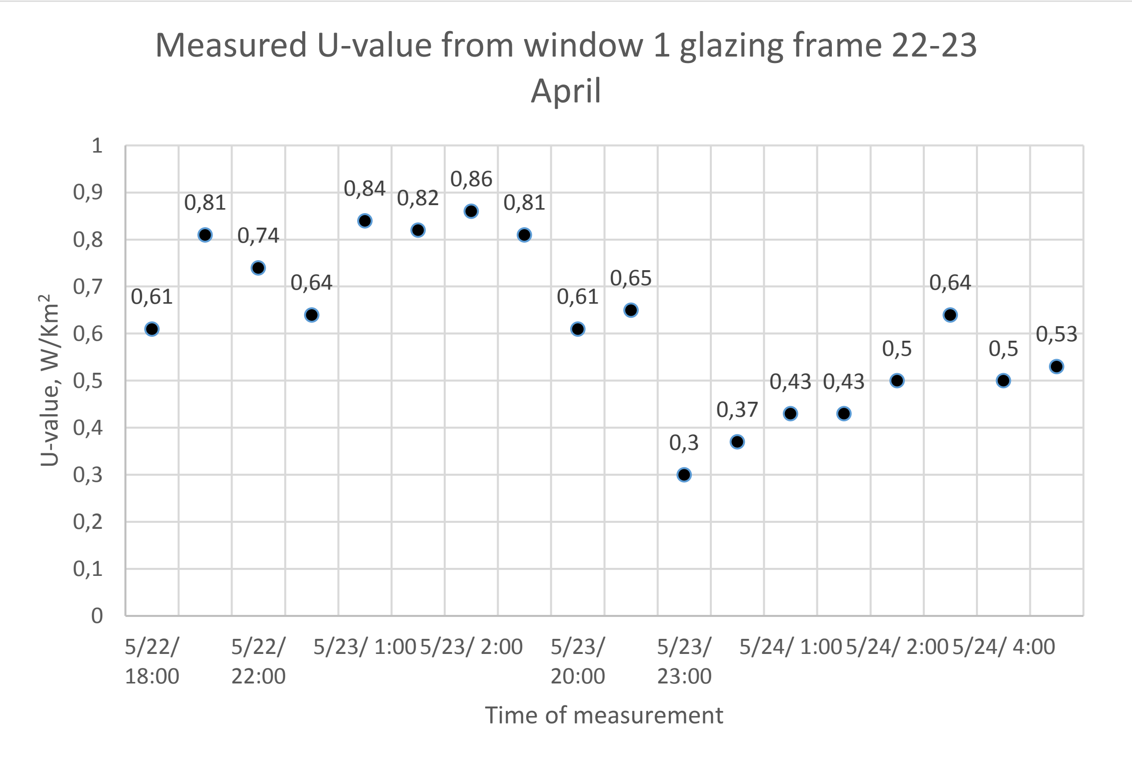


Figure 22. U-value measurements from window 1 glazing frame

4.6.1 Conclusions

From 4.6 figure 22 we can see that when measuring directly on the glazing frame, the measured U-value does spread over a wider range compared with measurements at the glazing. The measuring area is narrower than the instrument main body causing conditions that the instrument have not been calibrated and tested for. In addition the frames surface temperature profile is changing causing significantly different U-values depending on the position that is measured. This means that measuring the window frame gives varying U-values depending on the placement, and the individual measurements diverges more between each other.

The U-value of the glazing frame is partly included in the glazing U-value. However a key part of the heat losses comes from the edge of the glazing and glazing frame (see 2.3.3). This is accounted theoretically as the heat transmission coefficient and a part of this is spread through convection to the glazing. This means that when measuring at the glazing frame surface a part of this heat transmission have already dissipated to the sides. The actual U-value of the glazing frame is not given, so there is no expected theoretical U-value to compare the measured U-values with. The glazing frame U-value is expected to be higher than the glazing U-value. This can also be seen from the thermal images in 4.2-3.

Measurement of the glazing frame is only possible for windows where the frame is in the same level with the wall so that there is space for the instrument. In addition thermal imaging of the glazing frame shows a rapid change of temperature in the horizontal direction, requiring the instrument to be perfectly aligned vertically so that both temperature sensors is placed in the same temperature direction. Furthermore the accuracy of measuring a frame or list have not been satisfactorily determined.

The key issue here is that measuring areas that is narrower than the instruments main body have not yet been properly tested and verified. In order to circumvent this issue this thesis outlines a fully new approach founded on measuring the effect of the glazing frame on glazing (see 2.3.4 and 4.9).

The conclusion is that measuring the glazing frame U-value directly is not possible yet.

4.7 Influence of the vertical location of the measurement position

In figure 23 the U-values have been taken from different vertical positions of the windows 1, 3 and 4. The measuring spots are 1a, 1b, 1c, 1d, 1e, 1f, 3a, 3b, 3c, 4a, 4b and 4c for respective windows. The measurements have been taken from the horizontal center of each window, at vertical center, below vertical center and above vertical center. In figure 23 the x-axis stands for the window glazing height from 0 at the bottom and 1 at the top. The height of the measuring positions have been converted accordingly. The measured U-value for each measuring position is based on an average of 20 measurements.

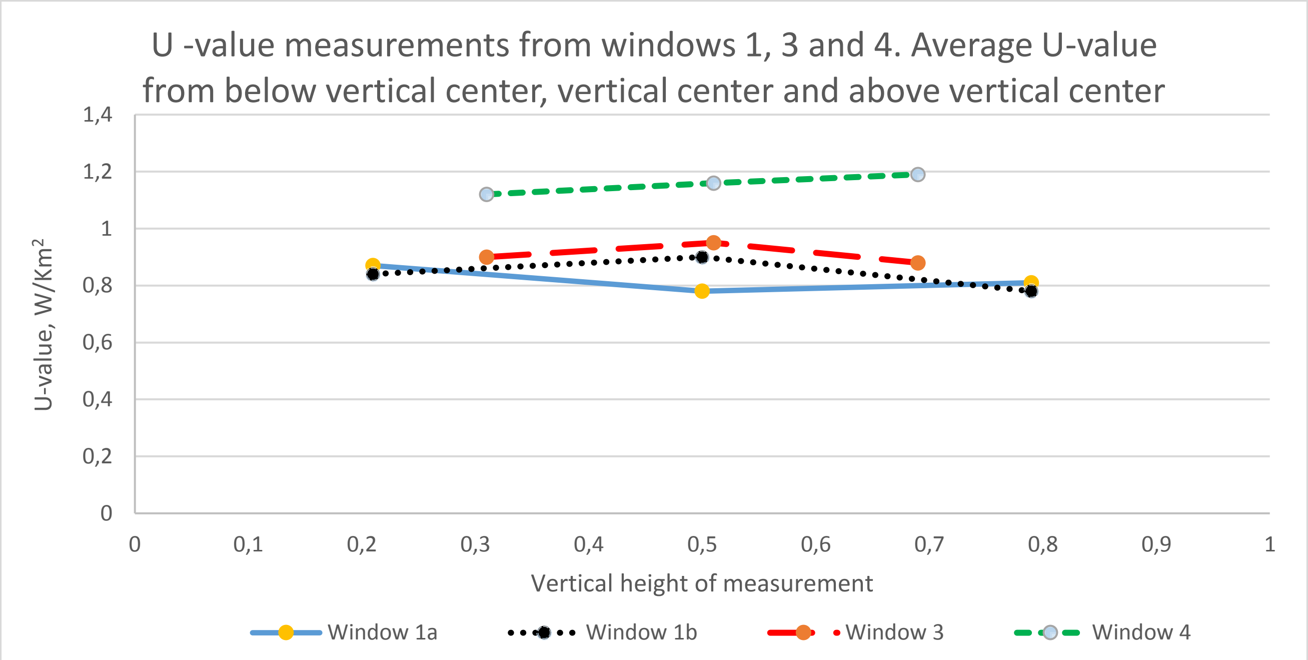


Figure 23. U-value measurements from different heights

4.7.1 Conclusions

From 4.7 figure 23 we can see that the vertical measuring position does not necessary affect the U-value significantly. When comparing measurement positions at different heights between windows 1, 3 and 4 there is some differences depending on the height of the measurement. But this is not conclusive for all windows. For window 4 the measurements were done with the temperature sensor pointing upwards.

To avoid questionable measuring results, the recommendation is to measure at center or close to it.

4.8 U-value measurements with different directions of the reference temperature sensor

In figure 24 the U-values have been measured from the same spot for windows 1, 2 and 5 but with different directions of the reference temperature sensor.

The measuring positions were 1b, 1e, 2a and 5. The measuring positions were in the center part of the windows to limit the disturbance from other factors.

For windows 1 only vertical and upwards direction have been measured due to limited time. The given U-values are the average values for each measurement positions and sensor directions. The U-values are based on an average of 21 measurements for each measuring position.

From figure 24 we can see that the upward sensor direction gives higher U-values compared with downward sensor direction.

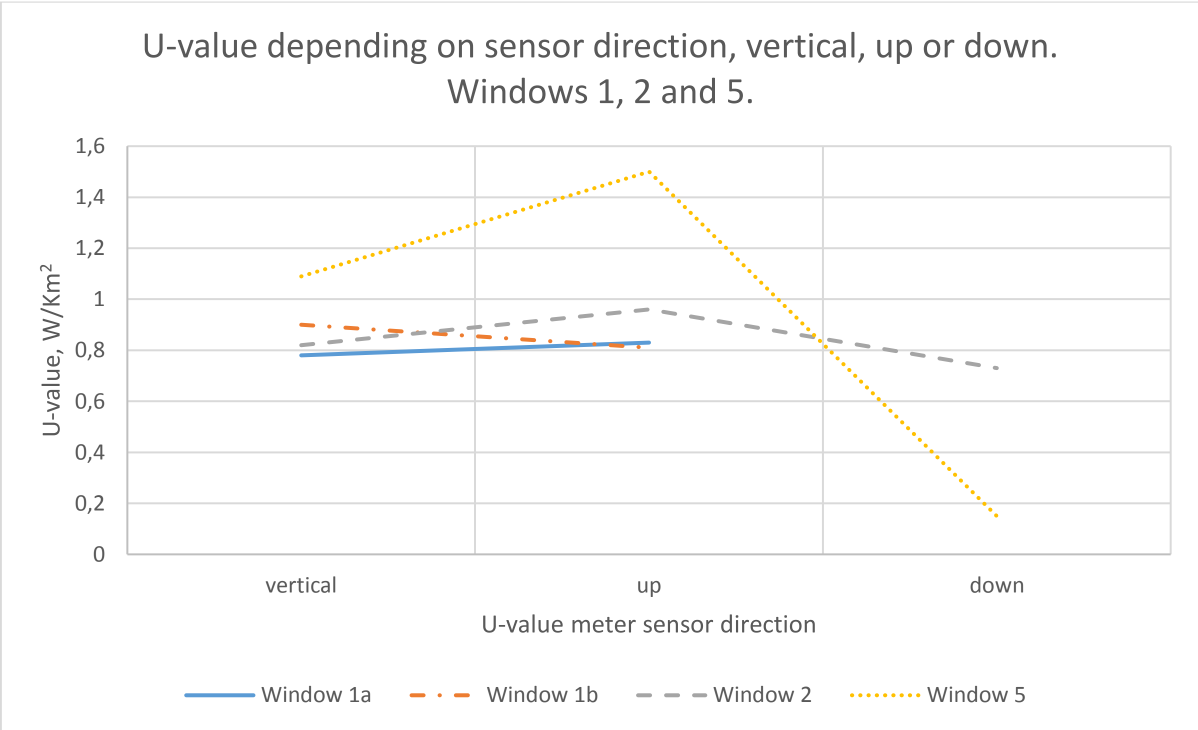


Figure 24. U-value measurements depending on the sensor direction

4.8.1 Conclusions

Measurements on window 5 shows that the small size of the window does cause difficulties due to frames being close to the instrument from all sides (figure 24 in 4.8). Here measurements is still possible if the instrument is placed horizontally and both of the temperature sensors placed on equal distance from the center point. The measurements shows that for the small window 5 the upward direction gives a high U-value 1,5 and downwards low 0,15. Here the expected U-value for the glass due to frame interference is between 1 and 1,2.

The measurements shows that for smaller windows the sensor direction matters more. For the bigger windows 1 and 2 the center glazing part vertical surface temperature change is at the local measuring position hardly noticeable.

The conclusion is that the best temperature sensor direction for the Rapid U-value measurer for window glazing measurements is vertical. However for bigger windows the difference might not be practically noticeable.

4.9 Linear heat transfer C coefficient from window 1 and 2

For windows 1 the linear heat transfer coefficient is given Ψ_g = 0,033 according to the existing specifications (see 2.5.1.1).
For window 1 the center is assumed to be undisturbed due to the distance to the frame. This is also indicated by the thermal images shown in 4.2 and 4.3 where the frame interference can be seen to be negligible with longer than 7 cm distance from frame. While for window 1 the linear heat transmission coefficient is provided by the manufacturer. Respective coefficient for the other windows were calculated from U-value measurements by first using equation 11 with the parameters for window 1 in table 8 to get C. After this the heat transmission constant ψ_{gC} can be calculated for the other windows with the equation 12 and based on the U-value measurements (see table 8)

$$C = \frac{\psi_g}{U_{gf} - Ug}$$

(18)

This gives C = 0,132

The heat transmission constant ψ_{gC} can now be calculated with equation 12.

$$\psi_{gC} = C * (U_{gf} - U_g) \tag{19}$$

Where

ψ_{gC} is the linear heat transmission coefficient calculated from locally measured U-value differences at the glazing next to the glazing frame and the glazing center.

U_g is the measured U-value at the measurement position in the middle of the window.

U_{gf} is the measured U-value at the measurement position on the window glazing next to the frame

C is the constant that gives the relationship between the U-value difference U_{gf}-$U_g$and ψ_{gC}.

In table 8:

1) for windows 3, 4 and 5 average values were used for the glazing center, U_g
2) for windows 4, 5, 8 and 9 the linear heat transfer coefficient were interpolated from window 1 heat transmission coefficient by assuming the surface temperature difference 2 cm and 10cm away were linearly depending at the linear heat transmission coefficient.
3) for window 12 the center glazing U-value, U_g have been measured during Mars 30-31.
4) the glazing U-value close to the frame were measured 16th June as well as glazing center. Due to the low temperature difference the measurements were not reliable for direct use. However from these measurements it was possible to get the U-value difference between center part and close to frame and solve for the heat transfer coefficient.

Table 8. Heat transmission coefficients for windows 1-12

Window type	Measurement day	U_g	U_{gf}	U_{gf}-U_g	ψ_g
Window 1	14-15.6	0,81	1,06	0,25	0,033
Window 2	1-2.6	0,77	1,03	0,26	0,034
Window 2	2-3.6	0,83	1,02	0,19	0,025
Window 2	3-4.6	0,74	1,08	0,34	0,045
Window 3	1-3.6	[1]0,95			0,028
Window 4	1-3.6	[1]1,16			[2]0,0094
Window 5	May	[1]1,09			[2]0,0094
Window 6	12-15.6	0,87	1,17	0,3	0,040
Window 7	12-15.6	0,96	1,17	0,21	0,028
Window 8	12-15.6	0,72			[2]0,024
Window 9	12-15.6	1,06			[2]0,020
Window 10	12-15.6	1,46	1,49	0,03	0,0040
Window 11	12-15.6	1,36	1,49	0,13	0,017
Window 12	30-31.3,16.6	[3]0,66		[4]0,4	0,053

4.9.1 Conclusions

The linear heat transmission coefficient that takes the edge losses between the glazing frame and glazing into account cannot be measured directly with on-site measurements. However the resulting effect on the window glass from both the frame and the linear heat transmission can be measured indirectly from the window glass next to the frame. The hypothesis for this relationship and equation is given in 2.3.4.

4.10 Comparison between measured and expected U-values

For table 9 the measured U-value for whole window, U_w, have been calculated using equation 10 (see 2.3.3). The area and length dimensions A_g, A_f and l_g are avaible in table 2, 3 and 4. U_g and $\psi_g$is in table 9. The frame U-value, U_f, is available from the window specifications and outer frame structure given in 3.3.

Equation 10:

$$U_w = \frac{A_g U_g + A_f U_f + l_g \psi_g}{A_g + A_f} \tag{20}$$

The expected U-values in table 9 is from tables 2- 4. For windows 2-5 and 12 the expected U-values is based on given values from the manufacturer with an accuracy of 5% (see 3.3.1 and 3.3.3). For windows 6-11 the U-value and accuracy is based on the window specifications (see 3.3.2). These windows are older and some leakage of argon have to be expected. For windows 10 and 11 the window frame is more compact and there is no mention of argon making the expected U-value less accurate.

Table 9. Measured and expected U-value for windows

Window Type	Measurement test day	Measured U_w-value	Expected U_w -value	Accuracy
Window 2	1-2.6	1,017	1,038	+/- 5%
Window 2	2-3.6	1,023	1,038	+/- 5%
Window 2	3-4.6	1,035	1,038	+/- 5%
Window 3	1-3.6	1,18	1,133	+/- 5%
Window 4	1-3.6	1,2	1,228	+/- 5%
Window 5	May	1,167	1,189	+/- 5%
Window 6	12-15.6	1,131	1,1	+/-10%
Window 7	12-15.6	1,138	1,1	+/-10%
Window 8	12-15.6	1,017	1,1	+/-10%
Window 9	12-15.6	1,226	1,2	+/-10%
Window 10	12-15.6	1,423	1,3	+/-23%
Window 11	12-15.6	1,389	1,3	+/-23%
Window 12	30-31.3,16.6	0,927	0,98	+/- 5%

In figure 25 is the average measured U-values for all windows expected for the reference window 1. All U-values are from table 9. The black line is drawn between the measured U-values of the windows from 2 to 12. The red line is drawn for upper limit and also for the lower limit. This comes from the given accuracy of the expected value in table 9. The precise U-value is not known, and so the actual U-value can be anywhere inside the red lines.

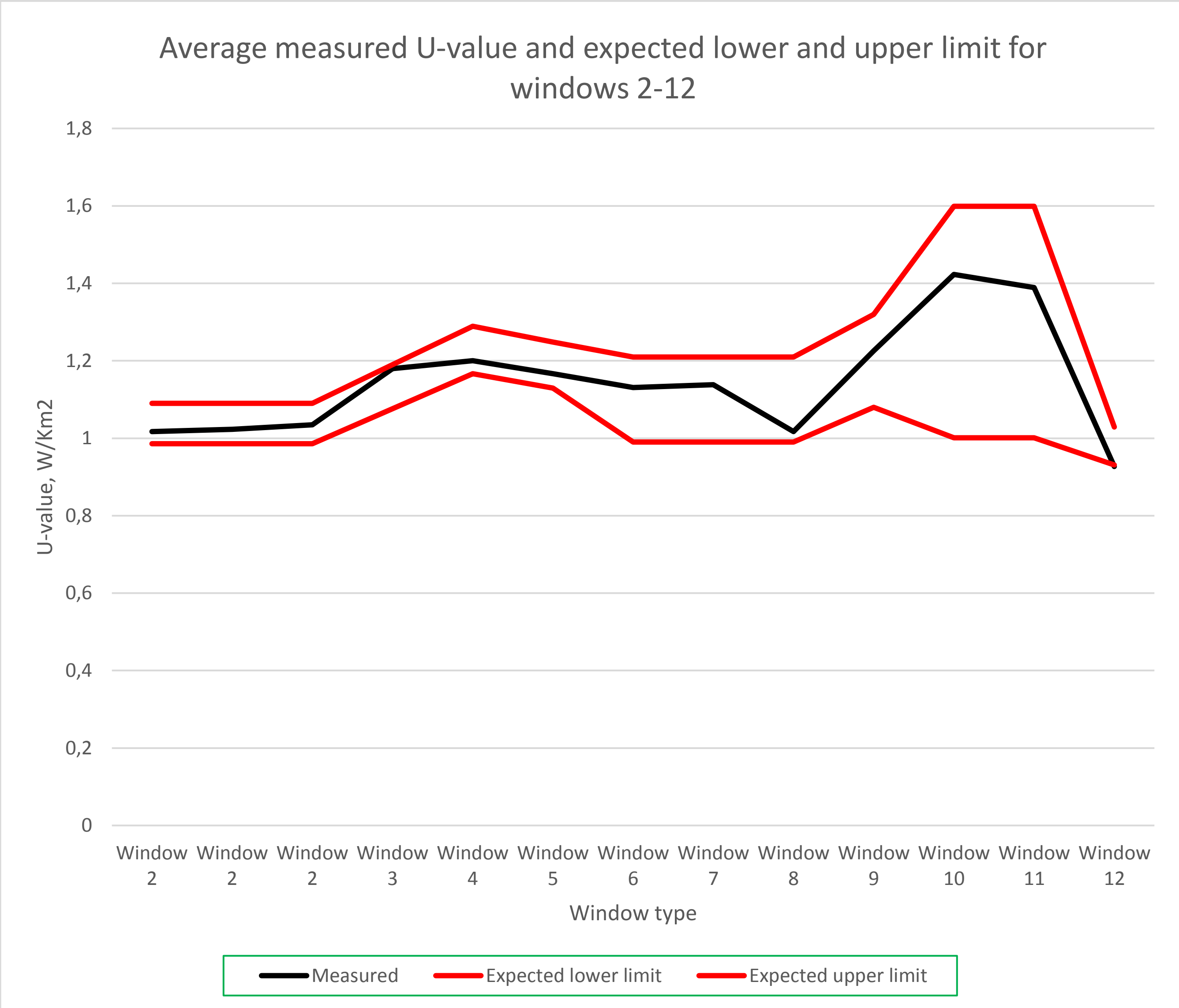


Figure 25. Measured U-value from windows 2-12 compared with expected limits

4.10.1 Conclusions

From 4.10 we can see that all measured U-values for the window were within the expected U-value range in figure 25. We get a clear indication that this method can significantly improve the accuracy of U-value measurements for windows. These measurements were done during challenging conditions with summer closing by rapidly.

Due to the limited amount of windows available the accuracy and reliability of the method is still unclear. These preliminary results indicated that the methods accuracy might be able to rival the theoretically calculated official U-values given by the manufacturer with an accuracy of +/- 5 %.

For small windows U-value measuring have a higher margin of error due to more disturbance from the glazing frame. The U-vale for small windows can also be calculated based on measurements on same type of bigger windows. For practical purposes the focus is on the bigger windows as these makes the main impact on a buildings heating demand. For bigger windows the accuracy of the Rapid U-value meter is good when measuring the glazing part thanks to the windows temperature being horizontally almost perfectly even. Due to temperature differences in vertical direction, especially next to the frame Rapid U-value meter would not work accurately for small windows that is narrower than 30 cm. For bigger windows the vertical temperature difference evens out to a longer distance making measurements possible. Measuring close to the vertical frame also have rapid change of temperature in horizontally direction.

5 ANSWERS TO RESEARCH QUESTIONS

In Chapter 5 the answers to the questions outlined in 1.4 are given.

5.1 How to measure the U-value of a window

The U-value of the window, U_w, can be calculated with equation 10 in 2.3.3.
For the equation 10 the linear heat transmission coefficient, ψ_g, can be approximated by measuring at the local glazing U-values from the center part of the glazing and next to the glazing frame and then use equation 12 and 11 explained in 2.3.4.
The glazing U-value, U_g, is measured directly with the Rapid U-value meter. The U-value for the frame, U_f, cannot practically be measured with Rapid U-value meter. However the frame has a simple construction and thus making a theoretical calculation for it both practical precise enough. This is based on the facts that both the materials and respective dimensions can normally be determined based on visible inspection (see 2.5).

5.2 Reliability of the result

Rapid U-value meters were tested during this project (see 4.5) with repeated measurement on windows 1 and 2 with known U-value at the glazing center. The results for each instrument did come within +/- 5% of the expected U-value at the glazing center. This confirms the reliability and accuracy of the devices.
All of the measured windows U-values did come within the expected U-values during the testing of the method described in 6.1 Based on the results this method to calculate the windows U-value is reliable with an accuracy to up to +/- 5% for the windows measured. To draw a more general conclusion more testing needs to be done additionally with other types of window elements and different installations.

5.3 The accuracy and measuring time of the measurement

The accuracy of the measured windows U-value can possibly be as high as 95% during the right conditions with many measurements during different weather conditions. For the conditions here the required time for credibly measurements of the windows U-value can be done in about 5-6 hours. During this time the temperature first decreases during and after the sunset, while starting to rise again before sunset. Here the key point is to measure the U-values when the outside temperature is decreasing and again when the outside temperature is increasing. This recommendation is based on conditions where the outside temperature is changing noticeably and shorter measuring times can be possible if the weather conditions are more favorable. The accuracy is also related to the amount of measurements and can thus be improved with more measurements.

From table 9 and figure 25 we can see that all measured U-values on new windows comes within the theoretically expected U-values given accuracy range of +/- 5%. This indicates that the in site measurements might be able to rival the accuracy of theoretically calculated U-values. Also, we know that the theoretical values does not in any way take into account the individual variations between windows occurring during production, transportation, installation and use.

5.4 The effect of solar interference

Based on the measurements and explanation in 4.5 measuring U-values of window glazing during times with indirect solar radiation is possible up to an intensity of at least 2 W/m^2.

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APPENDICES

Annex 1 - Arcada window product description

Pihla TUOTELUETTELO 10.10.2018 Sivu 1 / 1

Arcada Pekkala Ossian

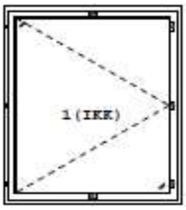
Rivinro	Tuote	Leveys	Korkeus	Määrä	Malli	Karmi
1	VARMA	1230	1480	1	A	170

Pintak. Puuosat: Ma/Valk — Ulkoputte: Ma/Valk — Verhous: Ma/Valk

Tunnus: 1

Sisäp.lasi: 2K4/4Se-16 AR TGI

Pintahelat: Valkoiset — Ulkop.lasi: Float 4



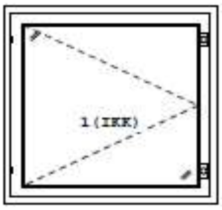
Rivinro	Tuote	Leveys	Korkeus	Määrä	Malli	Karmi
2	VARMA	900	900	1	A	170

Pintak. Puuosat: Ma/Valk — Ulkoputte: Ma/Valk — Verhous: Ma/Valk

Tunnus: 2

Sisäp.lasi: 2K4/4Se-16 AR TGI

Pintahelat: Valkoiset — Ulkop.lasi: Float 4



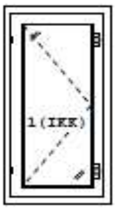
Rivinro	Tuote	Leveys	Korkeus	Määrä	Malli	Karmi
3	VARMA	450	900	1	A	170

Pintak. Puuosat: Ma/Valk — Ulkoputte: Ma/Valk — Verhous: Ma/Valk

Tunnus: 3

Sisäp.lasi: 2K4/4Se-16 AR TGI

Pintahelat: Valkoiset — Ulkop.lasi: Float 4



Rivinro	Tuote	Leveys	Korkeus	Määrä	Malli	Karmi
4	VARMA	300	900	1	A	170

Pintak. Puuosat: Ma/Valk — Ulkoputte: Ma/Valk — Verhous: Ma/Valk

Tunnus: 4

Sisäp.lasi: 2K4/4Se-16 AR TGI

Pintahelat: Valkoiset — Ulkop.lasi: Float 4

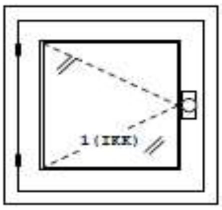
Rivinro	Tuote	Leveys	Korkeus	Määrä	Malli	Karmi
5	VARMA	450	450	1	A	170

Pintak. Puuosat: Ma/Valk — Ulkoputte: Ma/Valk — Verhous: Ma/Valk

Tunnus: 5

Sisäp.lasi: 2K4/4Se-16 AR TGI

Pintahelat: Valkoiset — Ulkop.lasi: Float 4



Ikkunat: kätisyys sisältäpäin Ovet: kätisyys avautumispuolelta Liukuovet: kätisyys sisältäpäin
Kokonaismäärä = määrä+peilikuvat TI=tuuletusikkuna, L=luukku, U=umpiosa, H=hyttyspuite

Annex 2 – Calibration validation test Case number 11 RAKSYSTEMS

Calibration validation test:

Case number: 11 RAKSYSTEMS

Test system: cold box test system with variable front walls:

- Test wall 1: Window frame with double glazing (interstitial space 30 mm, silicone sealing on frames) with U-value of 2.8 W/K*m^2
- Test wall 2: 100 mm thick EPS wall tested earlier by VTT expert services and having a U-value of 0.31 W/K*m^2

Table: Measured values and calculated U-values given as U-air.

instr. No	position X,Y	Rse	wind on facade	Rse-wind	Rsi	outdoor T	meas time	P/mW	T-in	U-air	Expected
110	B2R2L4	0.04	0.5	-0.07	0.13	5.8	20	35	20.4	0.27	0.3
110	B1R1L4	0.04	0.5	-0.07	0.13	8.8	50	287	16.9	2.96	2.8
111	B2R1L2	0.04	0.5	-0.07	0.13	5.8	45	29	19.6	0.24	0.3
111	B2R1L1	0.04	0.5	-0.07	0.13	8.8	60	237	15.9	2.83	2.8
112	B1R2L3	0.04	0.5	-0.07	0.13	5.8	40	24	20.6	0.19	0.3
112	B1R2L2	0.04	0.5	-0.07	0.13	8.8	65	250	17.0	2.62	2.8
113	B1R2L4	0.04	0.5	-0.07	0.13	5.8	30	24	20.3	0.20	0.3
113	B2R1L4	0.04	0.5	-0.07	0.13	8.8	65	227	16.6	2.52	2.8
114	B2R2L2	0.04	0.5	-0.07	0.13	5.8	20	49	20.4	0.36	0.3
114	B1R1L1	0.04	0.5	-0.07	0.13	8.8	55	275	17.0	2.83	2.8
115	B1R1L3	0.04	0.5	-0.07	0.13	5.8	20	40	20.3	0.30	0.3
115	B1R1L2	0.04	0.5	-0.07	0.13	8.8	70	303	17.1	3.04	2.8
116	B1R2L2	0.04	0.5	-0.07	0.13	5.8	45	33	20.6	0.25	0.3
116	B2R2L3	0.04	0.5	-0.07	0.13	8.8	45	248	17.0	2.60	2.8
117	B2R1L1	0.04	0.5	-0.07	0.13	5.8	25	24	20.3	0.20	0.3
117	B1R2L4	0.04	0.5	-0.07	0.13	8.8	50	309	17.2	3.05	2.8
118	B1R2L1	0.04	0.5	-0.07	0.13	5.7	65	50	19.8	0.38	0.3
118	B2R1L2	0.04	0.5	-0.07	0.13	8.8	65	241	16.8	2.60	2.8
119	B2R1L4	0.04	0.5	-0.07	0.13	5.8	40	36	20.4	0.28	0.3
119	B2R1L3	0.04	0.5	-0.07	0.13	8.8	55	275	17.3	2.75	2.8

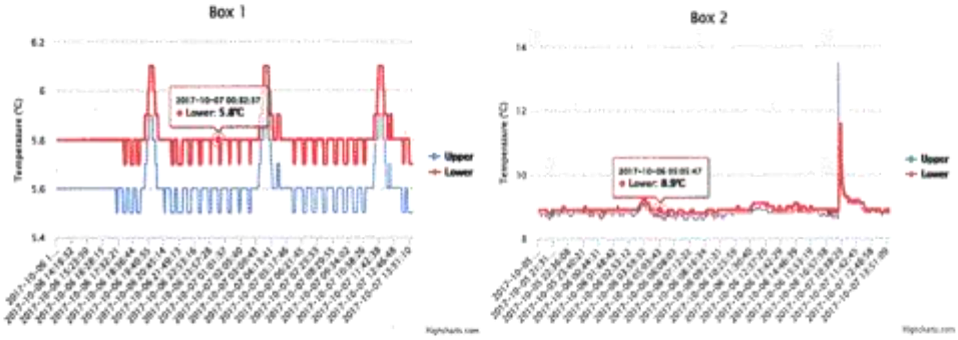


Fig: Cold box temperatures during measurements and > 20 hrs before measurements.

Notes on the tests: Notable variation found between various measurements; this was associated to test position and never instrument specific ones. Therefore we expect that in general, these instruments are allowing similar precision as earlier and thus error typically less than 0.1 W/K*m^2.

Date: 16/10/17

Tested by: ______________________ (Mikael Paronen)

Annex 3 - Product specification for window 12

Tuotekuvaukset

MSEA

Avattava, kaksipuitteinen ja kolmilasinen MSEA-puualumiini -ikkuna

Avattava, kaksipuitteinen ja kolmilasinen MSEA-puualumiini -ikkuna on Suomessa yleisimmin asuinrakennuksissa käytetty ikkunarakenne.

Rakenne on varmatoiminen ja sillä on hyvä lämmöneristyskyky sekä erinomainen ääneneristyskyky ja säänkesto.

Tekniset tiedot

Sisäpuitteen lasi	2K elementti (Super Spacer® –listalla)
Ulkopuitteen lasi	Tasolasi
Materiaali sisäpuite	Oksaton sormijatkettu mänty
Materiaali karmi	2-sivun oksaton sormijatkettu mänty
Materiaali ulkopuoli	Alumiini
Helat	Metallia. Valkoisessa ikkunassa valkoiset helat, muissa kromiset
Tiivisteet	Kolminkertainen TPE-Tiiviste
Paino (1 m²)	42,2 Kg
Säänkesto	Erinomainen EN12208, E1050
U-arvo W/m²K	0.98
Äänieristys	38 dB/Rw + Ctr
Karmisyvyydet	131, 170 ja 200 mm

CE

PIKLAS OY
LEIVISKÄNTIE 2
92930 PYHÄNTÄ
18

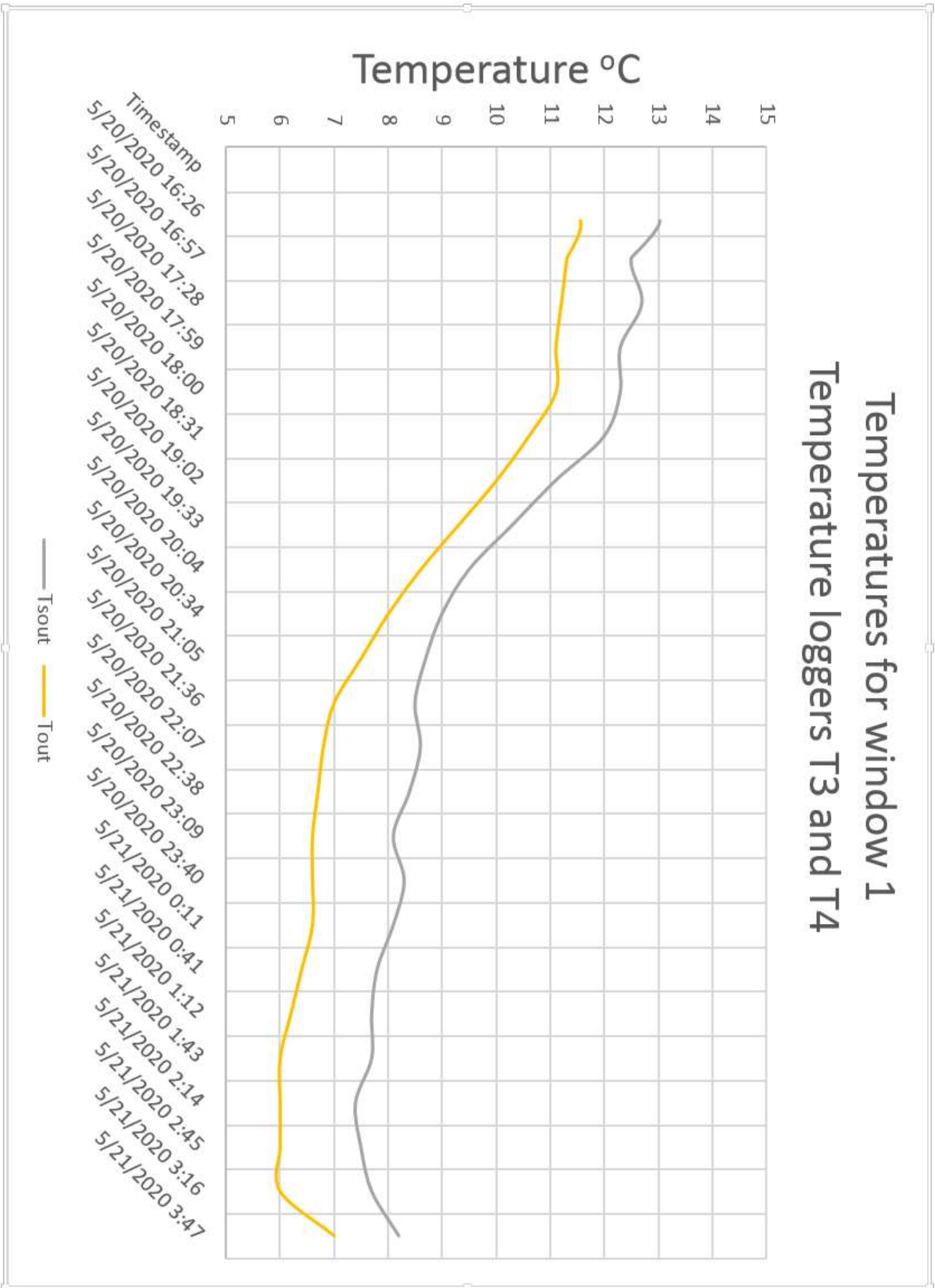
EN 14351 – 1:2006+A1

Puualumiini-ikkuna on tarkoitettu rakentamiseen uudis- ja saneerauskohteissa

Sateenpitävyys- Ei suojattu (A):	NPD
Vaaralliset aineet:	NPD
Tuulenpaineen kestävyys – Testipaine	NPD
Tuulenpaineen kestävyys- Kehän taipuma:	NPD
Turvalaitteidem kestävyys:	NPD
Ilmoitettu lämmönläpäisykerroin	Us 0,98 W/m2K
Säteilyominaisuudet- Aurinkotekijä	≤0,55
Äänitekniset ominaisuudet:	NPD
Ilmanpitävyys	NPD

Annex 4 - Logged temperatures for window 1

Logged temperatures for window 1. Temperature logger T3 measures the exterior surface temperature, T_{se} of window 1. Temperature logger T4 measures the exterior air temperature, T_e. The measurement period from 20th April to 21th April. The graph shows how the temperature changes during the measuring period.



Annex 5

For calculations of U-value in table 2 R_{si} = 0,13 and wind corr R_{se} = -0,07 have been used.

Table 10. Measurements used for verification of the instruments from windows 1 and 2

instr. No	Time	Temp. difference Delta T, C	meas. time min.	instr. power P/mW	solar meas.	U-value meas. W/Km2	U-value Expected W/Km2	Difference from expected
112	18.5.2020 22:00	18,9	70	115		0,61	0,81	24%
112	18.5.2020 23:00	19,6	55	126		0,64	0,81	21%
112	19.5.2020 0:00	19,9	45	144		0,72	0,81	12%
112	19.5.2020 2:00	22,1	60	163		0,73	0,81	10%
112	19.5.2020 3:00	22,3	65	163		0,72	0,81	11%
112	10.5.2020 21:00	13,1	60	61	1,4	0,63	0,81	22%
112	11.5.2020 0:00	13	85	117		0,96	0,81	18%
112	20.5.2020 1:00	21,2	200	165		0,84	0,81	3%
112	20.5.2020 4:00	18,3	135	179		1,01	0,81	24%
112	23.5.2020 18:00	16,1	140	101	1,5	0,78	0,81	3%
112	23.5.2020 19:00	16,1	100	108	0,1	0,73	0,81	10%
112	23.5.2020 22:00	16,2	110	162		1,02	0,81	26%
112	23.5.2020 23:00	16,1	65	107		0,71	0,81	12%
112	24.5.2020 1:00	16	40	102		0,69	0,81	14%
112	24.5.2020 2:00	16,1	40	126		0,84	0,81	4%
112	5/24/2020 23:50	12,8	65	106		0,82	0,81	2%
112	5/25/2020 0:53	12,7	50	115		0,89	0,81	10%
112	5/25/2020 1:55	12,6	45	115		0,9	0,81	11%
114	13.5.2020 0:00	22,7	60	154		0,67	0,81	17%
114	16.5.2020 2:00	17,8	200	161		0,88	0,81	9%
114	17.5.2020 3:00	22,8	75	183		0,79	0,81	3%
114	10.5.2020 1:00	23	155	212		0,95	0,81	17%
114	22.5.2020 22:00	25,9	200	181		0,69	0,81	15%
114	23.5.2020 2:00	30,6	200	292		0,92	0,81	13%
114	23.5.2020 5:00	25,1	170	250		0,96	0,81	18%
114	23.5.2020 7:00	17,7	90	139	9	1,22	0,81	51%
114	24.5.2020 21:00	14,2	25	60	0,3	0,54	0,81	33%
114	25.5.2020 0:00	16,4	60	80		0,57	0,81	29%
114	25.5.2020 1:00	14,1	55	115		0,94	0,81	16%
114	25.5.2020 2:00	13,9	40	105		0,86	0,81	6%
114	25.5.2020 3:00	13,8	45	122		0,96	0,81	19%
114	27.5.2020 22:00	11,6	50	81		0,71	0,81	12%
114	27.5.2020 23:00	11,4	50	29		0,29	0,81	64%
114	28.5.2020 0:00	11,8	45	106		0,89	0,81	10%
114	28.5.2020 1:00	11,9	45	101		0,85	0,81	4%
114	28.5.2020 3:00	12,4	50	105		0,84	0,81	4%
114	28.5.2020 5:00	11,7	65	105		0,89	0,81	10%
114	5/11/2020 18:04	18,7	120	200	0,8	1,07	0,81	32%
114	5/11/2020 23:49	20,2	85	143		0,7	0,81	13%
114	5/20/2020 0:45	19,3	200	141		0,72	0,81	11%
114	5/20/2020 3:53	18,7	195	183		0,95	0,81	17%
115	10.5.2020 1:00	22,8	130	173		0,75	0,81	8%
115	12.5.2020 0:00	21,6	60	164		0,81	0,81	0%

115	12.5.2020 3:00	21,5	60	166		0,81	0,81	0%
115	12.5.2020 5:00	19	55	156		0,84	0,81	4%
115	13.5.2020 21:00	22,6	115	158		0,76	0,81	6%
115	14.5.2020 5:00	17	200	199		1,1	0,81	36%
115	17.5.2020 0:00	21,6	125	115		0,59	0,81	27%
115	17.5.2020 3:00	22,8	140	145		0,67	0,81	18%
115	17.5.2020 4:00	20,7	105	173		0,84	0,81	3%
115	20.5.2020 21:00	16,9	70	119	0,2	0,8	0,81	1%
115	20.5.2020 22:00	17,7	45	88		0,57	0,81	30%
115	21.5.2020 2:00	18,2	70	131		0,79	0,81	2%
115	21.5.2020 3:00	17,6	40	149		0,89	0,81	10%
115	21.5.2020 4:00	16	40	152		0,95	0,81	18%
115	22.5.2020 14:00	8,2	20	44	2	0,92	0,81	13%
115	22.5.2020 15:00	8	20	9	2	0,5	0,81	38%
115	22.5.2020 17:00	9,1	25	36	2	0,75	0,81	8%
115	23.5.2020 0:00	29,5	200	179		0,66	0,81	18%
115	23.5.2020 4:00	28,6	65	243		0,88	0,81	8%
115	23.5.2020 5:00	25,5	80	240	0,8	1,06	0,81	31%
115	5/8/2020 22:11	15,4	90	124		0,8	0,81	2%
115	5/8/2020 23:45	15	55	106		0,71	0,81	13%
115	5/27/2020 18:07	8,6	20	36		0,46	0,81	43%
115	5/27/2020 18:39	8,8	45	55		0,66	0,81	19%
115	5/27/2020 19:41	9,4	45	41		0,48	0,81	41%
115	5/27/2020 21:15	10,1	40	66		0,67	0,81	17%
115	5/27/2020 22:49	10,4	55	77		0,75	0,81	7%
115	5/28/2020 0:23	11,3	45	81		0,73	0,81	10%
115	5/28/2020 1:26	11,4	30	76		0,68	0,81	16%
115	5/28/2020 3:00	11,7	40	85		0,74	0,81	9%
115	5/28/2020 5:05	12	25	74		0,63	0,81	22%
116	10.5.2020 21:00	12,4	50	114		0,91	0,81	12%
116	26.5.2020 3:00	16,4	70	140		0,84	0,81	4%
116	5/20/2020 23:14	17	200	156		0,9	0,81	11%
116	5/21/2020 2:53	17,7	200	160		0,88	0,81	9%
116	5/16/2020 3:09	16,6	70	147		0,87	0,81	7%
116	5/24/2020 17:03	10,2	35	73	0,4	0,77	0,81	5%
116	5/24/2020 18:06	10,6	55	90	0,1	0,86	0,81	6%
116	5/24/2020 19:08	11,2	55	86	0,1	0,78	0,81	3%
118	12.5.2020 0:00	21,2	75	175		0,81	0,81	0%
118	12.5.2020 3:00	21,2	60	185		0,85	0,81	5%
118	12.5.2020 5:00	18,5	65	175		0,92	0,81	13%
118	19.5.2020 23:00	19,9	100	145		0,72	0,81	11%
118	20.5.2020 0:00	20,2	110	161		0,78	0,81	3%
118	20.5.2020 4:00	17,6	150	153		0,85	0,81	5%
118	20.5.2020 22:00	17,2	90	99	0,1	0,59	0,81	27%
118	20.5.2020 23:00	17,2	65	144		0,82	0,81	2%
118	21.5.2020 0:00	17,1	65	145		0,83	0,81	3%
118	21.5.2020 2:00	17,8	90	158		0,87	0,81	7%
118	8.5.2020 22:00	14,6	50	111	0,1	0,8	0,81	2%
118	8.5.2020 23:00	16,1	105	123		0,85	0,81	5%
118	5/12/2020 23:51	20,4	50	134		0,65	0,81	19%

118	5/16/2020 23:01	18,9	70	197		1	0,81	24%
118	5/17/2020 0:04	19,1	60	178		0,91	0,81	12%
118	5/17/2020 4:46	18,8	200	168		0,87	0,81	8%
118	5/21/2020 21:42	13,6	60	105		0,77	0,81	5%
118	5/21/2020 23:47	14	105	107		0,76	0,81	6%
118	5/22/2020 1:53	14,7	40	108		0,73	0,81	9%
118	5/22/2020 2:56	15,2	95	137		0,88	0,81	9%
118	5/22/2020 6:04	12,7	200	125		0,96	0,81	19%
118	5/14/2020 5:08	17,7	200	172		0,94	0,81	16%
118	5/15/2020 22:27	16,4	65	106		0,65	0,81	20%
118	5/26/2020 2:59	13,8	65	96		0,7	0,81	13%
118	5/26/2020 4:02	12,7	175	108		0,84	0,81	4%
118	5/21/2020 11:47	9	175	103	0,6	1,18	0,81	45%
118	5/21/2020 17:00	9,6	85	99	0,5	1,06	0,81	31%
118	5/21/2020 19:37	12,1	160	74	0,5	0,67	0,81	18%
119	8.5.2020 22:00	14,9	95	143	0,2	0,95	0,81	17%
119	8.5.2020 23:00	16,4	40	124		0,75	0,81	7%
119	15.5.2020 21:00	17,8	60	63	4	0,59	0,81	28%
119	15.5.2020 23:00	19	80	134		0,7	0,81	13%
119	13.5.2020 0:00	23	65	141		0,66	0,81	19%
119	21.5.2020 10:00	9,3	20	13	7	0,99	0,81	22%
119	21.5.2020 17:00	10,5	95	82	1,2	1	0,81	24%
119	21.5.2020 19:00	13,8	50	77	1,2	0,75	0,81	8%
119	21.5.2020 20:00	14,7	40	79	0,2	0,65	0,81	20%
119	21.5.2020 21:00	15,1	65	106		0,81	0,81	0%
119	5/10/2020 0:48	20	200	162		0,8	0,81	2%
119	5/23/2020 19:39	16,1	200	111	0,1	0,7	0,81	14%
119	5/23/2020 20:42	16,7	60	132		0,78	0,81	3%
119	5/23/2020 22:47	15,7	90	96		0,62	0,81	24%
119	5/24/2020 0:52	15,7	70	126		0,79	0,81	2%
119	5/24/2020 2:57	15,4	115	158		1	0,81	23%

Annex 6 – All measurements

Table 11. All measurements during the project

Instr. No	Measur location location	Temp. sensor direction	Time month/day hour	Temp. Exterior T5, R-294 Te, C	Wind corr coeffic. Rse	Measur time min	Measur Power [mW]	Temp Interior Surface Tis	measur Solar W/m2	U-value W/K*m2
Window 1, Frame										
119	1l	up	5/22 14:00	16,8	-0,07	20	14	25,6		0,21
119	1l	up	5/22 15:00	16,6	-0,07	*	*	*		#VALUE!
119	1l	up	5/22 16:00	16,1	-0,07	*	*	*		#VALUE!
119	1l	up	5/22 17:00	15,2	-0,07	35	28	24,9		0,33
183	1l	up	5/23 4:00	5,9	-0,07	150	199	37		0,63
183	1l	up	5/23 7:00	18	-0,07	75	185	37,5		0,92
183	1l	up	5/23 8:00	21	-0,07	60	147,4	36,4		0,93
115	1l	up	5/23 20:00	10,6	-0,07	200	37	28,4		0,23
115	1l	up	5/23 23:00	9,5	-0,07	165	49	26,9		0,30
115	1l	up	5/24 0:00	9,3	-0,07	40	60	26,3		0,37
115	1l	up	5/24 1:00	9,1	-0,07	53	68	25,6		0,43
115	1l	up	5/24 3:00	8,8	-0,07	15	109	25,5		0,66
115	1l	up	5/24 4:00	9,3	-0,07	45	79	25,2		0,51
118	1m	up	5/22 14:00	16,8	-0,07	30	5	24,8		0,12
118	1m	up	5/22 15:00	16,6	-0,07	15	5	24,6		0,12
118	1m	up	5/22 17:00	15,2	-0,07	40	30	24,3		0,38
118	1m	up	5/22 18:00	14	-0,07	*	*	*		#VALUE!
180	1m	up	5/23 3:00	3,4	-0,07	70	205	36,4		0,61
180	1m	up	5/23 7:00	18	-0,07	50	215	37,1		1,08
180	1m	up	5/23 8:00	21	-0,07	65	163	36,3		1,03
114	1m	up	5/23 20:00	10,6	-0,07	200	108	28,4		0,61
114	1m	up	5/23 22:00	9,8	-0,07	100	110	26,7		0,65
114	1m	up	5/24 1:00	9,1	-0,07	50	70	26,1		0,43
114	1m	up	5/24 2:00	8,8	-0,07	40	82	25,6		0,50
114	1m	up	5/24 4:00	9,3	-0,07	60	82	25,1		0,53
116	1h	up	5/22 14:00	16,8	-0,07	25	25	25,4		0,34
116	1h	up	5/22 15:00	16,6	-0,07	35	21	25		0,30
116	1h	up	5/22 16:00	16,1	-0,07	50	54	24,8		0,65
116	1h	up	5/22 17:00	15,2	-0,07	*	*	*		#VALUE!
116	1h	up	5/22 22:00	7,4	-0,07	200	227	34,8		0,81
116	1h	up	5/23 1:00	4,3	-0,07	200	202	35,6		0,64
116	1h	up	5/23 2:00	3,5	-0,07	50	291	36		0,86
116	1h	up	5/23 16:00	15,2	-0,07	40	293	36,8		1,27
116	1h	up	5/23 17:00	14	-0,07	60	184	35,8		0,82
186	1h	up	5/23 20:00	10,6	-0,07	200	138	28,4		0,77
186	1h	up	5/23 23:00	9,5	-0,07	160	64	26,5		0,40
186	1h	up	5/24 0:00	9,3	-0,07	60	66	25,9		0,42
186	1h	up	5/24 1:00	9,1	-0,07	75	76	25,5		0,48
186	1h	up	5/24 2:00	8,8	-0,07	45	78	25,5		0,48
186	1h	up	5/24 4:00	9,3	-0,07	70	77	24,8		0,51

Instr. No	Measur location location	Temp. sensor direction	Time month/day hour	Temp. Exterior T5, R-294 Te, C	Wind corr coeffic. Rse	Measur time min	Measur Power [mW]	Temp Interior Surface Tis	measur Solar W/m2	U-value W/K*m2
Window 1, Frame										
112	1i	up	5/22 14:00	16,8	-0,07	40	31	24,9		0,43
112	1i	up	5/22 15:00	16,6	-0,07	20	20	24,8		0,30
112	1i	up	5/22 18:00	14	-0,07	95	61	24,5		0,61
112	1i	up	5/22 22:00	7,4	-0,07	200	202	34,3		0,74
112	1i	up	5/23 0:00	4,6	-0,07	160	269	35,1		0,85
112	1i	up	5/23 2:00	3,5	-0,07	35	271	36		0,81
112	1i	up	5/23 7:00	18	-0,07	70	321	36,5		1,59
112	1i	up	5/23 8:00	21	-0,07	60	200	35,3		1,32
188	1i	up	5/23 18:00	12,2	-0,07	95	60	27,8		0,41
188	1i	up	5/23 20:00	10,6	-0,07	120	65	27		0,42
188	1i	up	5/23 22:00	9,8	-0,07	80	70	26,5		0,44
188	1i	up	5/24 0:00	9,3	-0,07	70	73	25,7		0,46
188	1i	up	5/24 1:00	9,1	-0,07	40	67	25,4		0,43
188	1i	up	5/24 2:00	8,8	-0,07	45	70	24,9		0,45
188	1i	up	5/24 4:00	9,3	-0,07	*	*	*		#VALUE!
189	1j	up	5/23 4:00	5,9	-0,07	170	211	36,1		0,69
189	1j	up	5/23 6:00	15,9	-0,07	55	276	36,6		1,26
189	1j	up	5/23 7:00	18	-0,07	45	182	35,7		0,99
180	1j	up	5/23 20:00	10,6	-0,07	200	167	28,7		0,90
180	1j	up	5/23 23:00	9,5	-0,07	165	99	26,8		0,58
180	1j	up	5/24 0:00	9,3	-0,07	40	87	26,2		0,53
180	1j	up	5/24 1:00	9,1	-0,07	35	98	25,8		0,59
188	1k	up	5/23 3:00	3,4	-0,07	70	252	34,2		0,79
188	1k	up	5/23 7:00	18	-0,07	80	257	34,9		1,42
188	1k	up	5/23 8:00	21	-0,07	60	150	34,6		1,07
183	1k	up	5/23 20:00	10,6	-0,07	200	90	27,5		0,54
183	1k	up	5/23 23:00	9,5	-0,07	180	94	25,9		0,58
183	1k	up	5/24 0:00	9,3	-0,07	45	80	25,4		0,51
183	1k	up	5/24 1:00	9,1	-0,07	50	85	24,9		0,55
183	1k	up	5/24 2:00	8,8	-0,07	65	109	24,5		0,70
Window 1 glass										
110	1a	right	5/11 15:00	1,8	-0,07	70	74	22,6	1,8	0,45
110	1a	right	5/11 17:00	2,2	-0,07	*	*	*	20	
110	1a	right	5/14 3:00	0,9	-0,07	80	189	21,6		0,89
119	1a	right	5/15 22:00	3,7	-0,07	85	158	22,4	3	0,97
119	1a	right	5/17 22:00	2	-0,07	105	137	21,3	0,3	0,72
119	1a	right	5/18 2:00	0,8	-0,07	55	165	21,5		0,78
119	1a	right	5/18 3:00	1,2	-0,07	80	164	21,6		0,79
119	1b	right	5/8 22:00	7,7	-0,07	95	143	22,6	0,2	0,95
119	1b	right	5/8 23:00	5,7	-0,07	40	124	22,1		0,75
115	1b	right	5/10 1:00	-1,6	-0,07	130	173	21,2		0,75
116	1b	right	5/10 21:00	10,3	-0,07	*	*	*	10,6	*
116	1b	right	5/11 0:00	9,9	-0,07	50	114	22,7		0,88
118	1b	right	5/12 0:00	-0,6	-0,07	75	175	20,6		0,81
118	1b	right	5/12 3:00	-0,5	-0,07	60	185	20,7		0,85
118	1b	right	5/12 5:00	1,8	-0,07	65	175	20,3		0,92
114	1b	right	5/13 0:00	-1,6	-0,07	60	154	21,1		0,67

Instr. No	Measur location location	Temp. sensor direction	Time month/day hour	Temp. Exterior T5, R-294 Te, C	Wind corr coeffic. Rse	Measur time min	Measur Power [mW]	Temp Interior Surface Tis	measur Solar W/m2	U-value W/K*m2
114	1b	right	5/13 2:00	-2,2	-0,07	*	*	*		*
110	1b	right	5/13 21:00	-0,1	-0,07	70	136	22,1	0,4	0,63
110	1b	right	5/14 1:00	0,5	-0,07	200	132	20,5		0,66
119	1b	right	5/15 21:00	4,5	-0,07	60	63	22,3	4	0,59
119	1b	right	5/15 23:00	2,4	-0,07	80	134	21,4		0,70
114	1b	right	5/16 2:00	4	-0,07	200	161	21,8		0,88
114	1b	right	5/17 3:00	-1	-0,07	75	183	21,8		0,79
112	1b	right	5/18 22:00	4	-0,07	70	115	22,9	0,3	0,63
112	1b	right	5/18 23:00	3	-0,07	55	126	22,6		0,64
112	1b	right	5/19 0:00	2,5	-0,07	45	144	22,4		0,72
112	1b	right	5/19 2:00	0,3	-0,07	60	163	22,4		0,73
112	1b	right	5/19 3:00	0,1	-0,07	65	163	22,4		0,72
118	1b	right	5/19 23:00	2,2	-0,07	100	145	22,1		0,72
118	1b	right	5/20 0:00	1,7	-0,07	110	161	21,9		0,78
118	1b	right	5/20 4:00	4	-0,07	150	153	21,6		0,85
118	1b	right	5/20 20:00	5,9	-0,07	*	*	*	11	
118	1b	right	5/20 22:00	5	-0,07	90	99	22,2	0,1	0,59
118	1b	right	5/20 23:00	5	-0,07	65	144	22,2		0,82
118	1b	right	5/21 0:00	5	-0,07	65	145	22,1		0,83
118	1b	right	5/21 2:00	4,2	-0,07	90	158	22		0,87
114	1b	right	5/22 14:00	16,8	-0,07	200	*	*	9	#VALUE!
114	1b	right	5/22 17:00	15,2	-0,07	*	*	*	9	#VALUE!
114	1b	right	5/22 18:00	14	-0,07	*	*			#VALUE!
114	1b	right	5/22 19:00	12,3	-0,07	*	*	*		#VALUE!
185	1b	right	5/22 20:00	10,6	-0,07	*	*	*	6	#VALUE!
185	1b	right	5/22 21:00	9,1	-0,07	70	44	23,4	1	0,40
114	1b	right	5/22 22:00	7,4	-0,07	200	181	33,3		0,67
114	1b	right	5/23 2:00	3,5	-0,07	200	292	34,1		0,91
114	1b	right	5/23 5:00	9,9	-0,07	170	250	35		1,24
114	1b	right	5/23 7:00	18	-0,07	90	139	35,7	9	1,45
114	1b	right	5/23 8:00	21	-0,07	*	*	*		#VALUE!
189	1b	right	5/23 18:00	12,2	-0,07	45	*	*	7,2	#VALUE!
189	1b	right	5/23 20:00	10,6	-0,07	80	8	28,3	10,5	0,62
189	1b	right	5/23 21:00	9,9	-0,07	*	*	*		#VALUE!
189	1b	right	5/24 0:00	9,3	-0,07	200	114	25,8		0,68
189	1b	right	5/24 1:00	9,1	-0,07	35	126	25,4		0,75
189	1b	right	5/24 2:00	8,8	-0,07	55	120	24,7		0,75
189	1b	right	5/24 3:00	8,8	-0,07	85	128	24,3		0,84
185	1b	right	5/24 22:00	9,5	-0,07	20	91	23,6	0,6	0,69
185	1b	right	5/24 23:00	9,4	-0,07	55	80	23,3	0,2	0,60
185	1b	right	5/25 0:00	9,5	-0,07	50	84	23,1		0,63
185	1b	right	5/25 1:00	9,5	-0,07	40	99	22,9		0,74
185	1b	right	5/25 2:00	9,5	-0,07	55	104	22,9		0,78
114	1c	right	5/13 3:00	-1,1	-0,07	60	163	20,4		0,75
114	1c	right	5/13 5:00	5,9	-0,07	50	204	20,1		1,35
114	1c	right	5/13 6:00	7	-0,07	35	204	19,9		1,48
119	1c	right	5/16 3:00	4,7	-0,07	60	167	21,1		0,99
116	1g	up	5/26 3:00	6,7	-0,07	70	140	23,1		0,84

Instr. No	Measur location location	Temp. sensor direction	Time month/day hour	Temp. Exterior T5, R-294 Te, C	Wind corr coeffic. Rse	Measur time min	Measur Power [mW]	Temp Interior Surface Tis	measur Solar W/m2	U-value W/K*m2
180	1g	up	5/26 4:00	9,1	-0,07	35	157	22,9		1,10
184	1g	up	5/26 22:00	11,8	-0,07	60	50	24,9		0,41
184	1g	up	5/26 23:00	10,4	-0,07	60	75	24,6		0,54
184	1g	up	5/27 1:00	7,8	-0,07	45	91	24,3		0,56
187	1g	up	5/27 2:00	7	-0,07	80	115	23,9		0,68
187	1g	up	5/27 3:00	7	-0,07	35	136	23,6		0,81
187	1g	up	5/27 4:00	9,3	-0,07	40	132	23,2		0,93
114	1g	up	5/27 22:00	13,8	-0,04	50	81	25,4		0,70
114	1g	up	5/27 23:00	13,6	-0,04	50	29	25		0,29
114	1g	up	5/28 0:00	13,1	-0,04	45	106	24,9		0,87
114	1g	up	5/28 1:00	12,8	-0,04	45	101	24,7		0,82
114	1g	up	5/28 3:00	12,1	-0,04	50	105	24,5		0,82
114	1g	up	5/28 5:00	12,4	-0,04	65	105	24,1		0,87
112	1g	up	5/28 18:00	14,4	-0,04	20	28	25,4	6	0,79
112	1g	up	5/28 19:00	13,2	-0,07	65	41	25,1	2	0,54
112	1g	up	5/28 21:00	10,7	-0,04	60	79	24,8		0,57
112	1g	up	5/28 22:00	9,5	-0,04	40	123	24,1		0,81
112	1g	up	5/28 23:00	8,7	-0,04	45	126	23,8		0,80
119	1n	up	5/29 1:00	7	-0,07	60	165	23,5		0,97
116	1n	up	5/29 3:00	7	-0,07	70	176	23,6		1,02
116	1n	up	5/29 5:00	10	-0,07	70	169	22,9		1,25
119	1n	up	5/30 1:00	10	-0,07	55	147	22,9		1,10
119	1n	up	5/30 2:00	10,8	-0,07	55	149	22,9		1,18
119	1n	up	5/30 3:00	11,5	-0,07	50	153	22,3		1,34
119	1n	up	5/30 4:00	12	-0,07	95	133	22,4		1,23
116	1n	up	5/30 22:00	11,8	-0,07	45	72	24,3		0,59
116	1n	up	5/30 23:00	11,2	-0,07	70	114	24		0,88
116	1n	up	5/31 1:00	11,4	-0,07	110	157	23,4		1,25
116	1n	up	5/31 4:00	12	-0,07	50	145	23,1		1,25
112	1o	up	5/29 1:00	7	-0,07	45	175	23,3		1,04
112	1o	up	5/29 2:00	6,5	-0,07	65	187	22,6		1,11
118	1o	up	5/29 3:00	7	-0,07	60	156	21,9		1,01
116	1o	up	5/30 1:00	10	-0,07	70	149	22,6		1,14
116	1o	up	5/30 3:00	11,5	-0,07	65	160	22,4		1,39
116	1o	up	5/30 4:00	12	-0,07	45	147	22,3		1,36
114	1o	up	5/30 22:00	11,8	-0,07	45	91	23,8		0,76
114	1o	up	5/30 23:00	11,2	-0,07	45	103	23,4		0,84
114	1o	up	5/31 0:00	10,6	-0,07	50	135	23,3		1,03
114	1o	up	5/31 1:00	11,4	-0,07	60	155	23		1,27
114	1o	up	5/31 3:00	11	-0,07	55	175	22,8		1,40
114	1o	up	5/31 4:00	12	-0,07	85	144	22,5		1,31
118	1d	left	5/8 22:00	8,3	-0,07	50	111	22,3	0,1	0,80
118	1d	left	5/8 23:00	7,5	-0,07	105	123	21,8		0,85
110	1d	left	5/10 1:00	-0,2	-0,07	155	212	21,4		0,95
118	1d	left	5/10 21:00	11,2	-0,07	60	61	23,4	1,4	0,63
110	1d	left	5/11 0:00	10,9	-0,07	85	117	22,9		0,96
118	1d	left	5/11 16:00	4,1	-0,07	115	124	21,6	2	0,81
118	1d	left	5/11 17:00	4,1	-0,07	200	143	21,9	2	0,89

Instr. No	Measur location location	Temp. sensor direction	Time month/day hour	Temp. Exterior T5, R-294 Te, C	Wind corr coeffic. Rse	Measur time min	Measur Power [mW]	Temp Interior Surface Tis	measur Solar W/m2	U-value W/K*m2
118	1d	left	5/11 18:00	3,9	-0,07	35	126	21,8	1,7	0,79
118	1d	left	5/11 20:00	2,6	-0,07	60	124	21,6	0,3	0,67
112	1d	left	5/12 0:00	1,1	-0,07	60	164	21		0,81
187	1d	left	5/12 3:00	0,9	-0,07	60	166	21		0,81
187	1d	left	5/12 5:00	2,6	-0,07	55	156	20,8		0,84
187	1d	left	5/13 0:00	0,1	-0,07	65	141	21,4		0,66
118	1e	left	5/13 21:00	2,1	-0,07	115	158	22,5		0,76
118	1e	left	5/14 5:00	4	-0,07	200	199	21,3		1,10
114	1e	left	5/15 22:00	5,5	-0,07	155	141	21,9	0,1	0,85
112	1e	left	5/15 23:00	4,5	-0,07	70	106	21,6		0,62
112	1e	left	5/16 3:00	5,8	-0,07	60	129	21,1		0,83
115	1e	left	5/17 0:00	2,2	-0,07	125	115	21,9		*
115	1e	left	5/17 3:00	0,2	-0,07	140	145	21,8		0,67
115	1e	left	5/17 4:00	1,5	-0,07	105	173	21,7		0,84
119	1e	left	5/18 22:00	6,2	-0,07	60	104	22,6		0,64
115	1e	left	5/18 23:00	5,2	-0,07	70	115	22,3		0,67
115	1e	left	5/19 0:00	4,4	-0,07	55	122	22,1		0,69
110	1e	left	5/19 3:00	2,1	-0,07	195	143	22,1		0,71
110	1e	left	5/20 1:00	3,4	-0,07	200	165	22,7		0,84
115	1e	left	5/20 4:00	5,1	-0,07	135	179	22,3		1,01
115	1e	left	5/20 21:00	7,5	-0,07	70	119	22,4	0,2	0,80
115	1e	left	5/20 22:00	6,8	-0,07	45	88	22,7		0,57
112	1e	left	5/21 2:00	6	-0,07	70	131	22,4		0,79
112	1e	left	5/21 3:00	6	-0,07	40	149	22,4		0,89
115	1e	left	5/21 4:00	7	-0,07	40	152	22,5		0,95
115	1e	left	5/21 10:00	15,1	-0,07	20	13	24,4	7	0,99
115	1e	left	5/21 12:00	14,5	-0,07	*	*	*	7	#VALUE!
115	1e	left	5/21 17:00	12,9	-0,07	95	82	23,4	1,2	1,00
115	1e	left	5/21 19:00	10,2	-0,07	50	77	24	1,2	0,75
119	1e	left	5/21 20:00	9,1	-0,07	40	79	23,8	0,2	0,65
119	1e	left	5/21 21:00	8,7	-0,07	65	106	23,8		0,81
119	1e	left	5/22 14:00	16,8	-0,07	20	44	25	2	0,92
119	1e	left	5/22 15:00	16,6	-0,07	20	9	24,6	2	0,50
119	1e	left	5/22 17:00	15,2	-0,07	25	36	24,3	2	0,75
119	1e	left	5/22 22:00	10	-0,07	200	*	*		#VALUE!
115	1e	left	5/23 1:00	6,4	-0,07	200	179	34,1		0,62
115	1e	left	5/23 4:00	7,7	-0,07	65	243	34,5		1,08
115	1e	left	5/23 6:00	22,5	-0,07	80	240	35,4	0,8	1,83
115	1e	left	5/23 7:00	23,1	-0,07	*	*	*	1	#VALUE!
115	1e	left	5/23 19:00	12,7	-0,07	140	101	28,3	1,5	0,70
115	1e	left	5/23 20:00	11,7	-0,07	100	108	27,6	0,1	0,66
115	1e	left	5/23 23:00	10,5	-0,07	110	162	26		1,00
115	1e	left	5/24 0:00	10,3	-0,07	65	107	25,6		0,70
112	1e	left	5/24 2:00	10,1	-0,07	40	102	25,1		0,67
112	1e	left	5/24 3:00	9,8	-0,07	40	126	24,9		0,85
112	1e	left	5/24 7:00	14,3	-0,07	70	90	24,1	0,6	0,97
112	1e	left	5/24 18:00	15,2	-0,07	40	64	24,4	1,1	0,83
112	1e	left	5/24 19:00	14,8	-0,07	50	80	24,3	0,2	0,87

Instr. No	Measur location location	Temp. sensor direction	Time month/day hour	Temp. Exterior T5, R-294 Te, C	Wind corr coeffic. Rse	Measur time min	Measur Power [mW]	Temp Interior Surface Tis	measur Solar W/m2	U-value W/K*m2
112	1e	left	5/24 20:00	14,5	-0,07	55	62	24,2	0,2	0,68
114	1e	left	5/24 21:00	9,7	-0,07	25	60	23,9	0,3	0,68
114	1e	left	5/25 0:00	9,5	-0,07	60	80	25,9		0,58
114	1e	left	5/25 1:00	9,5	-0,07	55	115	23,6		0,92
114	1e	left	5/25 2:00	9,5	-0,07	40	105	23,4		0,86
114	1e	left	5/25 3:00	9,6	-0,07	45	122	23,4		0,99
119	1f	left	5/13 3:00		-0,07	80	174	20,6		0,81
119	1f	left	5/13 4:00	-0,4	-0,07	35	224	20,6		1,16
112	1f	left	5/17 23:00	2,3	-0,07	115	115	21,1		0,67
112	1f	left	5/18 0:00	3,8	-0,07	65	147	21,3		0,80
112	1f	left	5/18 3:00	3,2	-0,07	75	148	21,2		0,78
186	1f	left	5/24 7:00	2,4	-0,07	70	80	23,8	0,6	0,91
114	1f	left	5/24 18:00	14,3	-0,07	40	84	24,1	1,1	1,05
114	1f	left	5/24 19:00	15,2	-0,07	40	82	24,1	0,4	0,92
114	1f	left	5/24 20:00	14,8	-0,07	30	55	23,9	0,4	0,65
114	1f	left	5/24 21:00	14,5	-0,07	35	82	23,7		0,88
Window 2 glass										
115	2a	right	4/17 1:00	1	-0,09	200	153	20,8		0,76
115	2a	right	4/17 4:00	1	-0,09	200	185	21,2		0,89
115	2a	right	4/17 6:00	2	-0,09	135	200	21,8		0,97
115	2a	right	4/18 1:00	4	-0,09	200	129	21,7		0,72
118	2a	right	4/18 4:00	3	-0,09	135	143	20,9		0,79
118	2a	right	4/19 4:00	4	-0,09	140	138	20,6		0,82
115	2a	right	4/19 21:00	8	-0,09	35	160	21,9		1,11
115	2a	right	4/20 4:00	7	-0,09	180	171	21,9		1,10
114	2a	right	4/21 2:00	9	-0,09	190	123	22,9		0,87
114	2a	right	4/21 4:00	8	-0,09	155	120	22,6		0,81
114	2a	right	4/21 5:00	8	-0,09	50	142	22,3		0,97
118	2a	right	4/22 4:00	6	-0,09	200	153	21,9		0,94
118	2a	right	4/22 8:00	7	-0,09	200	162	21,9		1,05
115	2a	right	5/8 22:11	7,4	-0,09	90	124	22,8		0,81
115	2a	right	5/8 23:45	7,2	-0,09	55	106	22,2		0,72
119	2a	right	5/10 0:48	1,8	-0,09	200	162	21,8		0,81
114	2a	right	5/11 18:04	3,3	-0,09	120	200	22	0,8	1,09
114	2a	right	5/11 23:49	1,2	-0,09	85	143	21,4		0,71
118	2a	right	5/12 23:51	1	-0,09	50	134	21,4		0,66
118	2a	right	5/14 5:08	4	-0,09	200	172	21,7		0,96
118	2a	right	5/15 22:27	4,8	-0,09	65	106	21,2		0,66
116	2a	right	5/16 3:09	5	-0,09	70	147	21,6		0,88
118	2a	right	5/16 23:01	2,9	-0,09	70	197	21,8		1,02
118	2a	right	5/17 0:04	2,5	-0,09	60	178	21,6		0,92
118	2a	right	5/17 4:46	2,9	-0,09	200	168	21,7		0,89
114	2a	right	5/20 0:45	3,3	-0,09	200	141	22,6		0,73
114	2a	right	5/20 3:53	3,6	-0,09	195	183	22,3		0,97
116	2a	right	5/20 23:14	6,1	-0,09	200	156	23,1		0,91
116	2a	right	5/21 2:53	5,2	-0,09	200	160	22,9		0,90
118	2a	right	5/21 11:47	13,8	-0,09	175	103	22,8	0,6	1,21
118	2a	right	5/21 17:00	13,6	-0,09	85	99	23,2	0,5	1,09

Instr. No	Measur location location	Temp. sensor direction	Time month/day hour	Temp. Exterior T5, R-294 Te, C	Wind corr coeffic. Rse	Measur time min	Measur Power [mW]	Temp Interior Surface Tis	measur Solar W/m2	U-value W/K*m2
118	2a	right	5/21 19:37	10,8	-0,09	160	74	22,9	0,5	0,68
118	2a	right	5/21 21:42	9,5	-0,09	60	105	23,1		0,78
118	2a	right	5/21 23:47	8,6	-0,09	105	107	22,6		0,78
118	2a	right	5/22 1:53	7,6	-0,09	40	108	22,3		0,75
118	2a	right	5/22 2:56	7,2	-0,09	95	137	22,4		0,90
118	2a	right	5/22 6:04	9,9	-0,09	200	125	22,6		0,98
187	2a	right	5/22 21:43	10,1	-0,09	200	197	33,9		0,82
187	2a	right	5/23 1:54	5,5	-0,09	200	289	34,6		0,97
187	2a	right	5/23 7:08	14,2	-0,09	80	233	36,1		1,04
187	2a	right	5/23 8:10	15,3	-0,09	60	200	36,4		0,94
185	2a	right	5/23 11:18	16,6	-0,09	160	84	30,6		0,62
119	2a	right	5/23 19:39	12	-0,09	200	111	28,1	0,1	0,71
119	2a	right	5/23 20:42	11,2	-0,09	60	132	27,9		0,79
119	2a	right	5/23 22:47	10,5	-0,09	90	96	26,2		0,63
119	2a	right	5/24 0:52	9,9	-0,09	70	126	25,6		0,81
119	2a	right	5/24 2:57	9,5	-0,09	115	158	24,9		1,02
184	2a	right	5/24 4:00	9,7	-0,09	45	65	24,3		0,47
182	2a	right	5/24 13:55	14,5	-0,09	115	85	23,8	1,4	1,07
116	2a	right	5/24 17:03	14,1	-0,09	35	73	24,3	0,4	0,78
116	2a	right	5/24 18:06	13,7	-0,09	55	90	24,3	0,1	0,87
116	2a	right	5/24 19:08	12,9	-0,09	55	86	24,1	0,1	0,80
188	2a	right	5/24 20:11	12,1	-0,09	45	63	23,6		0,58
188	2a	right	5/24 21:45	11,2	-0,09	45	95	23,7		0,78
188	2a	right	5/24 22:47	11	-0,09	55	88	23,5		0,72
112	2a	right	5/24 23:50	11	-0,09	65	106	23,8		0,84
112	2a	right	5/25 0:53	11	-0,09	50	115	23,7		0,91
112	2a	right	5/25 1:55	10,8	-0,09	45	115	23,4		0,92
118	2a	right	5/26 2:59	8,9	-0,09	65	96	22,7		0,71
118	2a	right	5/26 4:02	10,2	-0,09	175	108	22,9		0,86
189	2a	right	5/26 12:54	21,5	-0,09	35	24	24,7	0,3	0,96
189	2a	right	5/26 13:57	21,4	-0,09	20	22	24,8	1,1	1,07
189	2a	right	5/26 14:59	21,7	-0,09	20	26	24,8	0,6	1,14
189	2a	right	5/26 16:02	21,9	-0,09	20	12	24,5	1	1,00
189	2a	right	5/26 17:05	21,2	-0,09	20	21	24,5	0,5	0,91
187	2a	right	5/26 17:36	20,8	-0,09	40	23	25,3	0,7	0,75
187	2a	right	5/26 18:07	20,2	-0,09	45	22	25,4	0,5	0,60
187	2a	right	5/26 20:13	17,4	-0,09	35	22	25,4	0,1	0,35
187	2a	right	5/26 21:15	15,6	-0,09	25	20	25,3		0,26
187	2a	right	5/26 22:18	14,8	-0,09	45	35	24,9		0,39
187	2a	right	5/27 0:54	10,8	-0,09	70	79	24,6		0,59
184	2a	right	5/27 1:57	9,9	-0,09	60	70	24,2		0,51
184	2a	right	5/27 2:59	9,5	-0,09	65	97	23,8		0,69
184	2a	right	5/27 4:02	11	-0,09	40	105	23,4		0,86
115	2a	right	5/27 18:07	17,3	-0,09	20	36	25,9		0,47
115	2a	right	5/27 18:39	16,9	-0,09	45	55	25,7		0,66
115	2a	right	5/27 19:41	16,2	-0,09	45	41	25,6		0,48
115	2a	right	5/27 21:15	15,3	-0,09	40	66	25,4		0,68
115	2a	right	5/27 22:49	14,6	-0,09	55	77	25		0,76

Instr. No	Measur location location	Temp. sensor direction	Time month/day hour	Temp. Exterior T5, R-294 Te, C	Wind corr coeffic. Rse	Measur time min	Measur Power [mW]	Temp Interior Surface Tis	measur Solar W/m2	U-value W/K*m2
115	2a	right	5/28 0:23	13,6	-0,09	45	81	24,9		0,74
115	2a	right	5/28 1:26	13,3	-0,09	30	76	24,7		0,69
115	2a	right	5/28 3:00	12,7	-0,09	40	85	24,4		0,75
115	2a	right	5/28 5:05	12,1	-0,09	25	74	24,1		0,64
116	2a	right	5/28 16:34	15,9	-0,09	65	74	24,7	0,5	0,92
116	2a	right	5/28 17:37	15,5	-0,09	60	95	25,1	0,5	1,05
116	2a	right	5/28 18:08	15,3	-0,09	65	83	24,9	0,2	0,90
116	2a	right	5/28 20:13	13,3	-0,09	60	84	24,8	0,1	0,76
116	2a	right	5/28 21:47	11,4	-0,09	60	92	24,7		0,71
116	2a	right	5/28 23:52	9,3	-0,09	55	112	24,1		0,77
116	2a	right	5/29 1:26	8	-0,09	65	109	23,8		0,70
118	2a	up	5/13 3:00	-0,5	-0,09	80	158	20,8		0,74
118	2a	up	5/13 5:05	4	-0,09	45	196	20,7		1,15
118	2a	up	5/13 5:37	5	-0,09	40	207	20,5		1,30
118	2a	up	5/15 21:55	5,2	-0,09	150	158	21,8		0,94
115	2a	up	5/16 21:58	3,1	-0,09	55	133	21,6		0,72
115	2a	up	5/17 1:07	1,6	-0,09	190	188	21,6		0,93
118	2a	down	5/13 19:43	4,1	-0,09	35	104	22		0,59
118	2a	down	5/13 20:46	2,8	-0,09	40	150	22,1		0,78
118	2a	down	5/13 21:49	1,8	-0,09	55	163	21,5		0,82
116	2a	down	5/18 22:05	5,9	-0,09	60	111	22,8		0,67
116	2a	down	5/18 23:07	5,1	-0,09	45	111	22,6		0,65
116	2a	down	5/18 23:39	4,7	-0,09	60	121	22,4		0,69
116	2a	down	5/19 4:53	4,8	-0,09	135	157	22,4		0,89
114	2b	up	5/29 1:26	8	-0,09	100	151	23,8		0,95
114	2b	up	5/29 1:58	7,6	-0,09	35	164	23,4		1,03
114	2b	up	5/29 3:32	8	-0,09	60	181	22,9		1,19
114	2b	up	5/29 4:34	9,7	-0,09	70	167	22,5		1,28
114	2b	up	5/30 0:56	10,6	-0,09	50	126	22,7		1,04
114	2b	up	5/30 1:58	11,2	-0,09	45	121	22,5		1,07
114	2b	up	5/30 2:30	11,4	-0,09	50	139	22,2		1,27
116	2b	up	5/30 22:19	13	-0,09	45	72	24,3		0,66
116	2b	up	5/30 23:22	12,3	-0,09	70	114	24		0,98
116	2b	up	5/31 1:27	11,4	-0,09	110	157	23,4		1,28
116	2b	up	5/31 4:04	12,1	-0,09	50	145	23,1		1,29
115	2c	up	5/29 1:26	8	-0,09	50	130	23,6		0,84
115	2c	up	5/29 1:58	7,6	-0,09	35	148	23,4		0,93
115	2c	up	5/29 3:00	7,6	-0,09	50	168	23,1		1,07
115	2c	up	5/30 1:58	11,2	-0,09	50	119	22,8		1,03
115	2c	up	5/30 2:30	11,4	-0,09	40	119	22,6		1,06
115	2c	up	5/30 3:32	12,1	-0,09	120	129	22,2		1,26
114	2c	up	5/30 22:19	13	-0,09	45	91	23,8		0,86
114	2c	up	5/30 23:22	12,3	-0,09	45	103	23,4		0,94
114	2c	up	5/31 0:56	11,6	-0,09	50	135	23,3		1,14
114	2c	up	5/31 1:27	11,4	-0,09	60	155	23		1,31
114	2c	up	5/31 3:33	11,3	-0,09	55	175	22,8		1,47
114	2c	up	5/31 4:04	12,1	-0,09	85	144	22,5		1,36

Instr. No	Measur location location	Temp. sensor direction	Time month/day hour	Temp. Exterior T5, R-294 Te, C	Wind corr coeffic. Rse	Measur time min	Measur Power [mW]	Temp Interior Surface Tis	measur Solar W/m2	U-value W/K*m2
Window 3 glass										
116	3a	right	5/11 17:32	3,3	-0,09	125	194	21,4	0,4	1,07
116	3a	right	5/11 18:35	3,1	-0,09	45	174	21,5		0,94
116	3a	right	5/11 20:41	2,2	-0,09	55	139	21,6	0,2	0,73
116	3a	right	5/17 22:01	4	-0,09	115	153	21,1		0,89
116	3a	right	5/17 23:04	3,7	-0,09	*	*	*		#VALUE!
116	3a	right	5/19 23:11	4	-0,09	55	167	22,3		0,91
116	3a	right	5/19 23:42	3,7	-0,09	50	168	22,5		0,89
116	3a	right	5/20 0:45	3,3	-0,09	*	*	*		#VALUE!
112	3a	right	5/20 21:08	7,3	-0,09	45	117	22,6	0,2	0,79
112	3a	right	5/20 21:40	7	-0,09	40	125	22,6		0,81
112	3a	right	5/20 22:42	6,3	-0,09	55	144	22,8		0,87
112	3a	right	5/20 23:45	6,1	-0,09	55	149	22,8		0,89
112	3a	right	5/21 1:51	5,4	-0,09	50	157	22,6		0,91
112	3a	right	5/21 2:22	5,2	-0,09	65	157	22,4		0,91
116	3a	right	5/24 4:00	9,7	-0,09	105	115	23,8		0,82
114	3b	right	4/16 22:00	3	-0,09	30	111	20,2		0,65
114	3b	right	4/17 0:00	2	-0,09	45	205	20		1,09
114	3b	right	4/17 4:00	1	-0,09	200	208	20		1,05
112	3b	right	4/17 23:00	5	-0,09	80	147	21,4		0,88
112	3b	right	4/18 3:00	4	-0,09	85	160	21,2		0,91
116	3b	right	4/19 0:00	5	-0,09	140	169	20,7		1,04
116	3b	right	4/19 3:00	4	-0,09	75	190	21,1		1,07
114	3b	right	4/20 2:00	7	-0,09	30	133	21		0,93
116	3b	right	4/21 0:00	10	-0,09	130	115	22,2		0,93
116	3b	right	4/21 6:00	9	-0,09	70	138	21,7		1,05
116	3b	right	4/22 2:00	5	-0,09	65	130	22		0,76
116	3b	right	4/22 5:00	6	-0,09	35	183	21,6		1,12
114	3b	right	5/8 21:40	7,8	-0,09	50	111	22,6		0,76
114	3b	right	5/8 23:45	7,2	-0,09	60	137	21,8		0,94
118	3b	right	5/9 22:43	3,9	-0,09	50	179	21,2		1,02
115	3b	right	5/9 23:45	2,7	-0,09	15	79	22		0,43
116	3b	right	5/11 23:49	1,2	-0,09	65	175	20,8		0,89
116	3b	right	5/12 1:54	0,8	-0,09	45	193	20,7		0,96
116	3b	right	5/12 4:31	1,4	-0,09	70	188	20,3		0,98
116	3b	right	5/12 23:51	1	-0,09	65	144	20,9		0,73
116	3b	right	5/14 2:00	1,7	-0,09	50	202	21		1,03
116	3b	right	5/15 21:55	5,2	-0,09	80	158	21,7		0,95
116	3b	right	5/15 22:27	4,8	-0,09	70	135	21,1		0,83
119	3b	right	5/16 21:58	3,1	-0,09	65	197	21,4		1,06
119	3b	right	5/16 22:30	2,9	-0,09	45	197	21,4		1,05
119	3b	right	5/17 0:35	2	-0,09	55	203	21,4		1,03
119	3b	right	5/17 1:38	1,2	-0,09	55	190	21,3		0,93
119	3b	right	5/17 2:41	0,5	-0,09	65	211	21,3		1,00
114	3b	right	5/18 21:33	6,3	-0,09	55	158	22,3		0,98
114	3b	right	5/18 23:39	4,7	-0,09	60	156	22		0,90
114	3b	right	5/19 0:42	4	-0,09	55	168	21,8		0,94
114	3b	right	5/19 1:44	2,9	-0,09	55	178	21,8		0,93

Instr. No	Measur location location	Temp. sensor direction	Time month/day hour	Temp. Exterior T5, R-294 Te, C	Wind corr coeffic. Rse	Measur time min	Measur Power [mW]	Temp Interior Surface Tis	measur Solar W/m2	U-value W/K*m2
114	3b	right	5/19 2:47	2,2	-0,09	55	171	21,6		0,88
116	3b	right	5/20 1:48	3,1	-0,09	*	*	*		#VALUE!
185	3b	right	5/27 15:31	19,5	-0,09	25	24	25,1	0,6	0,61
185	3b	right	5/27 17:05	18,1	-0,09	50	46	25,1	0,4	0,76
185	3b	right	5/27 18:39	16,9	-0,09	65	55	25,2	0,2	0,73
185	3b	right	5/27 19:41	16,2	-0,09	65	52	24,9		0,64
185	3b	right	5/27 21:15	15,3	-0,09	50	62	24,8		0,69
185	3b	right	5/27 23:20	14,2	-0,09	75	79	24,4		0,80
185	3b	right	5/28 1:26	13,3	-0,09	40	77	24,1		0,74
185	3b	right	5/28 3:00	12,7	-0,09	55	83	23,9		0,76
185	3b	right	5/28 5:05	12,1	-0,09	45	85	23,6		0,76
184	3b	right	5/23 0:51	6,3	-0,09	200	*	*		#VALUE!
184	3b	right	5/23 2:57	5,1	-0,09	55	309	33,3		1,07
184	3b	right	5/23 5:34	10,7	-0,09	50	310	33,9		1,29
184	3b	right	5/23 6:36	13,4	-0,09	60	246	33,4	0,6	1,22
184	3b	right	5/23 10:15	16,8	-0,09	170	103	29,7	0,4	0,84
185	3b	right	5/23 18:05	13,3	-0,09	60	121	27,8	0,2	0,85
185	3b	right	5/23 19:08	12,4	-0,09	35	131	27,8	0,1	0,86
116	3b	right	5/23 19:39	12	-0,09	60	132	27,6		0,85
116	3b	right	5/23 20:42	11,2	-0,09	65	131	27,3		0,82
116	3b	right	5/23 21:44	10,8	-0,09	65	128	26,9		0,80
116	3b	up	5/24 13:55	14,5	-0,09	80	109	23,8	0,7	1,24
182	3b	up	5/24 16:32	14,2	-0,09	35	95	23,8	0,2	1,02
182	3b	up	5/24 18:37	13,3	-0,09	65	101	23,9	0,1	0,97
184	3b	up	5/24 19:39	12,5	-0,09	60	96	23,7		0,87
184	3b	up	5/24 20:42	11,7	-0,09	70	104	23,6		0,88
184	3b	up	5/24 22:47	11	-0,09	75	98	23,4		0,80
184	3b	up	5/25 0:53	11	-0,09	105	113	23,1		0,94
184	3b	up	5/25 2:58	10,6	-0,09	70	111	23		0,90
112	3b	up	5/26 2:59	8,9	-0,09	60	95	22,9		0,69
112	3b	up	5/26 3:30	9,3	-0,09	55	117	22,6		0,88
187	3b	up	5/26 13:57	21,4	-0,09	65	50	24,8	0,6	1,67
187	3b	up	5/26 14:59	21,7	-0,09	45	41	24,6	0,4	1,61
187	3b	up	5/26 16:02	21,9	-0,09	55	46	24,5	0,2	1,88
189	3b	up	5/26 18:07	20,2	-0,09	120	54	24,9	0,3	1,25
189	3b	up	5/26 20:13	17,4	-0,09	20	25	24,8	0,1	0,41
189	3b	up	5/26 21:15	15,6	-0,09	55	62	24,7		0,72
189	3b	up	5/26 22:49	14	-0,09	40	50	24,3		0,52
189	3b	up	5/26 23:52	12,3	-0,09	45	57	24,1		0,51
188	3b	up	5/27 0:54	10,8	-0,09	65	85	23,9		0,67
188	3b	up	5/27 1:57	9,9	-0,09	45	93	23,4		0,71
188	3b	up	5/27 2:59	9,5	-0,09	75	119	23		0,89
114	3b	up	5/28 16:34	15,9	-0,09	45	72	24,2	0,4	0,94
114	3b	up	5/28 17:37	15,5	-0,09	50	94	24,4	0,2	1,09
114	3b	up	5/28 18:08	15,3	-0,09	25	60	24,5		0,69
114	3b	up	5/28 19:10	14,6	-0,09	35	82	24,4		0,86
114	3b	up	5/28 20:13	13,3	-0,09	40	87	24,3		0,81

Instr. No	Measur location location	Temp. sensor direction	Time month/day hour	Temp. Exterior T5, R-294 Te, C	Wind corr coeffic. Rse	Measur time min	Measur Power [mW]	Temp Interior Surface Tis	measur Solar W/m2	U-value W/K*m2
114	3b	up	5/28 21:16	12	-0,09	35	101	24,3		0,83
114	3b	up	5/28 21:47	11,4	-0,09	35	91	24,1		0,73
116	3c	right	5/13 3:00	-0,5	-0,09	75	128	20,2		0,63
116	3c	right	5/13 3:31	-0,1	-0,09	*	*	*		#VALUE!
116	3c	right	5/13 20:46	2,8	-0,09	70	175	21,6		0,92
116	3c	right	5/13 22:51	1,3	-0,09	40	182	21,7		0,88
116	3c	right	5/13 23:54	0,8	-0,09	60	183	20,9		0,90
114	3c	right	5/21 22:45	8,9	-0,09	50	99	22,6		0,74
114	3c	right	5/21 23:47	8,6	-0,09	60	138	22,3		1,00
114	3c	right	5/22 0:50	8,1	-0,09	45	146	22,2		1,03
114	3c	right	5/22 3:58	7,8	-0,09	60	144	22,2		0,99
114	3c	right	5/22 4:30	8,4	-0,09	40	144	22,1		1,04
Window 4 glass										
112	4a	up	5/12 2:57	0,8	-0,09	200	294	21,8		1,35
112	4a	up	5/12 5:34	2,4	-0,09	200	246	21,9		1,22
112	4a	up	5/16 0:32	3,5	-0,09	150	207	21,7		1,11
112	4a	up	5/16 2:38	4,6	-0,09	50	225	21,7		1,28
110	4a	up	5/17 20:59	4,8	-0,09	*	*	*		#VALUE!
110	4a	up	5/17 21:30	4,4	-0,09	*	*	*		#VALUE!
110	4a	up	5/17 22:01	4	-0,09	*	*	*		#VALUE!
115	4a	up	5/21 21:42	9,5	-0,09	35	152	23,4		1,08
115	4a	up	5/21 22:45	8,9	-0,09	60	167	22,8		1,18
115	4a	up	5/22 1:53	7,6	-0,09	140	166	22,8		1,08
183	4a	up	5/24 20:42	11,7	-0,09	75	133	23,9		1,08
183	4a	up	5/24 21:45	11,2	-0,09	50	158	23,7		1,24
183	4a	up	5/25 0:53	11	-0,09	70	158	23,4		1,25
115	4b	up	4/17 0:00	2	-0,09	135	276	20,8		1,37
115	4b	up	4/17 4:00	1	-0,09	200	196	20,9		0,95
115	4b	up	4/17 5:00	2	-0,09	40	343	21,5		1,61
110	4b	up	4/18 4:00	3	-0,09	200	262	21,6		1,32
119	4b	up	4/18 22:00	5	-0,09	200	558	21,8		2,79
119	4b	up	4/19 3:00	4	-0,09	115	225	21		1,25
112	4b	up	4/20 1:00	8	-0,09	200	205	22,3		1,35
112	4b	up	4/20 3:00	7	-0,09	115	201	21,8		1,28
116	4b	up	4/20 23:00	10	-0,09	70	111	22,5		0,88
116	4b	up	4/21 4:00	8	-0,09	200	136	22,4		0,92
118	4b	up	4/21 8:00	9	-0,09	200	173	22,1		1,26
116	4b	up	5/8 21:40	7,8	-0,09	105	163	22,6		1,09
116	4b	up	5/8 23:45	7,2	-0,09	65	173	22,1		1,14
116	4b	up	5/10 1:51	1,2	-0,09	200	230	21,9		1,09
110	4b	up	5/10 21:41	11	-0,09	90	130	22,5	0,4	1,15
110	4b	up	5/10 23:46	10,9	-0,09	50	157	22,4		1,33
110	4b	up	5/12 23:51	1	-0,09	65	191	21,3		0,93
112	4b	up	5/14 2:31	1,8	-0,09	200	251	22		1,21
112	4b	up	5/16 1:35	4	-0,09	50	172	21,3		0,98
116	4b	up	5/17 1:38	1,2	-0,09	200	248	22		1,16
116	4b	up	5/17 2:41	0,5	-0,09	200	255	21,9		1,16
115	4b	up	5/18 21:33	6,3	-0,09	45	161	22,3		1,00

Instr. No	Measur location location	Temp. sensor direction	Time month/day hour	Temp. Exterior T5, R-294 Te, C	Wind corr coeffic. Rse	Measur time min	Measur Power [mW]	Temp Interior Surface Tis	measur Solar W/m2	U-value W/K*m2
115	4b	up	5/18 22:36	5,5	-0,09	75	197	22,1		1,16
115	4b	up	5/18 23:39	4,7	-0,09	55	197	21,9		1,12
115	4b	up	5/19 2:47	2,2	-0,09	200	239	22,3		1,16
119	4b	up	5/20 0:45	3,3	-0,09	200	202	22,3		1,04
119	4b	up	5/20 3:53	3,6	-0,09	200	266	22,1		1,38
114	4b	up	5/20 22:42	6,3	-0,09	200	141	22,9		0,85
114	4b	up	5/21 2:53	5,2	-0,09	200	218	22,4		1,23
182	4b	up	5/26 13:57	21,4	-0,09	55	59	24,9	0,3	1,78
182	4b	up	5/26 14:28	21,4	-0,09	85	44	24,7	0,3	1,48
182	4b	up	5/26 14:59	21,7	-0,09	35	40	24,7	0,3	1,50
182	4b	up	5/26 15:31	21,9	-0,09	55	57	24,9	0,3	1,99
188	4b	up	5/26 16:02	21,9	-0,09	35	45	24,9	0,4	1,68
188	4b	up	5/26 17:05	21,2	-0,09	35	55	25	0,4	1,58
188	4b	up	5/26 17:36	20,8	-0,09	35	30	24,9		0,83
188	4b	up	5/26 18:07	20,2	-0,09	40	40	24,8		0,94
188	4b	up	5/26 21:15	15,6	-0,09	40	72	24,4		0,85
188	4b	up	5/26 22:49	14	-0,09	55	84	24,2		0,84
119	4b	up	5/27 16:02	19,1	-0,09	65	77	25,7	0,7	1,28
119	4b	up	5/27 18:07	17,3	-0,09	40	82	25,8	0,4	1,03
119	4b	up	5/27 18:39	16,9	-0,09	50	81	25,8	0,2	0,95
119	4b	up	5/27 19:10	16,7	-0,09	35	91	25,6	0,1	1,04
119	4b	up	5/27 21:15	15,3	-0,09	45	94	25,4		0,94
119	4b	up	5/27 22:18	14,8	-0,09	35	109	25,1		1,06
119	4b	up	5/28 0:23	13,6	-0,09	55	116	24,8		1,04
119	4b	up	5/28 1:57	13,1	-0,09	65	133	24,6		1,15
119	4b	up	5/28 3:00	12,7	-0,09	65	145	24,3		1,23
119	4b	up	5/28 5:36	12,1	-0,09	45	143	23,9		1,19
115	4b	up	5/28 16:34	15,9	-0,09	50	119	24,3	0,4	1,44
115	4b	up	5/28 17:37	15,5	-0,09	40	132	24,6	0,3	1,45
115	4b	up	5/28 18:39	15	-0,09	60	114	24,5	0,3	1,22
115	4b	up	5/28 20:13	13,3	-0,09	75	112	24,3		1,02
115	4b	up	5/28 20:44	12,7	-0,09	75	122	24,1		1,07
115	4b	up	5/28 23:52	9,3	-0,09	55	132	23,6		0,92
185	4b	up	5/23 10:15	16,8	-0,09	200	168	30,3	0,4	1,25
185	4b	up	5/23 19:39	12	-0,09	200	152	27,5		0,97
185	4b	up	5/23 22:47	10,5	-0,09	200	109	25,6		0,73
185	4b	up	5/23 23:50	10,2	-0,09	50	137	25		0,92
185	4b	up	5/24 0:52	9,9	-0,09	55	133	24,4		0,92
185	4b	up	5/24 4:00	9,7	-0,09	75	152	23,9		1,06
110	4c	up	5/13 3:00	-0,5	-0,09	80	247	20,7		1,13
110	4c	up	5/13 4:02	1	-0,09	50	314	20,5		1,54
110	4c	up	5/13 5:37	5	-0,09	45	305	20,3		1,87
112	4c	up	5/13 22:51	1,3	-0,09	200	*	*		#VALUE!
112	4c	up	5/15 21:24	5,6	-0,09	50	201	21,8		1,21
119	4c	up	5/24 4:00	9,7	-0,09	60	146	23,6		1,04
183	4c	up	5/24 16:00	14,4	-0,09	200	119	23,8	0,6	1,31
183	4c	up	5/24 17:34	13,9	-0,09	70	130	23,9	0,2	1,30
183	4c	up	5/24 19:39	12,5	-0,09	60	122	23,7	0,1	1,09

Instr. No	Measur location location	Temp. sensor direction	Time month/day hour	Temp. Exterior T5, R-294 Te, C	Wind corr coeffic. Rse	Measur time min	Measur Power [mW]	Temp Interior Surface Tis	measur Solar W/m2	U-value W/K*m2
Window 5 glass										
111	5	right	4/1 22:00	2	-0,07	95	250	19,62		1,33
111	5	right	4/1 23:00	1	-0,07	55	267	19,8		1,33
111	5	right	4/2 2:00	1	-0,07	140	268	20,6		1,29
110	5	right	4/2 23:00	5	-0,07	165	188	21,1		1,12
110	5	right	4/3 1:00	4	-0,07	200	217	19,8		1,30
112	5	right	4/10 20:00	4	-0,07	200	143	22,6		0,76
112	5	right	4/10 23:00	3	-0,07	200	*	*		#VALUE!
112	5	right	4/11 4:00	-1	-0,07	135	230	20,4		1,03
112	5	right	4/11 5:00	0	-0,07	100	303	20,9		1,35
112	5	right	4/11 23:00	3	-0,07	100	295	21,2		1,50
112	5	right	4/12 3:00	0	-0,07	65	253	20,8		1,15
119	5	right	4/12 18:00	6	-0,07	190	224	22,5		1,28
119	5	right	4/12 23:00	5	-0,07	100	211	22		1,18
119	5	right	4/13 3:00	4	-0,07	150	244	21,9		1,28
119	5	right	4/13 8:00	3	-0,07	200	173	22,3		0,87
119	5	right	4/13 12:00	6	-0,07	*	*	*		#VALUE!
119	5	right	4/13 18:00	4	-0,07	200	274	22,3		1,40
119	5	right	4/14 2:00	0	-0,07	75	239	20,4		1,12
119	5	right	4/14 6:00	0	-0,07	200	220	21,7		0,98
117	5	right	4/14 22:00	1	-0,07	200	*	*		-0,52
117	5	right	4/15 2:00	1	-0,07	200	*	*		-0,52
117	5	right	4/16 1:00	2	-0,07	200	*	*		#VALUE!
115	5	right	4/16 2:00	1	-0,07	50	203	19,9		1,03
115	5	right	4/16 6:00	1	-0,07	200	190	21,5		0,90
110	5	right	4/16 23:00	2	-0,07	105	206	20,3		1,08
110	5	right	4/17 4:00	1	-0,07	200	204	20,4		1,01
110	5	right	4/17 6:00	2	-0,07	135	269	21,4		1,30
114	5	right	4/18 1:00	4	-0,07	200	163	21,6		0,90
119	5	right	4/19 1:00	5	-0,07	200	54	21,8		0,34
119	5	right	4/20 3:00	7	-0,07	40	182	21,6		1,19
119	5	right	4/21 1:00	10	-0,07	200	150	22,8		1,13
119	5	right	4/21 8:00	9	-0,07	200	179	22,3		1,28
119	5	right	4/22 3:00	5	-0,07	170	240	21,7		1,35
119	5	right	4/22 8:00	7	-0,07	200	59	22,3		0,41
118	5	right	5/10 2:00	-2,2	-0,07	200	70	22,4		0,30
118	5	right	5/11 2:00	9,5	-0,07	200	166	22,4		1,23
119	5	right	5/12 0:00	-0,6	-0,07	70	273	21,3		1,18
119	5	right	5/12 5:00	1,8	-0,07	200	218	21,1		1,08
115	5	right	5/13 1:00	-2,2	-0,07	145	226	20,7		0,95
115	5	right	5/13 5:00	5,9	-0,07	55	291	20,4		1,82
119	5	right	5/13 20:00	0,8	-0,07	20	25	23,3	11	0,60
119	5	right	5/13 21:00	-0,1	-0,07	80	185	22,8	0,2	0,80
119	5	right	5/14 1:00	0,5	-0,07	200	209	22,5		0,92
119	5	right	5/14 4:00	2,2	-0,07	140	244	22,5		1,14
187	5	right	5/24 1:00	9,1	-0,07	70	160	25,4		0,95
187	5	right	5/24 2:00	8,8	-0,07	35	203	24,7		1,21
114	5	right	5/16 1:00	2,9	-0,07	150	202	21,4		1,05

Instr. No	Measur location location	Temp. sensor direction	Time month/day hour	Temp. Exterior T5, R-294 Te, C	Wind corr coeffic. Rse	Measur time min	Measur Power [mW]	Temp Interior Surface Tis	measur Solar W/m2	U-value W/K*m2
114	5	right	5/16 2:00	4	-0,07	35	226	21,3		1,24
116	5	right	5/22 0:00	7,4	-0,07	105	134	23,3		0,83
116	5	right	5/22 5:00	10,1	-0,07	200	179	23,5		1,27
115	5	up	5/13 6:00	7	-0,07	55	471	21		2,82
114	5	up	5/15 21:00	4,5	-0,07	60	227	22,7		1,18
110	5	up	5/17 1:00	-0,5	-0,07	185	414	21,8		1,69
110	5	up	5/17 5:00	4	-0,07	200	1474	*		#VALUE!
119	5	up	5/18 22:00	4	-0,07	85	273	22,8	0,2	1,37
119	5	up	5/18 23:00	3	-0,07	55	297	22,5		1,42
119	5	up	5/19 0:00	2,5	-0,07	50	343	22,4		1,58
119	5	up	5/19 4:00	2,5	-0,07	200	433	22,8		1,91
115	5	up	5/20 0:00	1,7	-0,07	165	311	22,7		1,38
115	5	up	5/20 4:00	4	-0,07	200	360	22,4		1,77
114	5	down	5/13 21:00	-0,1	-0,07	40	10	21,6	0,5	0,09
114	5	down	5/13 22:00	-0,5	-0,07	40	47	21,5		0,23
114	5	down	5/14 0:00	-1,2	-0,07	95	61	20,1		0,30
114	5	down	5/14 5:00	4,3	-0,07	200	37	21,3		0,24
118	5	down	5/17 21:00	2,7	-0,07	200	87	20,3		0,51
Total amount of measurements: 626 Failed measurements: 34 Noticed continued heating after measurement: 3 Measurements taking 200 minutes: 82										

Table 12. U-value measurements from windows 1 to 11

Instr. No	Measur location	Temp. sensor direction	Time month/day hour	Temp. Exterior T5, R-294 Te, C	Wind corr coeffic. Rse	Measur time min	Measur Power [mW]	Temp Interior Surface Tis	U-value W/K*m2
				Window 1					
112	1g	left	6/2 22:00	8,9	-0,07	55	60	22,4	0,52
112	1g	left	6/2 23:00	7,8	-0,07	55	89	22	0,71
112	1g	left	6/3 0:00	6,5	-0,07	35	107	21,9	0,83
112	1g	left	6/3 1:00	5,4	-0,07	55	101	21,6	0,7
112	1g	left	6/3 2:00	5,1	-0,07	40	121	21,3	0,83
112	1g	left	6/3 3:00	6,3	-0,07	65	138	21,1	1,02
116	1g	left	6/3 23:00	9,1	-0,07	40	58	22,5	0,46
116	1g	left	6/4 0:00	8,9	-0,07	75	98	22	0,75
116	1g	left	6/4 1:00	8,5	-0,07	50	113	21,7	0,85
116	1g	left	6/4 2:00	8,2	-0,07	40	123	21,6	0,9
116	1g	left	6/4 3:00	8,9	-0,07	55	122	21,4	0,96
114	1g	left	6/1 21:00	9,1	-0,09	80	69	23,3	0,59
114	1g	left	6/1 23:00	8	-0,09	95	103	22,8	0,79
114	1g	left	6/2 1:00	7,6	-0,09	50	97	22,5	0,74
114	1g	left	6/2 2:00	6,3	-0,09	35	101	22,2	0,72
115	1n	up	6/1 21:00	9,1	-0,09	60	107	24,1	0,77
115	1n	up	6/1 22:00	8,5	-0,09	40	133	23,8	0,87
115	1n	up	6/1 23:00	8	-0,09	35	151	23,6	0,96
115	1n	up	6/2 0:00	8	-0,09	50	162	23,4	1,04
115	1n	up	6/2 1:00	7,6	-0,09	55	171	23,1	1,09
115	1n	up	6/2 2:00	6,3	-0,09	55	185	22,8	1,10
118	1n	up	6/2 22:00	8,9	-0,07	35	100	22,7	0,73
118	1n	up	6/2 23:00	7,8	-0,07	60	139	22,4	0,93
118	1n	up	6/3 1:00	5,4	-0,07	80	174	21,9	1,02
118	1n	up	6/3 2:00	5,1	-0,07	65	180	21,6	1,05
118	1n	up	6/3 3:00	6,3	-0,07	60	179	21,3	1,14
119	1n	up	6/3 22:00	9,7	-0,07	55	109	22,6	0,84
119	1n	up	6/3 23:00	9,1	-0,07	55	126	22,2	0,94
119	1n	up	6/4 1:00	8,5	-0,07	45	155	21,8	1,12
119	1n	up	6/4 2:00	8,2	-0,07	100	167	21,6	1,19
118	1o	up	6/3 23:00	9,1	-0,07	75	114	21,7	0,89
118	1o	up	6/4 0:00	8,9	-0,07	40	140	21,3	1,09
118	1o	up	6/4 1:00	8,5	-0,07	65	147	21	1,13
118	1o	up	6/4 3:00	8,9	-0,07	75	165	20,9	1,31
112	1o	up	6/14 22:00	13,6	-0,07	65	84	25,3	0,73
112	1o	up	6/14 23:00	12,2	-0,07	65	130	24,9	1,00
112	1o	up	6/15 0:00	11	-0,07	45	142	24,6	1,02
112	1o	up	6/15 1:00	10,6	-0,07	55	152	24,3	1,07
114	1n	down	6/14 22:00	13,6	-0,07	50	88	25,2	0,76
114	1n	down	6/14 23:00	12,2	-0,07	50	123	24,8	0,96
114	1n	down	6/15 1:00	10,6	-0,07	35	147	24,5	1,03
114	1n	down	6/15 2:00	10,6	-0,07	60	166	24,1	1,18

Instr. No	Measur location	Temp. sensor direction	Time month/day hour	Temp. Exterior T5, R-294 Te, C	Wind corr coeffic. Rse	Measur time min	Measur Power [mW]	Temp Interior Surface Tis	U-value W/K*m2
Window 2									
116	2a	right	6/1 20:14	11,4	-0,09	40	60	24,4	0,49
116	2a	right	6/1 21:17	10,2	-0,09	55	78	24,2	0,58
116	2a	right	6/1 22:19	9,5	-0,09	75	97	24,1	0,68
116	2a	right	6/1 22:51	9	-0,09	55	121	23,8	0,82
116	2a	right	6/2 1:27	7,8	-0,09	70	121	23,3	0,79
116	2a	right	6/2 3:01	7,2	-0,09	40	124	23,3	0,78
115	2a	right	6/2 22:20	9,3	-0,09	30	54	23,2	0,42
115	2a	right	6/2 23:23	8,4	-0,09	50	92	22,8	0,66
115	2a	right	6/2 23:54	7,6	-0,09	60	108	22,4	0,74
115	2a	right	6/3 1:28	6,3	-0,09	45	118	22,2	0,75
115	2a	right	6/3 2:00	6,1	-0,09	45	120	21,9	0,77
115	2a	right	6/3 3:03	6,1	-0,09	45	138	21,7	0,88
115	2a	right	6/3 4:05	8,5	-0,09	50	131	21,4	1,01
114	2a	right	6/3 22:00	11	-0,09	45	57	22,6	0,52
114	2a	right	6/3 23:00	10	-0,09	20	43	22,4	0,38
114	2a	right	6/4 0:27	9,3	-0,09	50	91	22	0,73
114	2a	right	6/4 1:07	9,2	-0,09	50	91	21,8	0,74
118	2b	up	6/1 22:19	9,5	-0,09	60	98	23,6	0,71
118	2b	up	6/1 22:51	9	-0,09	55	129	23,4	0,9
118	2b	up	6/1 23:53	8,6	-0,09	60	145	23,1	0,99
118	2b	up	6/2 1:27	7,8	-0,09	100	167	22,6	1,11
118	2b	up	6/2 2:30	7,1	-0,09	90	172	22,1	1,13
114	2b	up	6/2 22:20	9,3	-0,09	75	116	22,9	0,86
114	2b	up	6/2 23:23	8,4	-0,09	45	153	22,7	1,06
114	2b	up	6/2 23:54	7,6	-0,09	40	136	22,4	0,92
114	2b	up	6/3 1:28	6,3	-0,09	30	138	22,2	0,87
114	2b	up	6/3 2:00	6,1	-0,09	45	171	22	1,06
114	2b	up	6/3 3:03	6,1	-0,09	34	171	21,6	1,09
114	2b	up	6/3 3:34	6,8	-0,09	50	168	21,3	1,14
115	2b	up	6/4 22:00	11	-0,09	55	85	22,3	0,77
115	2b	up	6/4 23:00	10	-0,09	55	85	22	0,73
115	2b	up	6/4 0:27	9,3	-0,09	35	138	21,6	1,11
115	2b	up	6/4 1:07	9,2	-0,09	35	164	21,4	1,31
115	2b	up	6/4 2:07	9,2	-0,09	95	143	21,1	1,18

Instr. No	Measur location	Temp. sensor direction	Time month/day hour	Temp. Exterior T5, R-294 Te, C	Wind corr coeffic. Rse	Measur time min	Measur Power [mW]	Temp Interior Surface Tis	U-value W/K*m2
Window 3									
119	3b f	up	6/1 20:14	11,4	-0,09	35	111	23,9	0,92
119	3b f	up	6/1 21:17	10,2	-0,09	45	118	23,6	0,89
119	3b f	up	6/1 22:19	9,5	-0,09	55	112	23,4	0,81
119	3b f	up	6/1 22:51	9	-0,09	35	97	23,3	0,69
119	3b f	up	6/2 0:25	8,6	-0,09	60	155	22,9	1,07
119	3b f	up	6/2 1:27	7,8	-0,09	60	133	22,7	0,89
119	3b f	up	6/2 2:30	7,1	-0,09	35	165	22,4	1,06
119	3b f	up	6/2 22:20	9,3	-0,09	65	108	22,6	0,82
119	3b f	up	6/2 23:23	8,4	-0,09	55	124	22,4	0,89
119	3b f	up	6/2 23:54	7,6	-0,09	80	157	22,1	1,07
119	3b f	up	6/3 1:28	6,3	-0,09	60	160	21,7	1,03
119	3b f	up	6/3 3:03	6,1	-0,09	40	163	21,4	1,05
Window 4									
112	4b f	up	6/1 20:14	11,4	-0,09	40	95	24,1	0,81
112	4b f	up	6/1 21:17	10,2	-0,09	55	130	23,9	0,95
112	4b f	up	6/1 22:51	9	-0,09	55	139	23,8	0,94
112	4b f	up	6/2 0:25	8,6	-0,09	35	144	23,6	0,96
112	4b f	up	6/2 1:27	7,8	-0,09	55	152	23,1	0,99
112	4b f	up	6/2 2:30	7,1	-0,09	55	158	23,1	0,98
112	4b f	up	6/2 3:33	7,6	-0,09	40	171	22,6	1,12
116	4b f	up	6/2 22:20	9,3	-0,09	65	122	23	0,89
116	4b f	up	6/2 23:54	7,6	-0,09	50	133	22,4	0,9
116	4b f	up	6/3 2:00	6,1	-0,09	70	171	22,2	1,05
116	4b f	up	6/3 3:03	6,1	-0,09	60	177	21,7	1,11
Window 5									
For window 5 average values have been used from all measurements during May									1,09
Window 6									
119	6	vertical	6/12 23:00	11,8	-0,07	60	141	27,1	0,90
119	6	vertical	6/13 0:00	11	-0,07	50	143	26,5	0,90
119	6	vertical	6/13 1:00	10,4	-0,07	45	115	26,1	0,73
119	6	vertical	6/13 2:00	9,9	-0,07	60	151	25,6	0,94
119	6	vertical	6/13 3:00	10,3	-0,07	55	139	25,4	0,90
116	6	vertical	6/13 23:00	11,4	-0,07	80	112	25,1	0,81
116	6	vertical	6/14 1:00	10	-0,07	80	127	24,4	0,87
116	6	vertical	6/14 2:00	9,7	-0,07	70	127	23,9	0,88

Instr. No	Measur location	Temp. sensor direction	Time month/day hour	Temp. Exterior T5, R-294 Te, C	Wind corr coeffic. Rse	Measur time min	Measur Power [mW]	Temp Interior Surface Tis	U-value W/K*m2
Window 7									
112	7	vertical	6/13 0:00	11	-0,07	155	164	27,1	0,99
112	7	vertical	6/13 1:00	10,4	-0,07	50	174	26,6	1,04
115	7	vertical	6/13 23:00	11,4	-0,07	115	124	25,5	0,87
115	7	vertical	6/14 1:00	10	-0,07	45	146	25,3	0,93
115	7	vertical	6/14 2:00	9,7	-0,07	45	142	24,8	0,92
115	7f	up	6/14 23:00	12,2	-0,07	60	135	24,5	1,07
115	7f	up	6/15 2:00	10,6	-0,07	50	162	24,1	1,15
115	7f	up	6/15 3:00	11,4	-0,07	90	158	23,8	1,22
116	7f	down	6/14 23:00	12,2	-0,07	85	142	24,7	1,10
116	7f	down	6/15 2:00	10,6	-0,07	40	172	24,6	1,18
116	7f	down	6/15 3:00	11,4	-0,07	35	152	24,1	1,15
Window 8									
118	8	vertical	6/12 22:00	13,5	-0,07	45	36	24,9	0,43
118	8	vertical	6/12 23:00	11,8	-0,07	40	46	24,8	0,45
118	8	vertical	6/13 1:00	10,4	-0,07	65	88	24,5	0,73
118	8	vertical	6/13 2:00	9,9	-0,07	115	88	23,8	0,75
114	8	vertical	6/13 23:00	11,4	-0,07	50	72	24,3	0,68
114	8	vertical	6/14 0:00	10	-0,07	50	91	24,3	0,75
114	8	vertical	6/14 1:00	10	-0,07	50	96	24,1	0,79
114	8	vertical	6/14 3:00	9,7	-0,07	40	106	23,9	0,86
Window 9									
116	9	vertical	6/12 23:00	13,8	-0,07	70	60	25,1	0,56
116	9	vertical	6/13 0:00	13	-0,07	40	103	24,9	0,86
116	9	vertical	6/13 1:00	12,4	-0,07	60	126	24,6	1,01
116	9	vertical	6/13 3:00	12,3	-0,07	100	168	24,4	1,32
112	9	vertical	6/13 23:00	13,4	-0,07	70	88	24,6	0,79
112	9	vertical	6/14 1:00	12	-0,07	100	131	24	1,06
Window 10									
114	10	vertical	6/12 23:00	11,8	-0,07	50	198	26,5	1,28
114	10	vertical	6/13 0:00	11	-0,07	100	225	25,7	1,43
114	10	vertical	6/13 2:00	9,9	-0,07	45	256	25,3	1,54
114	10	vertical	6/13 3:00	10,3	-0,07	35	265	25,1	1,64
114	10	vertical	6/13 4:00	11,6	-0,07	50	242	24,8	1,68
119	10	vertical	6/13 23:00	11,4	-0,07	60	176	25,1	1,22
119	10	vertical	6/14 0:00	10	-0,07	60	177	24,5	1,17
119	10	vertical	6/14 1:00	10	-0,07	50	207	24,2	1,37
119	10	vertical	6/14 3:00	9,7	-0,07	80	203	23,7	1,36
119	10f	up	6/14 23:00	12,2	-0,07	75	114	24,4	0,92
119	10f	up	6/15 1:00	10,6	-0,07	85	196	23,2	1,46
118	10f	down	6/14 23:00	12,2	-0,07	95	129	23,7	1,09
118	10f	down	6/15 1:00	10,6	-0,07	105	199	22,7	1,53
Window 11									
115	11	vertical	6/13 0:00	11	-0,07	135	204	25,8	1,30
115	11	vertical	6/13 2:00	9,9	-0,07	50	210	25,3	1,29
115	11	vertical	6/13 3:00	10,3	-0,07	50	215	24,9	1,38
118	11	vertical	6/13 23:00	11,4	-0,07	110	167	24,2	1,24
118	11	vertical	6/14 1:00	10	-0,07	65	206	23,7	1,41
118	11	vertical	6/14 3:00	9,7	-0,07	60	194	23,3	1,35

Instr. No	Measur location	Temp. sensor direction	Time month/day hour	Temp. Exterior T5, R-294 Te, C	Wind corr coeffic. Rse	Measur time min	Measur Power [mW]	Temp Interior Surface Tis	U-value W/K*m²
Window 12									
112	12	vertical	3/31 20:00	2	-0,04	60	81	16,7	0,56
114	12	vertical	3/31 20:00	2	-0,04	70	91	16,5	0,62
115	12	vertical	3/31 20:00	2	-0,04	60	103	16,7	0,69
116	12	vertical	3/31 20:00	2	-0,04	60	83	16,8	0,56
114	12	vertical	3/31 22:00	2	-0,04	80	93	16,5	0,64
115	12	vertical	3/31 21:00	2	-0,04	60	105	16,8	0,70
116	12	vertical	3/31 21:00	2	-0,04	60	91	16,2	0,64
116	12	vertical	6/16 1:00	16,6	-0,04	30	11	21,3	0,34
119	12	vertical	6/16 0:00	18,2	-0,04	20	6	21,1	0,3736
119	12	vertical	6/16 1:00	16,6	-0,04	20	9	21,1	0,3073
119	12	vertical	6/16 2:00	16,9	-0,04	20	14	21,1	0,4443
115	12f	up	6/16 1:00	16,6	-0,04	15	9	21	0,3142
115	12f	up	6/16 2:00	16,9	-0,04	30	15	20,9	0,4902
115	12f	up	6/16 3:00	17,1	-0,04	20	20	20,9	0,641
118	12f	down	6/16 1:00	16,6	-0,04	20	5	20,6	0,2475
118	12f	down	6/16 2:00	16,9	-0,04	30	8	20,6	0,3465
118	12f	down	6/16 3:00	17,1	-0,04	20	12	20,5	0,4902
112	12f	down	6/16 0:00	18,2	-0,04	25	6	21,1	0,3736
114	12f	up	6/16 1:00	16,6	-0,04	30	23	20,7	0,6648