IIB Module 4M19 Coursework **(RETURN TO EQUIPMENT CUPBOARD)**

Detailed notes for task BE1: Heat transfer characteristics of building envelope

Task (as outlined in main handout on Environmental Measurement)

The heat exchanges through the building envelope have a significant influence on the environmental performance of an indoor space. The convective heat transfer through the building envelope is assessed in Task V1. Therefore this task will focus on the conductive and radiative characteristics of the building envelope.

The task purpose is to characterize the thermal performance of the building envelope (opaque and transparent), in order to retrieve values that can be later use in the energy simulation of the environment. The three measurements that need to be performed are:

1. U-value of the opaque envelope;
2. U-value of the centre of glazing of the transparent envelope;
3. Tsol solar transmission coefficient of the transparent envelope;

The measure concerning the opaque envelope is the U-value [W/m2K], that describe the amount of heat passing through unit of surface due to 1K temperature difference between the outdoor and indoor environment. This is done by measuring the heat flux by means of a heat flux meter placed on the indoor surface of the external wall (in a homogeneous part of the indoor surface, i.e. at least 3 depth of the wall far from any window, pillar or beam), together with 2 inside and 2 outside surface temperatures and temperature of the indoor and outdoor environment. The measurement lasts for at least 3 consecutive days.

The same method must be applied for the measurement of the U-value of the centre of glazing, in this case when calculating the U-value try to consider all the measurements and then only the night measurement and comment. Together with the U-value centre of glazing, the Tsol [-] of the transparent façade must be measured, by means of two pyranometers parallel to the glazed façade. One pyranometer is placed in the internal environment and the other one external, this measure characterizes the amount of solar radiation entering the façade.

Equipment : 10 Thermocouples, DT80 and CEM20, 2 Heat Flux meters, 2 Pyranometers.

Detailed notes

One data logger plus its extension, 10 type T thermocouples, 2 heat flux meters and 2 pyranometers are available. The calibration for the thermocouples is given, while you can find the sensitivity of the heatflux meters and pyranometers on the data sheets available on the website "https://www.cambeep.eng.cam.ac.uk". An example of the program for the datalogger is also given on the website, but the students should write the program themselves. Please read carefully the instructions in order to use the DT80 software and to download the data. Please cancel the program and the data on the datataker after the download. The thermocouples are in a PVC tube casing in order to protect them, you can use some aluminium tape to stick the sensors on surfaces and to shield them from solar radiation (no more than 2 meters allowed per group).

First concentrate on the set-up of the measurement apparatus and verify that all the sensors are working properly and giving sensible and quite similar values when measuring the same thing (with the correct calibration): you should read more or less the same values, in the order of 10-50 W/m^2, on both Heat flux meters if placed next to each other, same ambient temperature for all the thermocouples, which should be around 20-25 C, and some amount of solar radiation for both pyranometers in the order of 100-300 W/m^2.
After verifying that all the sensors are working properly, place the 2 heat flux meters on the opaque part of the wall and on the centre of glazing respectively, take care to be as far as

possible (at least three thicknesses of the element you are measuring) from frames, pillars, beams, radiators etc…Use the aluminium tape to stick them on the surfaces and remember to shield them. Place 8 thermocouples near the heat flux meters on the surface of the wall and the glazing (2 on the internal surface and 2 on the external surface at the same locations for the wall and the glazing respectively). Use the other two thermocouples to measure indoor and outdoor air temperature and remember to shield them carefully in the case they are exposed to direct solar radiation. Place the pyranometers parallel to the glazing on a vertical position, one internal and on external.
Connect your PC to the datataker and trigger temperatures, heat fluxes and solar radiation every 1'30'' but store only the average measurements every 15 minutes. Measure continuously for at least 3 days and 3 nights.
Comment on the causes and significance of any noteworthy observations, and on the performance and suitability of the instruments.

Measurement of U-value
In order to measure the resistance R [Km^2/W], and the U-value [W/m^2K] of the opaque and transparent wall you can refer to the formulas below:

$$Q/A = 1/R\ (T_{Sin} - T_{Sout}) \quad (1)$$

and that

$$Q/A = U\ (T_{in} - T_{out}) \quad (2)$$

From 3D8 you for sure remember that

$$U\text{-value} = 1/(1/hi + R + 1/he) \quad (3)$$

Where A [m^2] is the area of the wall or window, Q [W] is the total heat flow through the wall/window, Q/A [W/m^2] is the specific heat flow through the wall/window measured by means of the heat flux meter, T_S [°C] is a surface temperature (either internal or external, average of the two surface measurement to be done next to each heat flux meter on either side of the wall/window) and T [°C] are the air measurements, h_i and h_e [W/m^2K] are the internal and external surface heat transfer coefficients.
Calculate the R value for the wall and glazing and combine them with the standard values (CIBSE guide A) of h_i and h_e in order to find the U-value (according to the standard) of the wall. After that calculate the actual U-value (considering T_{in} and T_{out}), and the actual h_e and h_i, and compare these with the U-value previously calculated and with the standard values. Remember that the opaque wall has a certain thermal inertia, so that a proper averaging of the data must be applied: try first with the instantaneous U-value, then with a moving average and finally with a progressive average and comment. In the case of the transparent envelope you have really low thermal inertia, so that you can calculate the U-value directly by plotting the specific heat flow measurement against the temperature difference. But remember that in the case of the transparent building envelope solar radiation can be a big source of disturbance, so that you must eliminate it by means of post-processing of the data, in order to have the correct value (plot the results with and without solar radiation and comment).

Measurement of solar transmittance and g-value of glazing
T_{sol} is the solar transmittance of the glazing, it represents the amount of solar radiation that is directly transmitted through the glazing in the total solar spectrum. Note that it is different from the g-value, which represents the total amount of solar radiation that is transmitted through the glazing (including that part that is absorbed by the glazing and re-emitted in the infra-red spectrum to the indoor environment, due to an increased temperature of the glazing). You can refer to the above definition for both of them:

$T_{sol} = I_{tr} / I_{in}$ [-] (4)

g-value = $T_{sol} + n^* \alpha_{sol}$ (5)

where $\alpha_{sol} + T_{sol} + \rho_{sol} = 1$ (6)

and $n = (1/h_e + 0.5^*R) / (1/h_e + R + 1/h_i) = U^* (1/h_e + 0.5^*R)$ (7)

I_{in} [W/m^2] is the total solar radiation impinging the façade (measured by an external pyranometer placed with the same orientation and inclination of the façade), I_{tr} [W/m^2] is the solar radiation transmitted through the glazing (measured by a pyranometer placed behind the glazing, in the indoor environment, with the same orientation and inclination of the façade). n is a factor representing the amount of solar radiation that is re-emitted towards the indoor environment once it has been absorbed by the glazing and determined an increase in the glazing temperature. α_{sol} and ρ_{sol} are respectively the solar absorption coefficient of the glazing and the solar reflection coefficient of the glazing, defined in the same way as T_{sol}.
Measure T_{sol} of the glazing by means of the pyranometers, and calculate the g-value of the glazing by considering the U-value calculated in the previous part of the assignment and considering first α_{sol} = 0.05, and afterwards considering the following relationship between T_{sol} and g-value:

if $T_{sol} > 0.634$, g-value = $[-0.20332 + (0.20332^2 + 4 * 0.94^* T_{sol})^{1/2}] / 2 * 0.94^* T_{sol}$ (8)

if $T_{sol} <= 0.634$, g-value = $(T_{sol} + 0.30515)/1.30415$ (9)

The formulas refer to the relationships in Reference (d), which are derived from more than 4000 glazing products commercially available and are valid for U-values > 4.5 W/m^{2}K. For other U-values please derive the above formulas from Reference (d).

Equipment

Datalogger DT80 and extension DT CEM20 (these are auto-installing when connecting the USB pen drive of the DT to the PC. Please read the instructions on the DT manual and on the document "https://www.cambeep.eng.cam.ac.uk/References/DT_schedule" carefully. Remember to shield the datalogger if exposed to direct solar radiation (you could use any kind of box).

10 thermocouples which are calibrated on the specific DT80 and CEM20 channels indicated in the labels. The thermocouples are extremely delicate and break easily especially the terminal parts, if a thermocouple is broken you have to fabricate a new one and calibrate it against a reference PT100 thermo resistor, on your own (contact Fabio Favoino for details). If a thermocouple is broken you will read "out of range" on the DT. The connection between the thermocouples and the DT needs to be carefully done, as if the metallic part of two thermocouples is touching the measure of both thermocouples is not reliable any more. Please read the document "https://www.cambeep.eng.cam.ac.uk/equipment/manuals/um-0085-b8-dt8x-users-manual.pdf" and "https://www.cambeep.eng.cam.ac.uk/equipment/certificate/thermocouple-calibration.pdf " in order to understand how to connect the thermocouples to the DT80 and CEM20.

Heat flux meters and pyranometers connect as well to the DT80 and CEM20 on the channels free from thermocouples. Read carefully the manuals of the sensors to understand how to connect them to the DT80 and how to place them on the surfaces. In particular pyranometers must be as parallel as possible to the glazed façade.

The acquisition of the measurement is done by means of programming the DT80, an example program will be provided on the website "https://www.cambeep.eng.cam.ac.uk/References/DT_schedule", this could be modified in order to input the calibration of all the sensors to the DT80.

NB: after sending the final program for measurement acquisition download the data first and check they are measuring sensible things (diffuse solar radiation about 150-200 W/m2, Heat flux of 50-80 W/m2 if the HF sensors are touching human hands).
If you are not able to program properly the CEM 20 and get it to work, Perform the BE experiment in two times rather than in one go. The first time measure the U-value of the opaque and glazed part, by performing the measurement for 3 days. Use just one surface temperature per measurement (one internal and one external for the glass, one internal and one external for the wall) so that you should have 8 total thermocouples, that are occupying 3 channels, place the HF sensors on the other 2 free channels of the DT. The second time only use the pyranometers connected to the DT to measure the total solar transmittance of the glazed part, along 1-2 days of measurements.

In order to stick the thermocouples and heatflux meters on surfaces use the aluminum tape provided (please do not use too much of it but it has to cover completely the sensing part of the sensor), moreover remember to shield the sensors that are exposed to direct solar radiation which could be a big source of inaccuracy (i.e. heat flux meter on the glazing can be shield with some aluminum tape on the external part of the glazing). Remember to clean all the surfaces after you remove the aluminum tape.

References

(a) New Metric Handbook; Planning and Design Data, Butterworths Architectural (pp.384-397 enclosed – see especially p. 384-7). (Folio AH32 in CUED Library.)

(b) CIBSE Guide A: Environmental Design of Buildings. Chartered Institution of Building Services Engineers, 2008.

(c) BS ISO 9869-1:2014: Thermal insulation. Building elements. 7IIn-situ7R measurement of thermal resistance and thermal transmittance. Heat flow meter method

(d) Dariush Arasteh and Christian Kohler, Modeling Windows in Energy Plus with Simple Performance Indices, available at http://gaia.lbl.gov/btech/papers/2804.pdf