Specification for Phase 2 of the thermal flow modelling for the Celsius project

This document specifies the work to be carried out by NPL during phase two of the thermal flow modelling for the Celsius project. This specification will replace the work as defined in the original proposal document supplied by NPL, and its acceptability will be confirmed by ENWL via email.

It is assumed that the reader has access to the report "Celsius project thermal modelling phase 1: Modelling the heat flow in transformer substations", NPL Report ENG66 [1]. This report documented the initial modelling of the heat and air flow within substations and identified a set of recommendations based on the results of that modelling. The recommendations were based on models of six substations of various types under various circumstances.

ENWL have requested that a similar set of recommendations be developed to guide best practice in new build transformer substations. This document provides a specification of the work required to develop these guidelines. The results of the work will also support the retrofitting work that will take place in April-July 2018, and additional models will be run to address the challenges associated with non-standard buildings.

The initial results of the work will be delivered by 31st March 2018 as an informal report to address proposed recommendations and associated evidence. This deadline is imposed to ensure that the recommendations can be followed during the retrofitting campaign, so the delivered results will be focussed on developing recommendations for new build and applying them to non-standard buildings. A further formal report will be delivered by 31st May 2018 that will fully specify all models and assumptions made, and may contain results of other possible scenarios if resource permits. There may be additional subsequent work after the retrofitting to assess the validity of the models used.

The following sections specify the geometry to be used, the weather conditions and transformer states to be considered, and the quantities to be varied as part of the study. Any quantity not explicitly stated to vary will be regarded as fixed, so for instance the dimensions of the buildings will not be varied. A list of models to be run is included in the final section.

All models will use the same governing equations as were used in the previous report: air flow will be treated as laminar; the density, thermal conductivity, specific heat capacity, and viscosity of air will be regarded as temperature-dependent using equations (8)-(11) of the previous report, and heat transfer coefficients will be defined as 3.6 W m^{-2} K^{-1} for the walls and floor as per section 3.4.6 of the previous report.

In order to ensure that the effects of solar radiation are captured correctly, transient models will be used rather than static ones. This approach will require redefinition of the boundary conditions to take the thermal mass of the building into account. This redevelopment will be the first step of the second phase of the project.

The models will be compared using temperature distributions, peak temperature within the building, energy leaving the building through the walls, ceiling, floor and vents, and amount of energy removed from the transformer.

Geometry

Two building geometries will be used for the majority of the work, based on the current new build specification for GRP and brick transformer substations. These specifications are given in documents supplied by ENWL. The critical details are listed in table 1 below.

	Brick	GRP
Internal width (m)	3.64	3.1
Internal length (m)	3.19	3.2
internal height (m)	2.668	2.44
Wall thickness (mm)	280	40

Table 1: Building dimensions for the brick and GRP new build specifications. Width is the horizontal dimension of the wall containing the door. GRP wall thickness estimated from existing builds.

The internal roof will be taken to be flat. The louvre geometry will be based on the documents supplied by ENWL, but the louvre orientation may be altered in some models to investigate the effects on the airflow.

The internal geometry of both substations will be taken to contain a transformer and two cabinets (containing low voltage switchgear (LV) and a ring main unit (RMU). The transformer and cabinet dimensions from Town Bridge substation will be used in all cases. The cabinet and transformer dimensions are specified in table 2, and the transformer dimensions are given in table 3, and figure 1 gives a sketch of the transformer geometry.

	Town Bridge
LV cabinet	
Length (m)	0.55
Width (m)	0.98
Height (m)	1.75
RMU cabinet	
Length (m)	0.74
Width (m)	0.56
Height (m)	1.75
Main transformer body	
Length (m)	1.3
Width (m)	0.46
Height (m)	1.56
Total enclosed cooling fin volume (m^3)	0.70

Table 2: Cabinet dimensions for the GRP build. Width is the dimension parallel to the orientation of the doors.

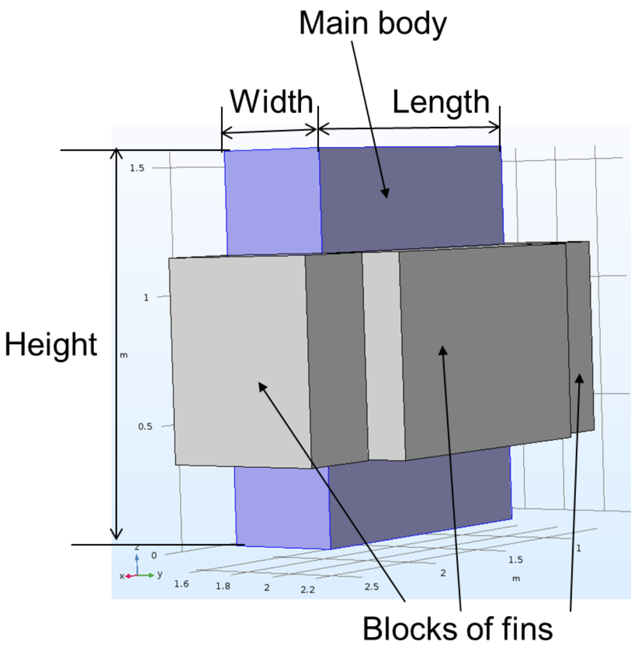

Figure 1: Transformer geometry

Two sets of locations will be defined for the plant within the building: one labelled as “tight” and one labelled as “spaced”. The tight specification will place the plant close together in the centre of the building, and the spaced configuration will separate the plant items as far as possible. In both cases the configuration will be consistent with the safety constraints on the plant, which are i) that an escape route 1 m wide must be available, and ii) that all plant must be at least 60 cm from a wall. These specifications will be developed by NPL and agreed with ENWL.

Two additional buildings will be modelled to assess the effect of the proposed recommendations on cooling in non-standard build substations. The two buildings chosen are Acorn Street, which has a dividing wall in it, and Portland Grove which has a wooden partition and small vents. The layout of these buildings is shown in figures 2 and 3.

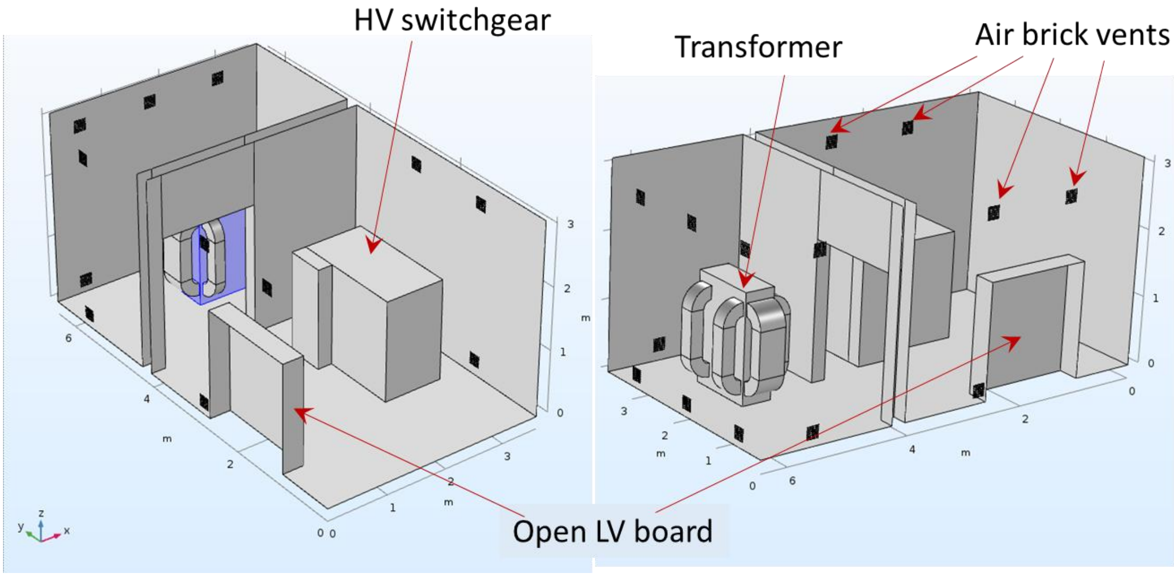

Figure 2: Internal layout of Acorn Street from two angles.

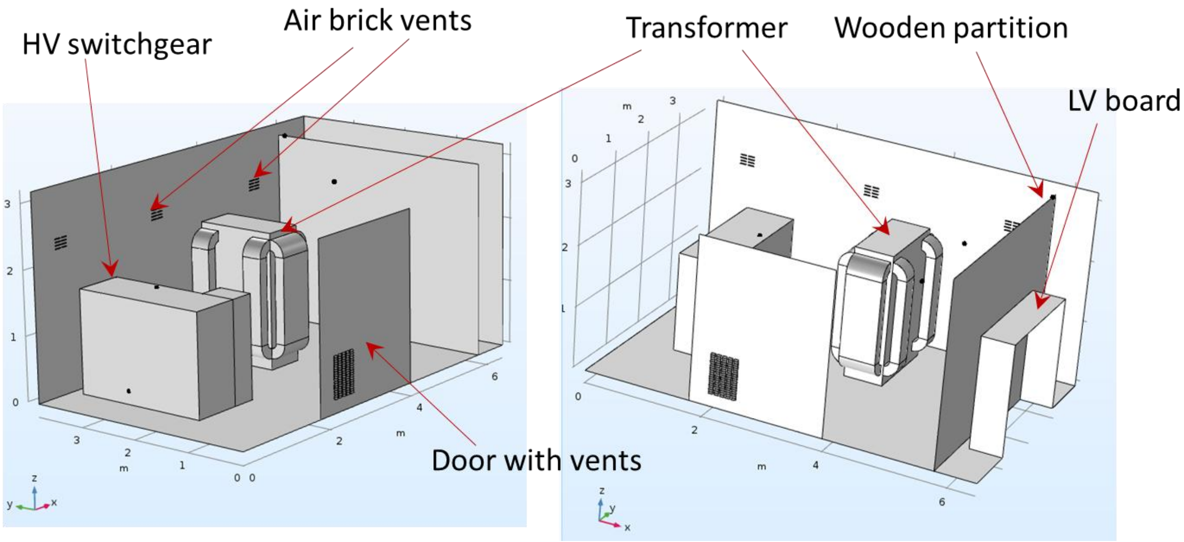

Figure 3: Internal layout of Portland Grove from two angles.

Weather conditions & transformer state

The models will simulate challenging conditions that a substation is likely to encounter.

The air temperature and solar radiation will be obtained from weather data. The CIBSE environmental design guide [2] gives mean values for solar irradiation in Manchester in each month. The maximum of these values (the June value of 4878 W h m^{-2}) will be used. The amount of this irradiation that is absorbed by a wall or ceiling will depend on the emissivity of the surface. Emissivity is a dimensionless value between 0 and 1, where 1 represents a perfectly black surface that absorbs all energy. A value of 1 will be used, because the irradiation data being used is a mean not a worst case value, so allowing all of it to be absorbed will lead to more heating than would typically be expected.

The irradiance will be multiplied by a time-dependent function to capture the way sun intensity varies as the sun moves through the sky. The sun will be regarded as rising at 04.40 and setting at 21.40, and the irradiation will be taken to vary like the positive part of a sinusoid between those two times (see figure 4).

It is suggested that the irradiation is applied to one wall and the ceiling. Implementation of a "moving sun" model would be computationally challenging and may not represent a worst case scenario.

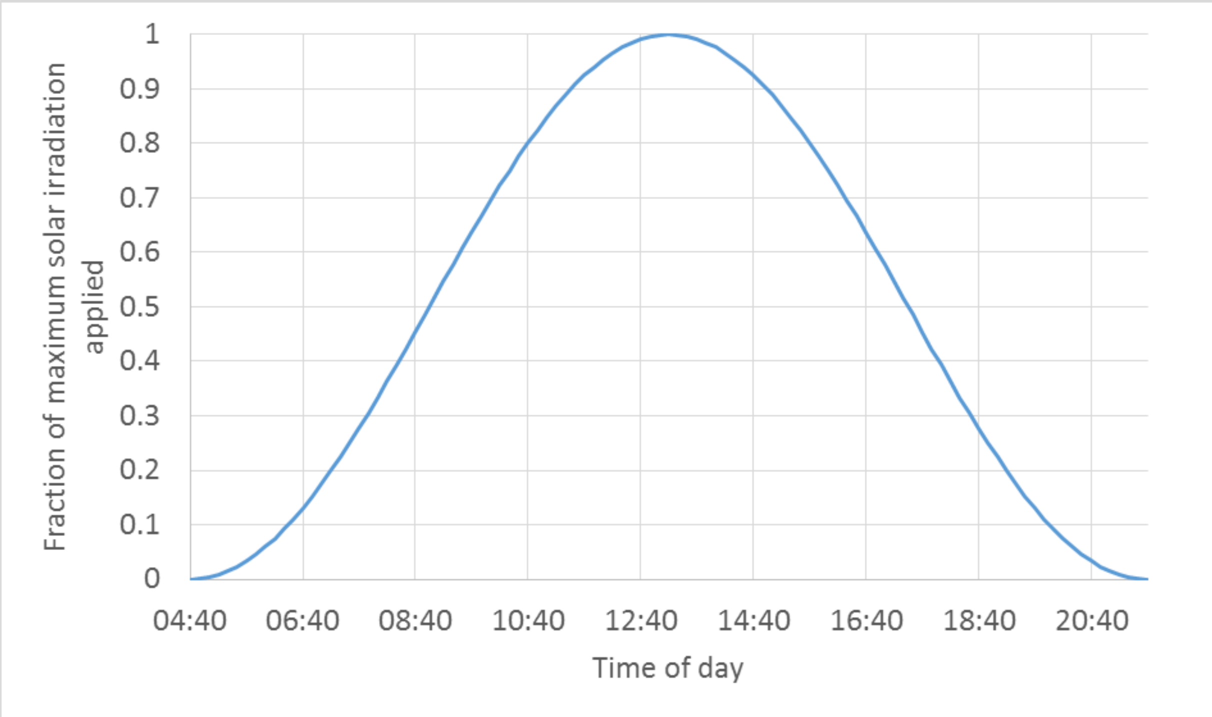

Figure 4: Irradiation variation over time.

The Met Office website [3] suggests that the mean maximum temperature in Manchester occurs in July and is 21 °C and the mean minimum temperature in July is 12 °C. The air temperature will be assumed to vary between those two temperatures using a function the same shape as that shown in figure 4.

It will be assumed that the peak load on the transformer and hence the peak top oil and bottom oil temperatures occur at the same time as the peaks of air temperature and irradiation. This combination will lead to a worst case scenario.

As with the previous models, the transformer is taken to be the only source of heat inside the building. The other objects inside the building will not gain or lose heat.

The wind will be considered by altering the pressure distribution on one side of the building, see section below for details. As with the previous models, the wind will be taken to increase the pressure on a face by 25 Pa.

The transformer thermal loading (top & bottom oil temperatures) will be defined by choosing the maximum temperatures reached by the most heavily loaded transformer from the sites due to undergo retrofitting. The list of these sites will be supplied by Ricardo, and the data gathered in summer 2018 will be assessed to define suitable temperatures.

The use of a transient model may mean that the method for defining how the transformer adds energy to the air needs to be altered. The measured top oil temperatures increase due to loading of the transformer and decrease due to the effects of the cooling air. Since the model needs to predict the cooling in order to look at the effectiveness of the proposed changes, it may be that an alternative approach needs to be taken. One possibility would be to estimate the internal energy of the transformer at its hottest and generate a model that cools the transformer, updates the internal energy as it loses that energy, and calculates a new transformer temperature distribution based on the new energy. This idea will be pursued in the initial stages of the project and an approach will be agreed with the project partners before the models are run.

If the specification of the transformer heat does not need to be changed, the transformer temperature distribution will be defined by identifying a time period including the highest top oil and bottom oil temperatures seen by the selected transformer, using this information to define a suitable temperature vs time curve for the two measurements, and defining a temperature distribution that interpolates linearly between top oil and bottom oil with height.

It will be assumed that the top oil and bottom oil sensor locations are the same as the locations of the equivalent sensors in the Town Bridge substation so that a height-dependent temperature distribution can be defined.

Model variations to be run

Each geometry will be run with the following conditions:

- A run of the building design exactly as specified under the thermal conditions specified as above with no wind and the “tight” specification for the plant placement. This situation is regarded as the base case.
- Two runs with the wind impinging on one wall leading to an increased pressure specification on that wall.
- A set of at most three models with altered louvre placement to attempt to improve air flow.
- A single model with the base case conditions and the spaced configuration.
- A single model with the spaced configuration and the conditions that gave best cooling of the tight configuration model.

This gives eight models per geometry and 16 models in total.

Four further models using non-standard build geometry will be created: two with the geometry as it currently is and two with ventilation adjusted based on the recommendations to support the retrofitting.

If time allows, more models may be added based on initial results.

“Altered louvre placement” here could mean the addition of extra louvres, addition of a ceiling vent (GRP only), movement of existing louvres, or reorientation of louvres to encourage air to leave or enter the building.

References

[1] “Celsius project thermal modelling phase 1: Modelling the heat flow in transformer substations”, L Wright and J Pearce, NPL Report ENG66, 2017.

[2] “GVA/15 CIBSE Guide A: Environmental Design”, Chartered Institution of Building Services Engineers (CIBSE), 2015.

[3] https://www.metoffice.gov.uk/public/weather/climate/gcw2hzs1u