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METHODOLOGIES FOR TRANSLATING BUILDING SECTIONS INTO THERMAL MODELS

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ABSTRACT

As designers evolve facade details to reduce heat flows, features such as corners and junctions between building elements, are of increasing importance. Groups such as the PassivHaus Institute view thermal bridges and junctions in constructions as often exceeding the thermal impact of primary facade elements. This suggests more rigorous approaches in dynamic simulation may be of interest.

Whole-building thermal simulation tools typically use 1D representations supplemented by linear thermal bridge coefficients. However, many advanced building sections are conceptually difficult to fit within a 1D heat flow regime. Those which offer 2D and 3D capabilities tend to be underutilized because of the resources required to attribute the additional dimensions of conduction.

Existing 2D and 3D conduction analysis tools have difficulty scaling up to full scale buildings with environmental control schemes and usage patterns. Many also use steady state approaches which makes their predictions difficult to associated with dynamic whole-building tools.

This paper explores methodologies for bridging the gap via better design of existing 1D models based on contributions from 2D and 3D tools as well as rules for translating complex building sections into model elements. It explores linear heat transfer coefficient representations of thermal bridges as well as hybrid models with a mix of 1D and 2D components.

INTRODUCTION

All simulation tools work with an abstraction of reality. The design of simulation models requires the user to transform physical entities into the virtual entities supported by the tool. Ideally, the geometric and compositional resolution of a simulation model should be based on the nature of the performance questions being asked as well as the available project data and the resources available. A model suited to answering questions about general demand patterns will be inappropriate for predicting asymmetrical radiant discomfort in a hospital ward. But the latter model could answer the first question.

Experts are able to coerce simulation tools to create the specific model they have in mind irregardless of the tool interface. Other are constrained by the functionality of the interface, and tend to follow the approaches covered in their introductory training and in similar projects of their peers. The risk of resources wasted on overly complex models and of opportunities missed because models were overly simplistic is substantial.

As a community of experts, developers rarely discuss the planning and design phase of the simulation process. What is written about the process is describing ease of use issues rather than methodology. Growth in the complexity of simulation models delivers less because of faults in our working processes.

There are some reality checks for this new status-quo. Firstly, if CAD data is being imported then many of the decisions about what is included in the simulation model will have already been taken. Who is making these decisions and do we agree with the criteria they used? CAD models may or may not be a good match to the needs of the simulation team and the attributes of the CAD entities may or may not prove useful within a simulation environment.

Those using facilities within the simulation tool interface to define their model will be 'differently' constrained. Interfaces can lead the unwary towards overly complex models just as they can influence users toward a finite set of standard building or system layouts. Are we not just a bit curious that so many office building models follow the same pattern of four perimeter zones an a core with one strip of glazing on each facade?

A wizard is someone else's idea about how to automate a task and a template is someone else's idea about how tens or hundreds of components or building elements should fit together. If we agree with the design implicit in the template or with the end product of the wizard then we have a win-win situation. Many practitioners who are not in a position to judge validity of such features or to manipulate the complexity wizards helped them create.

Of course some users have a preference for concise models which lump all of the glazing on one facade of an office together. They may omit doors or ignore ceiling voids because they think them unimportant. Such simplifications are unremarkable within the simulation community. Should they be unremarkable? Reality checks are a good idea.

One reality check is to view simulation practice in the light of the detailing that is emerging in response to the demands of low energy design practices or recent trends by facade engineering groups.

AN EXAMPLE

The Laegehus Stenlose Syd in Denmark is, in many ways, representative of a new generation of low energy designs. It uses a combination of thick insulation and careful detailing to eliminate thermal bridges. Its detailing is similar to that used in the PassivHaus standard (Feist 2007) and is illustrative of the many choices required in the planning and creation of building thermal models.

Inspecting the section in Figure 1:

• the thickness of ceiling insulation is substantial and at the perimeter it tapers - do we ignore the thickness when creating the geometry of the zones?

• the thickness of the external wall is substantial - do we use inside face or outside face and the glass does not align with either so where should it go?

• the wall section comprises a number of material types, especially around the window and at the foundation - do we use one (average) wall construction and rely on linear heat transfer coefficients to represent the exceptions or do we create special constructions at the window reveals?

• the depth of the wall and placement of the window result in a substantial inner window reveal which is subject to intermittent solar radiation - do we assume geometrically thin walls or explicitly represent the reveals?

• there is an overhang which is thermally isolated from the air within the roof space but forms a boundary for the upper section of the wall - do we ignore this boundary condition, do we treat it as a separate thermal entity or just assume that it shades the facade?

• there is an air space below the tiles which is separate from the air within the roof space - do we assume this is an unventilated cavity or give it an explicit treatment?

• the surface area at the top of the insulation layer is different from the surface area at the ceiling - which surface area takes precedence and do we try to represent the actual volume of the roof?

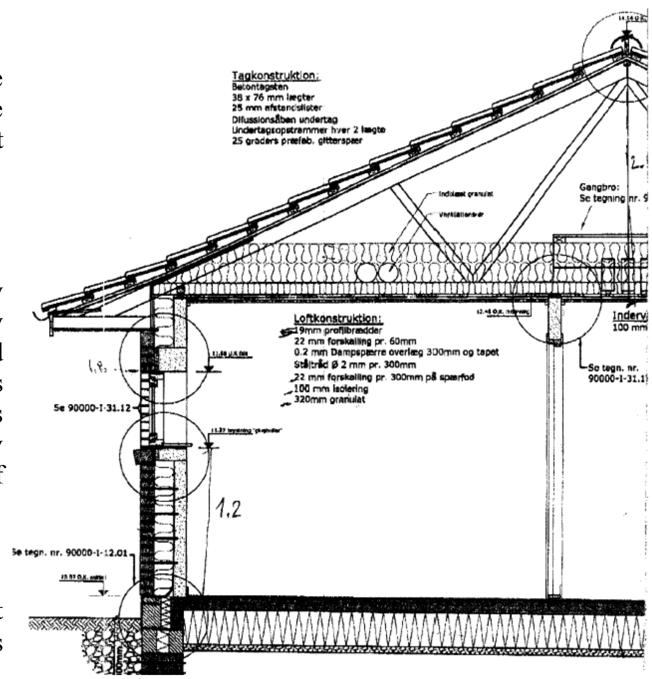

Figure 1: Section of Laegehus Stenlose Syd

The list could be much longer . These details call into question our typical assumptions of facades composed of planes. We need strategies for ranking thermo-physical issues, techniques for translating them into model entities and methods for deciding what needs to be included in our model(s) as well as the level of detail which is appropriate.

Simulation tools understand syntax, but not necessarily the intent of the user. A thermal zone might conceptually be as small as a thermostat housing or encompass a whole floor of an office building. Indeed, there are times when a core and four perimeter zones is a good fit for an open plan office building. But the form of the model is only one of our abstraction decisions.

Air flow and occupancy diversity and control logic all could be viewed critically.

In the context of this low energy dwelling, the following list is one possible ranking of what to preserve in the design of the model:

• zoning of rooms to reflect likely changes in air temperature, internal gains and environmental controls the volume of air

• the slope of the roof and relation of the overhang to facade elements

• the location of mass within constructions as well as in the spaces

• the room surface area in contact with the air

To apply this ranking requires opinions about or observations of where air and surface temperatures vary, sun paths and where mass may influence changes in temperature as well as where thermal bridges may be found.

A low resolution model could combine the bedrooms on the southwest (using internal mass to ensure that the surface area is maintained). It could treat the overhang as a solar obstruction and ignore that it acts as an additional boundary condition for the upper portion of the wall. It might assume the air is well mixed within the roof space (i.e. there is no temperature stratification) and assume an average thickness of the ceiling insulation.

If the design goal includes an evaluation of comfort then the radiant environment becomes important as does the variation in surface temperatures and this would require surface sub-division as well as acknowledging the variations in construction details. A medium resolution model might subdivide the ceiling surfaces and create multiple constructions to account for the sloped insulation. It might treat the centre of the floor slab differently from the perimeter. It might extend the roof zone to allow it to form a boundary at the upper wall section (as in Figure 1).

If the design goal is to improve summer comfort then our model planning needs to consider how the building reacts to events likely to cause overheating and would also need to explore the impact of user actions e.g. opening windows and moderating internal heat generation.

A high resolution model might subdivide the roof so that the temperature near the peak of the roof can be different from the air adjacent to the insulation layer. A high resolution model might include surfaces for the inside window reveals with adjusted constructions to represent the adjacent wall sections.

If the user is constrained in time, one could form the base of the roof space by using the existing room ceiling surfaces and then create a simple sloped roof above that (see Figure 2). This approach results in a model that is crude visually. The surface of the roof is at the correct slope, but the height of the building is not correct and the volume of air in the roof is approximate.

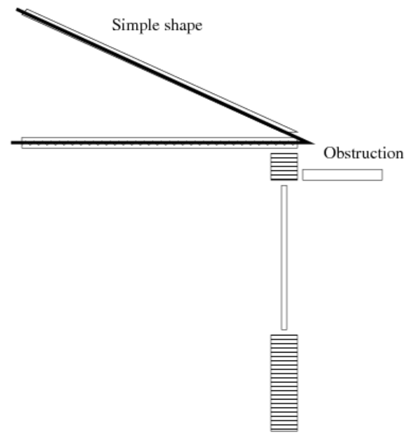

Figure 2: Constrained model

Given a bit more time the user could add a number of perimeter surfaces so as to raise the roof (excess air volume) as in Figure 3. Such trade-offs might not alter the overall performance of the building but may be useful to make the model more applicable to visual studies.

An initial simulation model wireframe by a user of limited experience is shown in Figure 7. This largely follows the time-constrained approach of Figure 2.

Checking this model indicated that the obstruction is placed at the same level as the ceiling rather than in its correct position in relation to the windows. This will alter the solar radiation falling on the facade elements.

Indeed, a critical issue for groups using simulation is to ensure that models are checked and that the documentation included with the model includes notations about the assumptions made and the critical coordinates.

In Figure 1 the ceiling has a substantial thickness and the areas of both faces differ. Treating the ceiling via as explicit 3D coordinates would be easy to implement at the planning stage but requires additional steps in the simulation tool interface if it is applied as a change.

It also introduces a gap between the roof zone and the occupied zone (as in Figure 4) which is in line with 3D

CAD data and the emerging attributes of building information management initiatives.

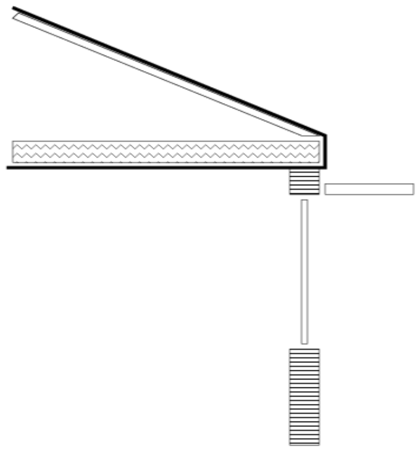

Figure 3: Variant placing roof at correct height

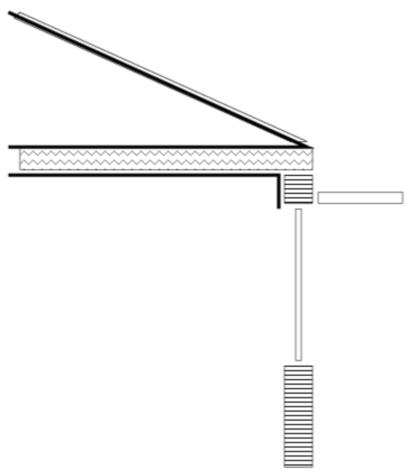

Figure 4: Variant with gap between zones.

To approximate the 3D geometry of an actual roof takes us a number of steps away from Figure 1 in order to reach the roof overhang in Figure 5. Note that this introduces a new boundary condition for the upper portion of the exterior walls.

In the building section the overhang is in contact with the upper portion of the wall. As the temperature in the roof space may differ from ambient temperature, the polygons should be adapted so as to sub-divide the wall into surfaces that face the outside and surfaces which connect to the overhang.

Experts know that planning is key and clear sketches of the model to be created and discussions with others prior to using the interface saves a lot of time! It is much less tedious to include such subdivisions when planning the model.

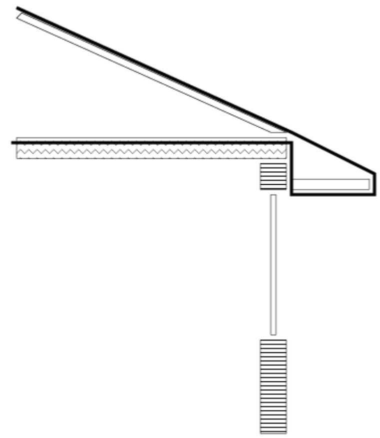

Figure 5: Variant extending overhang.

As mentioned in the introduction, the air within the overhang could be at a different temperature than the roof space. If such temperature differences were an issue (say in hot sunny climates), the overhang could be represented as a separate zone as in Figure 6. Again the existing wall will have to be revised to represent the connection to the outside and the connection to the overhang.

Investing resources to increase model resolution is a decision that should not be made lightly. Some differences in performance predictions can be subtle rather than dramatic. A user who wishes to explore this could define variant models at different levels of resolution to test the sensitivity of predictions.

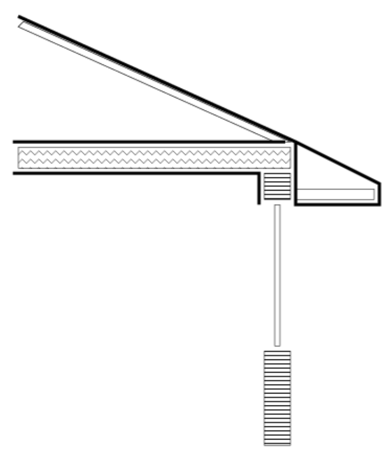

Figure 6: Variant with separate overhang zone.

Figure 8 shows the model roof zone adapted to follow the pattern in Figure 5.

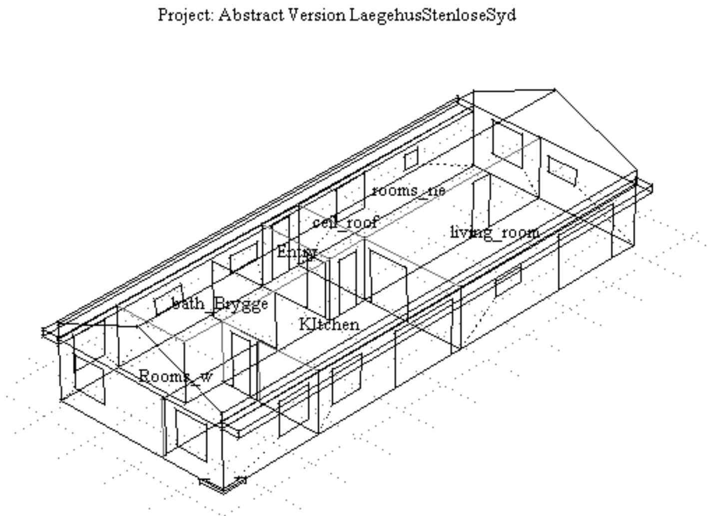

Figure 7: Wireframe view of users initail model.

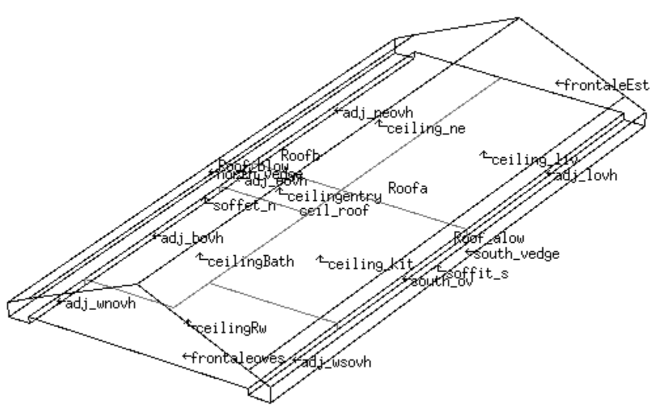

Figure 8: Wireframe view of extended roof model.

METHODOLOGY

As discussed, facade elements may have geometrical or thermodynamic aspects which are compromised by the use of one dimensional heat transfer algorithms. In these cases adapting the geometry is insufficient and additional assessments are required. 2D and 3D representations of thermal bridges require more data input from the users and are thus more resource intensive.

There are four major methods in main stream simulation today that can be used to address the problem:

1. No thermal Bridges: This method is employed in most models built for simulation purposes. Where this is an assumption made to keep models simple and easy to set up it has implications on overall heating and cooling demand. As building standards improve, the proportion of heat transfer due to thermal bridges will increase in proportion to that from better insulated portions of the facade. Models lacking thermal bridge descriptions will continually become less accurate. PassivHau is an extreme example of this trend in construction detailing and in assessment focus.

2. Thermal Bridges using linear thermal transmittance (psi) values: These models include a single transmittance value representative of geometric thermal bridges. This value is used to work out heat transfer through each thermal bridge. Transmittance is usually calculated via finite element methods using calculation procedures supplementary to the main simulation calculation. As an example transmittance values using 2D heat transfer software THERM (LBL 2006) can be used as inputs to whole building integrated software such as ESP-r (Hand 2008). This approach can be interrogated further in terms of the validity of a static transmittance value for the range of environmental conditions that the thermal bridge is subjected to during the course of a dynamic simulation. Furthermore dynamic software could include the effects of point thermal bridges in addition to linear thermal bridges.

3. Transient standalone 2D/3D calculations: It is possible to calculate transient effects using 2D/3D heat transfer software. Many issues remain due to the standalone nature of such calculations. Buildings and their associated energy systems are interlinked in a complex fashion and not taking into account some of these domains can seriously compromise results.

4. Transient integrated 2D/3D simulation: This is a first principles approach and requires significant expertise on the part of the user. 2D/3D effects are calculated in tandem with the main simulation calculation procedure. Simulation is consequentially more computer intensive because the 2D/3D heat transfer solver can take up equal or more time than the main thermal 1D solver. Results are deemed to be more accurate and can provide a benchmark against which other approaches can be calibrated in order to ascertain their usefulness and accuracy.

In the context of extreme low energy designs practitioners are confronted by the need to pay attention to thermal bridges, but are usually restricted in the resources they can deploy.

Some groups publish psi values for standard construction details (Waltjen 2007) and this saves a great deal of time, especially in the early stages of design. The user only needs to classify the bridge type, enter its psi value and the length of the bridge into each of the thermal zones.

And where published data is not available then the practitioner is confronted by subcontracting this assessment or carrying it out in house. The current rate for a 2D static psi value calculation for one building detail in Europe is ~300 Euros.

Tools such as THERM require 2D materials to be defined as well as boundary conditions (see Figure 9) and are able to produce outputs such as lines of constant flux (Figure 10) and isotherms through the section (Figure 11). Such reports are indicative of the magnitude of the thermal bridge under standard conditions but are difficult to incorporate into most whole building models.

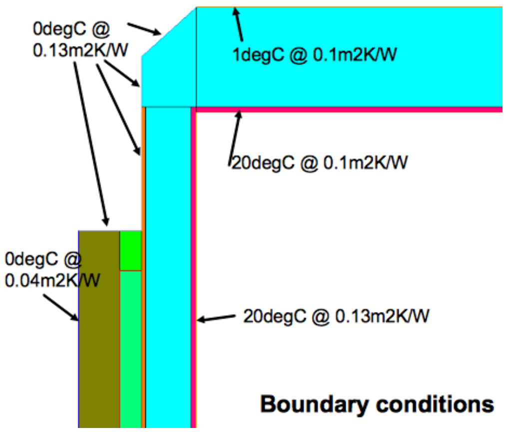

Figure 9: Materials & boundaries at a roof junction

Psi values can be included directly in some whole building simulation tools such as ESP-r. In other tools you have to create additional surfaces with adjusted thermophysical properties to approximate the thermal bridge.

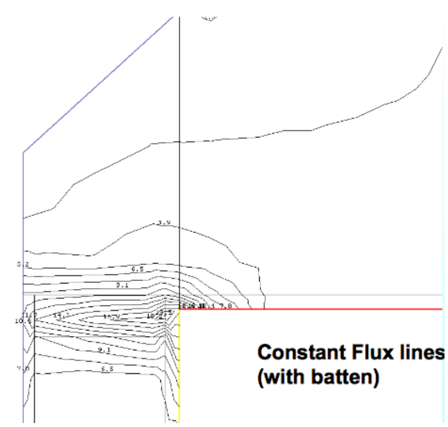

Figure 10: Flux lines for given conditions

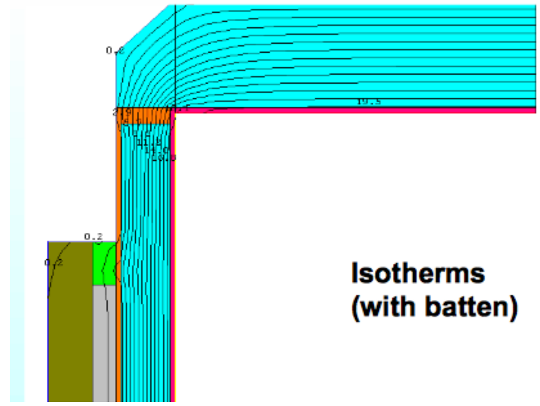

Figure 11: Isotherms for given conditions

SIMULATION

During the planning stage abstraction decisions are made based on opinions and prior experience. The ideas discussed earlier have an implementation cost as well as potential performance benefits. For example, the initial model shown in Figure 7 was found to have the solar obstructions placed incorrectly. To correct this, generate new shading predictions and then re-run the simulations and extract performance data required ~20 minutes and increased heating demands by 1.8 kWhr/m2/a and reduced cooling by 0.36 kWhr/m2/a.

In comparison with the corrected solar obstructions, the methodology which advocated extending the roof (as in Figures 5 and 10) and adjusting the zone walls required ~40 minutes and resulted in a reduction of heating of 0.12 kWhr/m2/a and essentially no difference in cooling.

The additional time taken to extend create a more explicit roof resulted in a small change, in part because the temperature within the roof space follows roughly the outside ambient temperature and in part because the extreme resistance to heat flows in the facade walls. This is still a useful test to undertake in order to build up working procedures for different facade details.

The introduction of thermal bridge descriptions (advanced method 2) into the thermal model required ~10 minutes (it can take several hours to generate detail-specific psi values). In comparison to the base case model resulted in heating increase of 3.43 kWhr/m2/a and small cooling differences (taking standard SAP (2005) values.

This magnitude of difference with linear thermal bridges is greater than the shading error discovered during model checking and much larger than for the model with the extended overhang.

As facade sections become more extreme, thermal bridges can become the issue that makes it possible to achieve the desired performance requirements of standards such as PassivHaus. Until recently, thermal bridge descriptions were absent from many whole building simulation tools. They are likely to be used much more frequently in the future but for now the burden is on the practitioner to manage the transfer of information from 3rd party tools.

RESULTS

Many standards bodies employ steady state approximations embodied in spreadsheets to check compliance. The performance data is sufficient for compliance but it is not of the same resolution as that used by designers who have access to dynamic thermal calculations. Some design questions, e.g. thermal comfort and the impact of thermal mass or natural ventilation controls require access to dynamic simulations.

This paper has identified a number of issues in creating whole building models of extreme design patterns such as PassivHaus. Working practices and methods need to be improved in order to deal with these new details. Testing different approaches to the design of models could be a critical step for practitioners who are working on low energy design studies.

CONCLUSIONS

This paper has explored facets of the model planning process in light of the extreme detailing used in some residential construction. It focused on a portion of a facade and only a few of the possible options that could have been discussed. Such attention to detail is needed for all aspects of the building fabric in order to design our virtual representations to reflect the complexity of the built environment. Abstracting models is not as straightforward as one might imagine when buildings are based on thick constructions and when thermal bridges are important.

The paper illustrated a number of decision points related to wall and roof details and found that changes in the predictions were small (in a conventional scale) but potentially important if the design team is attempting extreme reductions in environmental control demands.

The evolution of tools now needs to be matched by an evolution in training and practitioner support. IBPSA is in a central position to support and promote discussion and evolve what is considered best practice within the simulation community. And vendors have a part to play. Let us look closely at our training materials and example models in the light of new building ideas.

ACKNOWLEDGEMENTS

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