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IMPACT OF INCLUDING PRE-DEFINED OBJECTS ON HIGH RESOLUTION ASSESSMENTS

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ABSTRACT

Many simulation teams create models of empty buildings e.g. without the thermophysical and visual artefacts which are observed in the built environment or with highly abstract representations. This paper explores the impact of including explicit representations of furniture and fittings on multi-domain assessments vis-à-vis environmental control response, support for comfort and visual assessments and model clarity.

Typically increasing model resolution is a tedious process and added detail if included, may not be fully utilised. The concept of pre-defined entities, which include visual form, explicit thermophysical composition, IESNA light distributions and mass flow attributes has been introduced in ESP-r. ESP-r facilities for calculating view-factors and insolation distributions have been updated to include this extended data model. Issues related to creating and managing such entities is discussed and the impacts quantified via case studies.

INTRODUCTION

Many simulation teams create models of empty buildings e.g. without the thermophysical and visual artefacts which are observed in the built environment. Others create models with abstract representations of thermal mass and a very few with not-so-abstract representations. But what if we could regularly and reliably create models which were not empty and were less abstract? What could we learn from virtual offices with a dozen desks and 18 chairs and filing cabinets along the back wall?

This paper explores the impact of including explicit representations of furniture and fittings on multi-domain assessments vis-à-vis environmental control response, support for comfort and visual assessments and model clarity.

It takes as its premise that everything in a non-empty building is subject to the same physics and has the same thermophysical relationshipts as the entities found in a traditional empty building model.

The physics:

Office furniture has the potential to intercept solar radiation entering from the façade and absorb heat that we normally assume arrives at empty-room surfaces. And each has surfaces which exchange heat convectively and radiantly with the room and the occupants of the room. And each may obstruct the surface-to-surface long-wave exchanges assumed in empty rooms. Each also acts as thermal store(s) with the potential to time-shift heat exchanges. Their thermophysical state depends on not only on their form and composition but their location.

DOES IT MATTER?

Buildings host a diverse population of thermophysical clutter. Does excluding or including such clutter either abstractly or explicitly matter? Is there new information to be gained from designing models which are less abstract and solving for a more comprehensive virtual world?

Sometimes a client expresses an interest in ensuring that occupants have a low risk of discomfort. Hospital wards and operating theatres local comfort is certainly critical. Companies might want to ensure the comfort of critical and/or highly paid staff.

Being close to warm or cold surfaces is a classic source of discomfort and there exist metrics such as radiant asymmetry to track this. Our models routinely track the influence of facades but desks near facades often act like inefficient solar collectors which dump heat into the room air and onto nearby occupants. This might be one source of differences between the real reports of occupant dissatisfaction and virtual comfort metrics. The ubiquitous MRT and resultant temperature might be more indicative if it included a broader population of surfaces.

Reality check. Phase change materials embedded in walls or ceiling panels vs several hundred kg of metal, wood and wood pulp in the form of filing cabinets and book cases in the same room. Which gets ten times the buzz?

Furniture and fittings typically play a bigger role when we undertake visual assessments. Radiance models can certainly approach an almost photographic level of detail although a degree of abstraction is more common for engineering assessments. Whereas many simulation tools provide facilities to export the building form and composition to Radiance, practitioners typically have to hack the Radiance model to increase its resolution. Simulation data models, which are supposedly a super-set model, have gaps which get in the way of undertaking multi-domain assessments.

The potential to alter both the spatial and temporal distribution of heat exchanges within the room suggests the potential to alter the rooms response to environmental control actions.

Lets take a Monday morning start-up after a winter weekend setback condition. We make a model with a good representation of the façade and the layout and zoning of rooms and we count the number of occupants and the IT kit and put in a reasonable schedule and make sure that there is a fair match to the environmental system and controls. We find a weather sequence close to what happened last week and we set off an assessment and it tells us that it takes about 55 minutes to reach the set-point on that Monday morning. Except the building manager says his logs show that it took about 90 minutes and the shape of the logged data were rather different than the simulation report.

Lots of unbillable hours later we find that the model is syntactically correct but represented an empty building start-up sequence. Once the essential character of the various classes of thermophysical clutter were taken into account the predicted and measured data began to converge. So update procedures to ensure this gets done even though it is a hassle and a QA nightmare.

From a control engineer's perspective, the timing and the changes in the pattern of response is of considerable interest. This newly found inertia in the building is an opportunity to be exploited.

CHOICES

Why do simulation teams choose to exclude from their virtual worlds the desks, chairs, bookcases, filing cabinets, computer monitors, beds, sofas, kitchen cabinets that are utterly ubiquitous within the built environment?

Certainly there are practitioners who believe that thermophysical clutter has a minimal impact on the assessments they undertake and is certainly not worth being literal about. Any number of tools include provisions only for abstract representations (Crawley D. Hand J).

The investment in time required to characterise the nature of internal mass and then add this to the model depends on the data model of the tool and the facilities provided for creating and maintaining them. Training and reference materials might not clarify approaches to the task.

Simulation tools ability to accept representations of such artefacts is only a first step. Facilities for coupling them into numerical assessments vary considerably. Do the methods for assessing insolation distribution, long wave radiant exchanges and surface convective transfers treat these artefacts at the same or a different level of rigour as other building entities? Do the choices on offer support the delivery of useful performance metrics into the design process?

APPROACH

ESP-r simulation tool (Hand 2015) has been used as a test bed for a number or reasons:

- It is open source and can be adapted to support the need of the case studies
- Its data model already includes a number of entities which could be used to represent explicit thermal mass and visual entities.
- It supports calculated view-factors between surfaces in rooms of arbitrary complexity and thus only requires testing to confirm that such view-factors are correct for explicit mass entities.
- It supports local comfort assessments with radiant sensor bodies within rooms
- It supports insolation calculations in rooms with arbitrary complexity and thus only requires testing to confirm that explicit mass entities are correctly recognised.
- It supports exports to Radiance and would only require incremental changes to ensure that explicit mass and visual entities are correctly embedded.

Indeed, researchers and practitioners wanting to add mass to rooms in ESP-r have been simply inserting mass surface pairs within zones for more than a decade. Pairs of surfaces were required because each surface has one face adjacent to the zone. An example of this approach from a 2001 consulting project (Figure 6-8) which has been updated to form one of the case studies.

Initially these mass-surface pairs tended to use adiabatic connections. Setting the boundary as a surface in the same room rather than to another room began to predominate (especially when the automated topology checking was adapted to check within rooms). For some time the interface has supported the creation of internal mass surface pairs with simple forms.

In this regime, the user composed the mass-surface pairs to approximate the room contents according to their own preferences but it was done from scratch each time and one had to be both passionate and pedantic to achieve less abstract representations. What is required is a store of common entities that can be drawn from and placed into models without specialist skills or the need for pedantic working practices.

The concept of pre-defined entities is to provide access to a diverse collection of objects that commonly populate buildings and support their insertion into the simulation model. Each entity would include sufficient attribution to support multi-domain assessments with little or no additional interaction from the user (beyond their selection them from a list of known entities and directives that place them within the model). They should have a clear provenance (e.g. BIM attributes), documentation as to their intended use as well as subsequent actions required by the user. Each would include directives for use by the simulation tool to ensure dependencies were resolved.

Attributes of visual form and composition should support a range of visual assessments. Lighting fixtures would include IESNA references and non-opaque components would include visual and optical characteristics.

Entities with thermophysical properties should result in fully participating surfaces in the thermal model (e.g. representing the case of the monitor as well as the electronics it contains, the structure of the bookcase and if it is populated a representation of the books). The author of the entity would, of course need to ensure that this was a reasonable abstraction of the mass and surface area of the object components.

It should be possible to see pre-defined entities within the thermal model interface and they should be part of model contents reports and both the constituent parts of the object and the collection of parts named.

IMPLEMENTATION

Pre-defined entities have been implemented as an additional database within the ESP-r suite. The data structure of a pre-defined entity is a substantial subset of that used by ESP-r for thermal zones and surfaces. In some cases new concepts required extending the zone data structure. Each pre-defined entity supports the following:

- Header – object name, text for a menu entry, block of text for documentation, provenance, geometric origin and extents of its bounding box (for preview) and merge-into-model directives.
- List of vertices to be referenced by other types
- Mass surface pairs (name, composition, optics, usage and/or IESNA, ordered list of edges)
- Boundary surfaces (name, composition, optics, usage and/or IESNA, ordered list of edges)
- Visual primitives (name, composition, type, origin, rotations, bounds/list of vertices)
- Visual objects (name, documentation, list of visual primitives)
- Solar primitives (ESP-r entities which can shade facades) (name, composition, type, origin, rotations, bounds/list of vertices)
- Mass flow directives (component and placement not yet implemented)
- Power directives (real/reactive/voltage/phase not yet implemented)

Selection and management follows the same pattern as other databases (point to a common or model specific database, create or preview an entity). Figure 1 shows this for an office chair.

Populating the database essentially is gathering dimensional and composition attributes of the entity via tape measures, callipers and digital scales. Such measurements are straightforward if somewhat tedious. And some artefacts (see Figure 13) require disassembly. Of course, the limited sample only covers a few product variants and density of file storage and shelf clutter.

Pre-defined entities remain abstractions of visual and thermophysical complexity. The intent of the chair is to be recognisable. The mass of the seat and the back are represented but the mass of the legs and the arm-rests have been omitted. Overheating from sun falling on the mass is intended to be indicative.

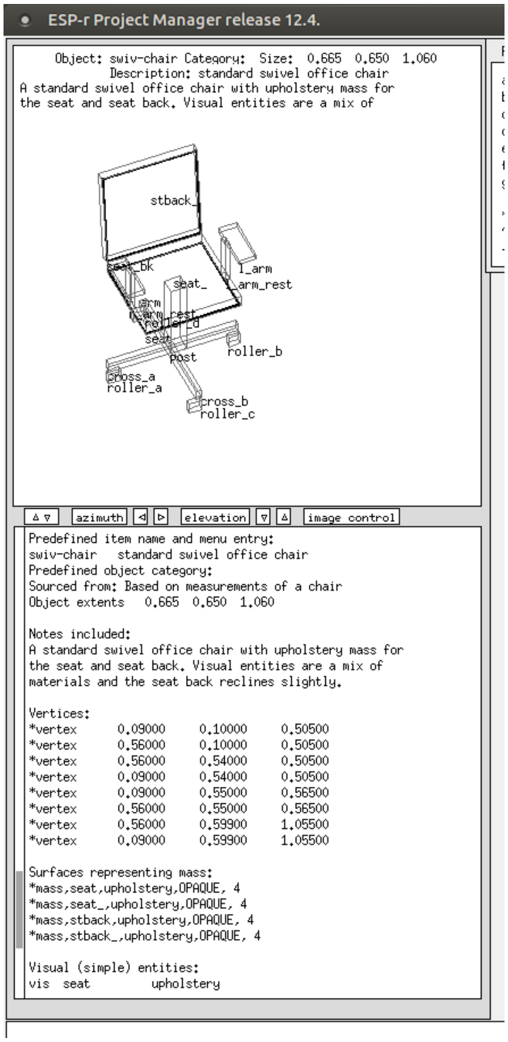

Figure 1: Pre-defined chair with feedback.

VISUAL ASSESSMENTS

The extension of the ESP-r data model has its first impact in visual assessments generated from thermal models. Their simplest use is to clarify the thermal model for other members of the design team. Other common uses are for creating animations of shading and shadow patterns or predicting daylight factors within rooms. These benefit from the inclusion of building contents.

Work flow was historically interrupted by the need to hack the Radiance files to populate rooms with visual entities. Iteration was required to correct their placement (no preview facility). Including visual entities within the simulation model, provides visual clues within the wire-frame image, allows their attribution to be embedded in the simulation model (Figure 2). A complete Radiance model is exported and can be processed (Figure 3) directly with no need to hack the files unless surface patterns are required.

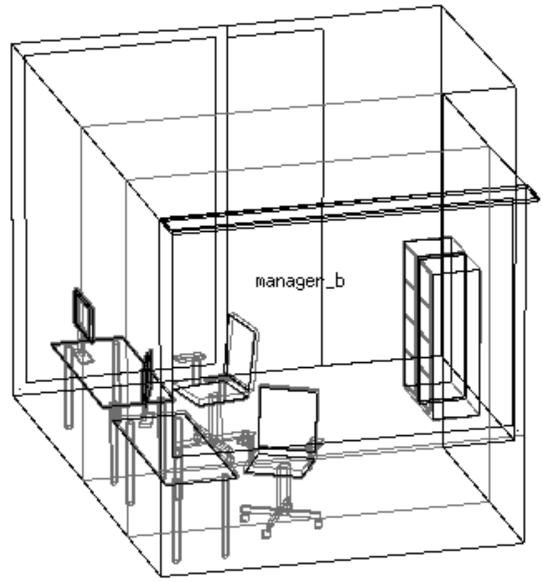

Figure 2: Visual and mass entities within simulation model.

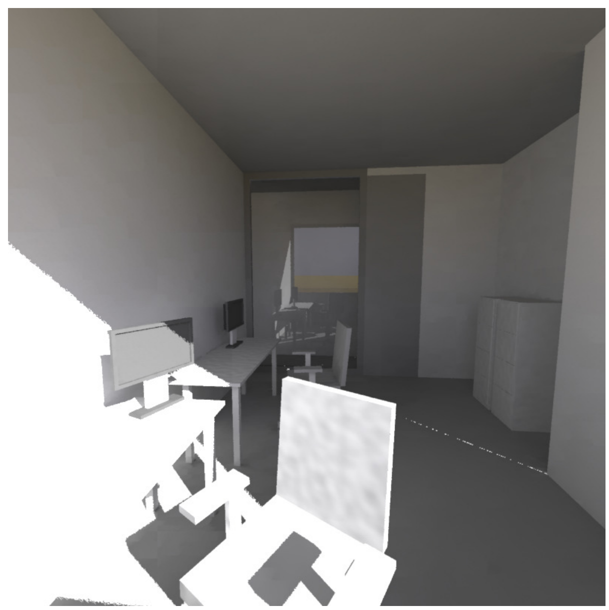

Figure 3: Radiance rendering of the room.

Working with lighting fixtures also require specialist skills to embed within Radiance models. The extended data model includes an IESNA attribute for surfaces in the zone so the export process now can populate the Radiance model with the source polygons as well as the light distribution pattern. For simple lighting schemes, this greatly reduces the overhead of exploring trade-offs between daylight and artificial lighting distribution (Figure 4).

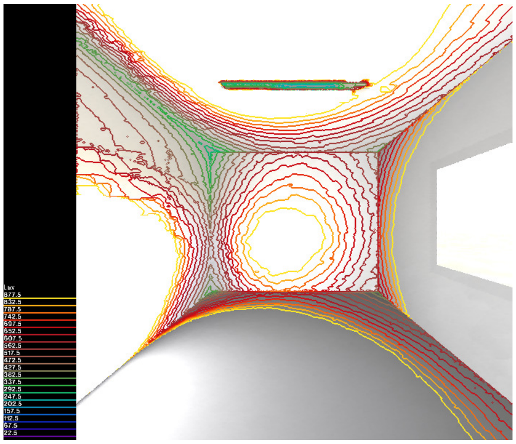

Figure 4: Simple light distribution tests.

NUMERICAL SUPPORT

For assessments where the thermal impact of furniture and fittings is of interest, the nature of their thermophysical interactions with conventional room surfaces (façades, partitions, floors and ceilings) within the numerical solution is critical. Referring back to the initial statement of "The physics" in the Introduction.

Their thermophysical state depends on not only on their form and composition but their location.

A desk at a façade will be subjected to stronger driving forces then on near the core of the room. For some projects these differences may not matter and a lumped abstraction may suffice. If creating a literal distribution of desks requires little additional attention on the part of the user and does not have a marked impact on the speed of solution the need for abstraction may be reduced. The case studies explore this.

And each has surfaces which exchange heat convectively and radiantly with the room and the occupants of the room.

The Mass and Boundary surfaces of a predefined entity are treated no differently than any other surface in the model within the solution process. This paper does not, however explore explicit representations of occupants other than as radiant sensor blocks vis-à-vis local comfort assessments.

Office furniture has the potential to intercept solar radiation entering from the façade and absorb heat that we normally assume arrives at empty-room surfaces.

It was always the case that mass-surface pairs absorb direct and diffuse radiation within the room on an area-absorption basis if no insolation directives were given. If insolation patterns were calculated the direct component was supposed to be correctly assigned, however testing exposed gaps in the logic. When these were corrected insolation within rooms of arbitrary form with arbitrary mass-surface pairs are correctly treated. Figure 5 shows grids of insolation points (blue dots) on the desk, adjacent wall and floor from a source window (red dots)).

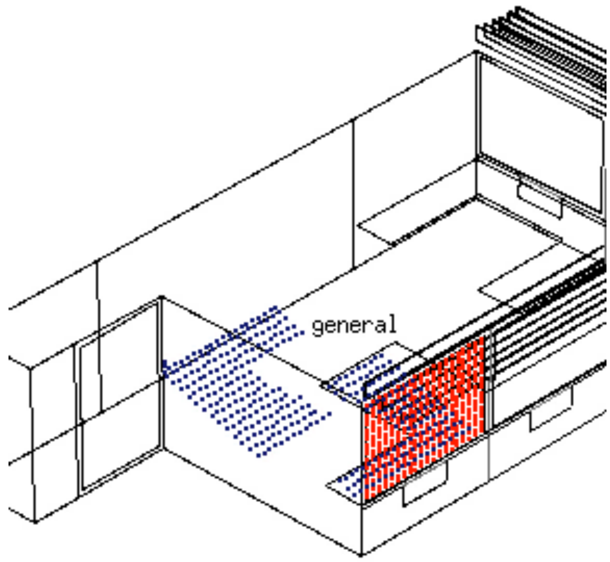

Figure 5: Insolation calculation display

And each may obstruct the surface-to-surface long-wave exchanges assumed in empty rooms.

Although the default treatment in ESP-r is to assume an area & emissivity distribution, surface-to-surface view factors can be calculated within rooms of arbitrary complexity. Tests indicate that this continues to be the case when pre-defined objects are embedded within zones. Insolation patterns require a few additional seconds to calculate in comparison with an empty model. The method used is sensitive to small dimensions so it is sometimes required that large surfaces be subdivided if very small surfaces are inserted.

Each also acts as thermal store(s) with the potential to time-shift heat exchanges.

Thermal storage is part of the normal solution process. But what as a simulation community do we really know about the temporal response characteristics of a full filing cabinet and a room? Clearly there is an outer metal case and lots of mass inside but how well are these coupled? A great PhD hybrid physical and virtual experiment. In this study the mass of the cabinet and the mass of the paper it contains are assumed to be in contact with the room air.

CASE STUDY

To test the thermophsical and visual impact lets take a building model and create variants at different levels of resolution. The first case study is a portion of an office block in Ottawa initially created in 2001 and upgraded for the current version of ESP-r (as seen in Figure 6). It was designed to investigate a hybrid mechanical ventilation and façade venting scheme for cooling. It included a somewhat abstract representation of desks near the perimeter of the rooms and a large table in conference room. The intent was both to improve the clients understanding of the model as well as account for some of the thermal impacts of internal mass.

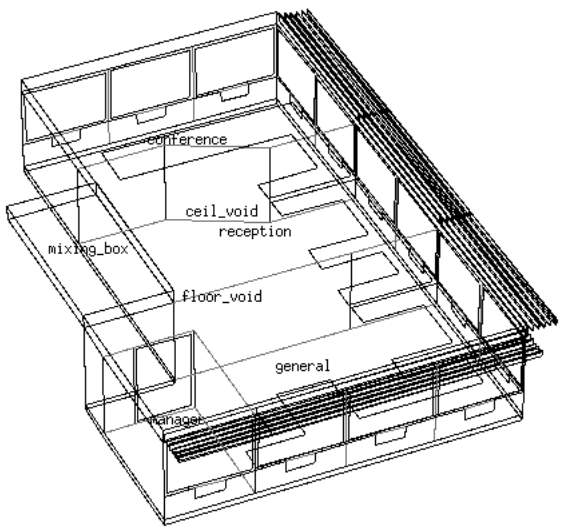

Figure 6: abstract model of a portion of an office block

The initial desk representation (Figure 7) was as one mass surface pair per room. No representations for chairs and storage were included. It preserves overall surface area, mass and placement of the desks but results in a single temperature at the upper face and lower face of the desk across the room. It took roughly 15 minutes to implement this in the original model.

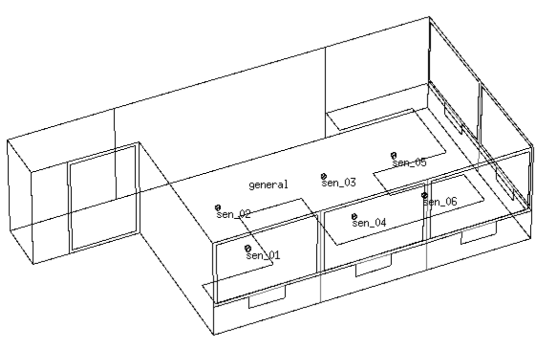

Figure 7: comfort sensors at partially abstracted desks in general office.

In the original model local thermal comfort was not an issue. For this case study the assessment resolution has been enhanced to include explicit surface-to-surface viewfactors, MRT sensor bodies (see Figure 7) as well as an insolation analysis. The model has been updated to include a raised floor system so that sensitivity to internal obstructions of longwave and shortwave distributions can be tested.

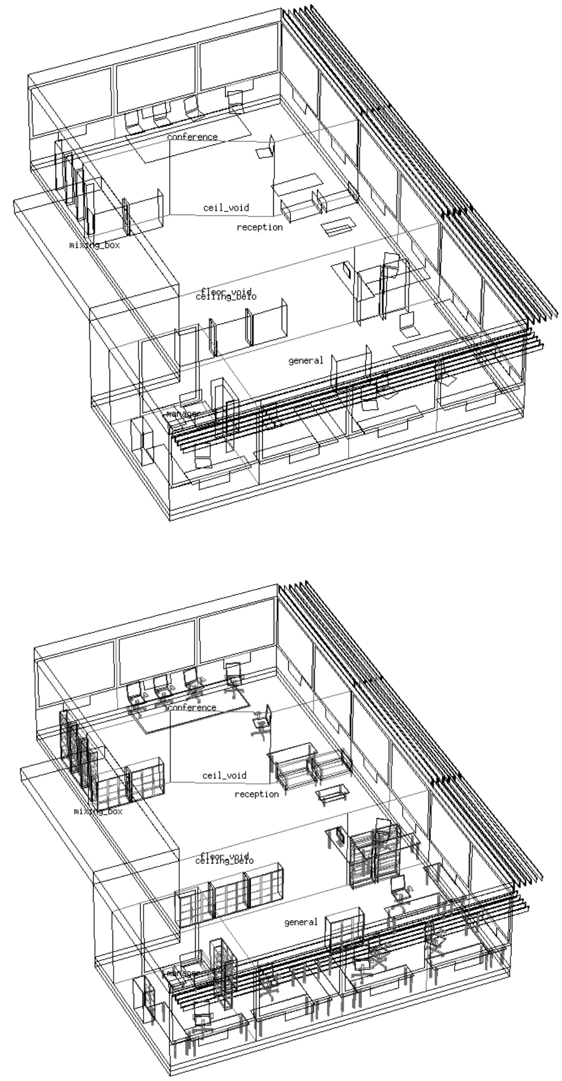

Figure 8: Updated model with pre-defined objects showing explicit mass (upper) and visual entities (lower).

An empty variant of the model, one with abstract desks (Figure 6) and one with the rooms populated with predefined objects (Figure 8) have also been created for this case study. The empty model includes 119 surfaces, the abstract model includes 125 surfaces and the model with predefined entities includes 311 surfaces and 446 visual blocks.

To run a 93 day assessment at 15 minute time-step for the empty/abstract/pre-defined required 9.4/10.2/93.5 seconds for the model with pre-defined entities on an older Dell 780 computer. Using the maximum level of performance data storage the zone results files were 214/224/1200MB respectively. Extracting data for a standard performance report task took 3/3/6 seconds. The jump in the size of the data storage is likely to have been a major factor as a rotational drive was used.

Radiance images of each model variant are shown at the end of the paper (Figures 15-17). The empty view of 42 million rays computed on two cores in 4m43s, the abstract desk view of 45 million rays took 5m1s and the view with pre-defined objects was 70 million rays and 9m1s.

Looking at the performance of the empty office model vs the populated office model the Figures below show the temperature of the floor and the radiation absorbed on the floor during a May week. The abstract desk model and the desks created via pre-defined objects roughly occluded the same amount of solar radiation. Clearly there is much more solar arriving on the floor in the Empty Office.

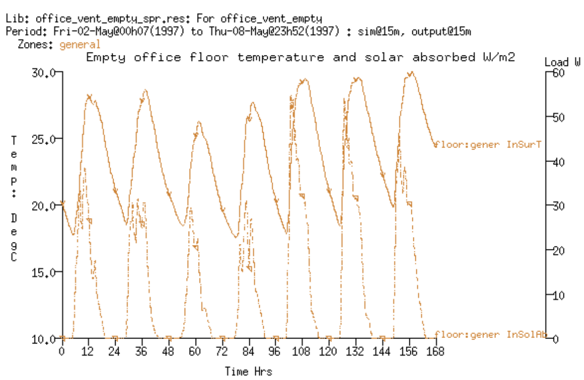

Figure 9: Empty office floor temperature and absorbed solar.

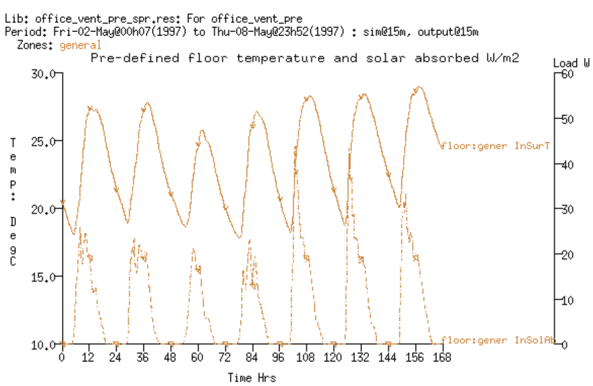

Figure 10: Populated office floor temperature and absorbed solar.

The desk gets directly insolated and the heat eventually works its way to the underside of the desk as seen in Figure 11. Where separate desks were implemented the range of temperatures during the same period ranged from a maximum of 29.8-39.7C and a minimum of 16.5-17.2C on the underside.

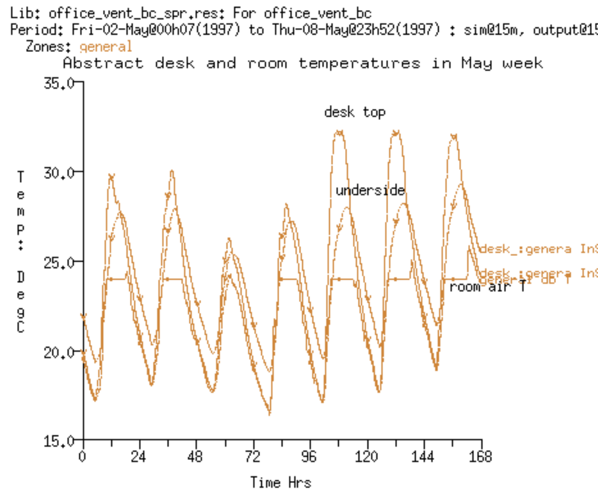

Figure 11: Desk temperatures during May week.

The annual impact on heating and cooling for the empty/abstract/pre-defined models are as follows:

- Heating kWhrs 17282/17066/17224
- Heating (hours required) 17134/16714/16700
- Cooling kWhrs 9796/9764/10938
- Cooling (hours required) 12949/12961/12801

The hours required sums, for each zone the number of hours over the year. The added mass has only minor impact on overall heating demands. We find a reduction in the number of hours heating is required and shifts in the timing of demands. We see an increase in cooling demands and a reduction in the number of hours cooling is required. There were minor differences in peak equipment capacity between the models. The added mass reduced the peak resultant temperature by ~0.6C in the winter and ~0.5C in the summer. The largest changes were in the cellular office where the lightweight components near the glazing caused the room to more quickly reach the cooling setpoint.

In models which primarily use pre-defined entities to ensure that thermophysical clutter is accounted for it is also possible to carry out quick visual assessments. Figures 15 - 17 are direct exports to Radiance. Only the image resolution parameters and viewing parameters were added.

One of the interesting artefacts of such visual assessments is that the height of the abstract desks were set at the bottom of the window frame whereas the pre-defined objects were correctly sized. The layout also had to be adapted so that there was room for the chairs in the rooms.

RESIDENTIAL CASE STUDY

Another case study reported at the IBPSA 2015 conference (Clarke 2015) looked at high resolution models. These also made use of predefined objects in the context of a standard semi-detached UK residence. Here entities associated with residential construction were used (as seen in Figure 12). This model also included a number of zonal system components such as the physically explicit water filled radiators and room thermostat imported via pre-defined entities. This allowed explicit radiant (with view-factors) and convective exchanges with the radiators and the rooms.

Figure 12: Ground level view of a high resolution residence.

In the study it was found that there was a multi-hour lag in the temperature response between the empty house and a fully populated house. System run-times were also noted.

Pre-defined object attribution should support conceptually complex objects such as the thermostat in Figure 13. The case, circuit board, battery, slots in the case and the surface mounted thermistor can all be represented explicitly, albeit that a calliper is needed to establish dimensions and really small crack components are required to represent mass flows between the room and the thermostat.

When imported it becomes a thermal zone with the full set of thermophysical analysis available. It shares its case with the zone it is embedded in so it has a full set of boundary conditions. Pedantic users could include this in a flow network and run view-factor calculations to establish high resolution radiant exchanges within the thermostat. Its response characteristics include the thermal lag introduced by the case as well as by the circuit board on which the sensor is mounted.

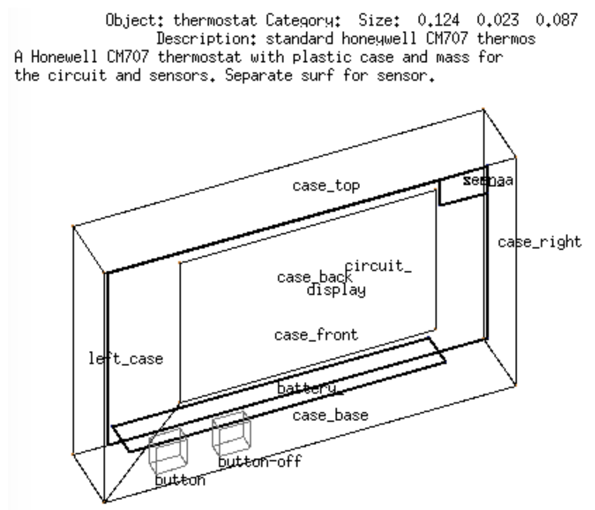

Figure 13: Explicit room thermostat.

MANAGING ENTITIES

Currently new entities are created in much the same was as ESP-r zones. For furniture a simple rectangular zone is usually populated with mass-pair surfaces and then visual entities, solar obstructions and the like and the bounding surfaces removed and then imported into the database via a conversion facility. The component parts are attributed as to their composition and usage (i.e. this component acts as a light source). For entities such as the thermostat the bounding surfaces are preserved. In both cases tags for documentation, provenance and model import directives are manually inserted. In the application interface combinations of zone surfaces and visual entities with and without names are available (Figure 14). Once the data model matures imports from other sources will be enabled.

DISCUSSION

This paper has explored how whole building simulation can draw from an additional database of pre-defined objects and the implications of such facilities. Among the things noticed is that although there are few keystrokes required to select and then place objects time is required to plan their locations. With visual feedback it was clear that the initial abstract desk layouts were, to some degree, unreal.

The complexity of rooms roughly doubles. This adds a few seconds to the calculation of surface-to-surface view factors and a similar additional resource to shading/insolation calculations. Differences in simulation run-time between the variant designs have been noted and the size of simulation results files increases as a function of the total number of surfaces in the model. With adequate memory this should only marginally impact production work flows.

For visual assessments the direct export to radiance (with only viewpoints and Radiance computational parameters to be set) brings a substantial streamlining of work flows. The wireframe preview of entities is particularly helpful.

The tests carried out thus far indicate that working with predefined entities has the potential to both reduce time and reduce errors during model creation.

Although the data model is in place to attribute the mass and surface area of entities work is still needed to verify how well this tracks with actual measurements of temperatures on the surface of and within filing cabinets and the like.

One hint of possible futures was the IBPSA 2015 presentation by Kashif et.al. Where users interactions follow the pattern used in computer games to inspect and interact with energy consuming devices in buildings. Devices are clearly drawing on a mix of sources to present and derive the performance implications of what is explored in the virtual world.

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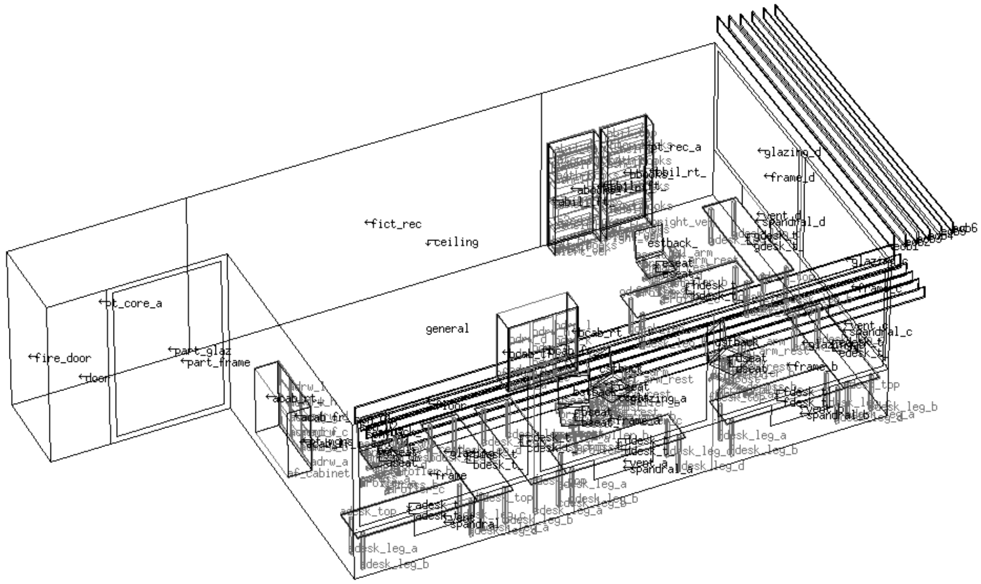

Figure 14 Detail of all surfaces, mass, visual and shading objects in interface wireframe.

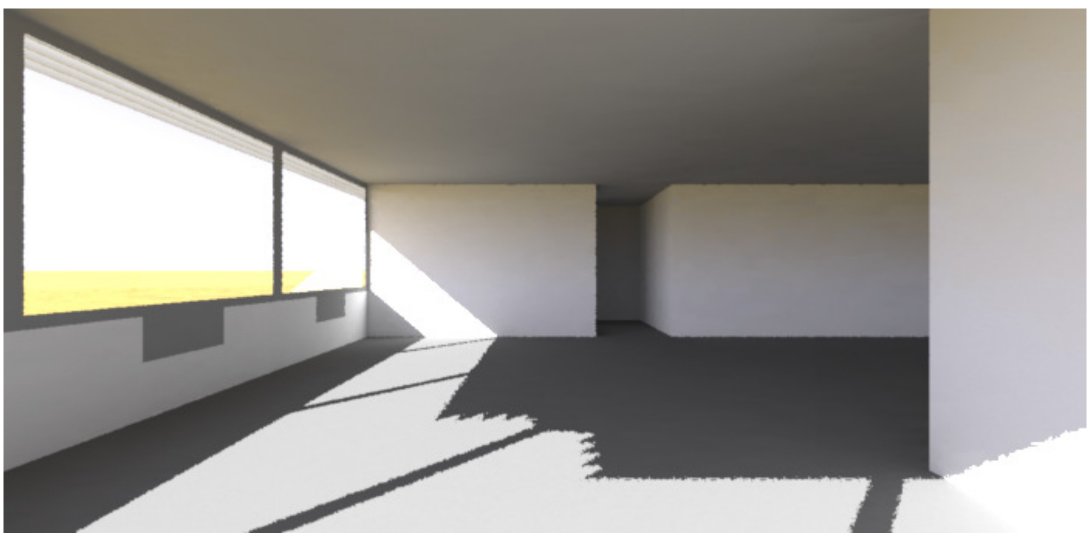
Figure 15 Radiance view of empty office.

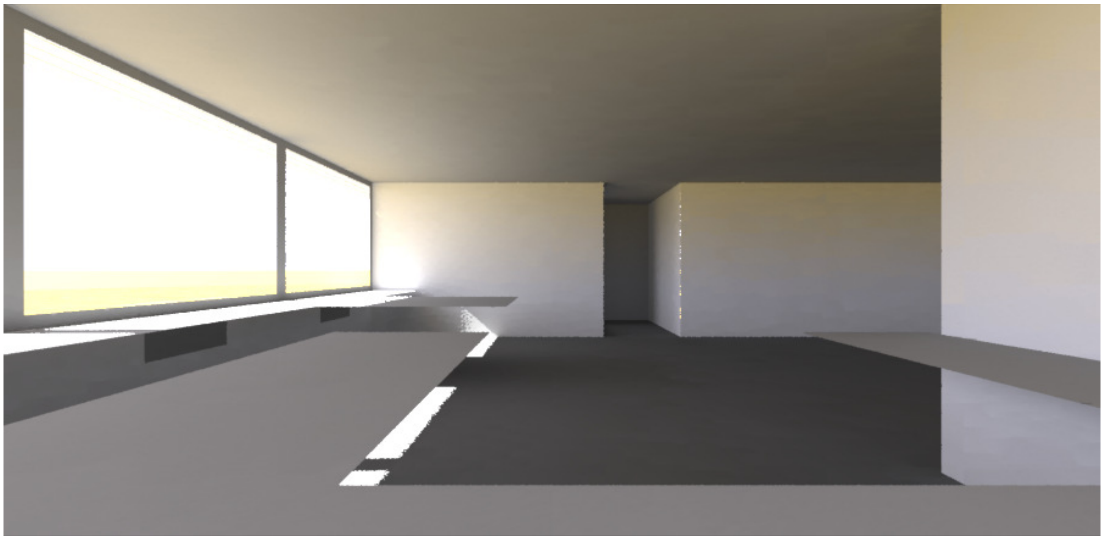

Figure 16 Radiance view of abstract desks in room.

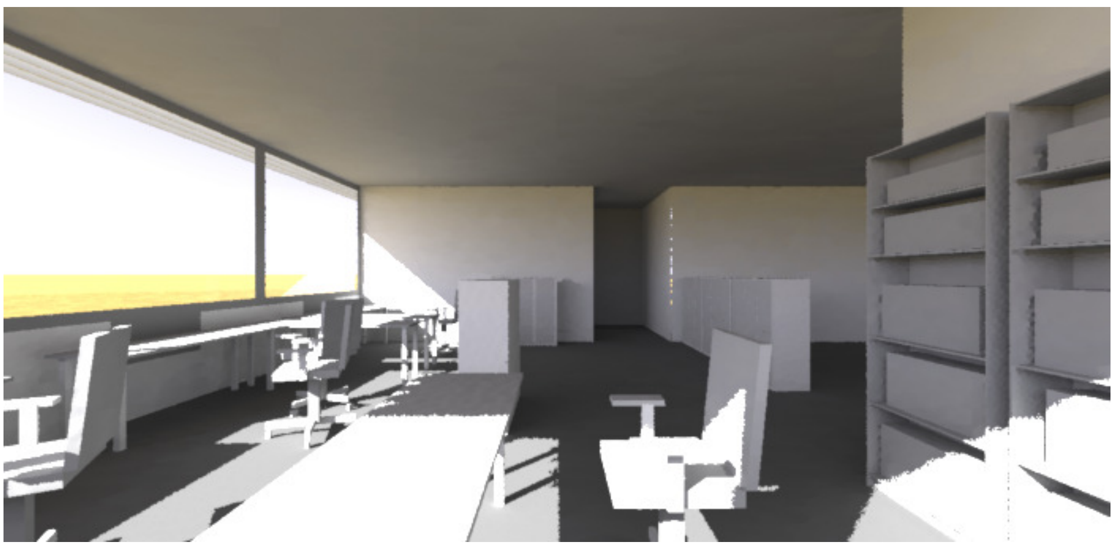

Figure 17 Radiance view of pre-defined entities in room.