Deliverable: 5.4
Organisation: BRE

FP7 – 285229 – Collaborative Project

Knowledge-based energy management for public buildings through holistic information modelling and 3D visualization

Deliverable 5.4

Demonstration Objects Energy Profiling and Energy Management System Enhancement

Authors	Dr. K V Jones
Reviewers	Yacine Regui (CU), Kris McGlinn (TCD)
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Executive Summary

From the description of works, Deliverable 5.4 is the enhancement of the profiling and simulation of the Demonstration Objects as broken down by the two sub-tasks within Work Package 5 (5.4. and 5.5). The sub task 5.4 seeks to *“establish an energy profiling of the building based on the building thermal properties, occupants’ interactions (with the building), daily-activities that take place within it, and overall performance of the existing building management system”* whilst task 5.5 seeks to *“undertake a virtual energy monitoring and configuration based on simulation and visualisation tools developed in earlier work packages, with a view of testing the energy management systems”*.

In order to achieve a building specific view of the energy management system, i.e. its set-points, operating hours and heating and cooling methods each building was simulated separately in a dynamic thermal model. The energy predictions produce by such DTM could then be analysed per end use, e.g. lighting, HVAC, small power etc, where there was sufficient set-up information to allow accurate modelling of the Demonstration Object. However, to collect enough information to perform each building simulation a large amount of data needed to be gathered regarding both the fabric and services within the buildings, whilst the complexity of some systems (e.g. CO_2 controlled demand ventilation) cannot be accurately replicated in a thermal model and simplifications were necessary to model the energy demand.

As reported in D5.3 due to buildings being replaced within the Project and late arrival of data (PICA and HHS respectively) an initial definition of all buildings was an unrealistic option at that point. Therefore, rather than an initial definition of all 5 buildings within the project, for which some information lagged behind the others, and then these simulations finalised within Deliverable 5.4, the buildings were modelled in series to completion. Therefore, the first building to have its simulation model completed was shown in D5.3 and is only summarised here - the Forum building in Eersel. The remaining buildings used within the project, MediaTic, PICA, HHS and Bluenet, have now had their simulations completed and are presented below in order for their “virtual energy monitoring” as the Work Task demands. These are completed simulations and focus on the “Basecase” energy demand within the buildings – i.e. their energy demand due to lighting, small power and HVAC systems derived from their design parameters. From these Basecases it is now possible to simulate any desired optimisation scenario by the changing of required inputs such as heating set-points. These multiple simulations will be carried out by the Project partner Cardiff University, and whilst the initial Basecase was created for each building in the commercial code Designbuilder these will be derived from the freeware Energyplus for which the Designbuilder model created a completed simulation input file. This methodology allows potentially thousands of iterations of the simulations to be run per building using multi-variable analysis on the Energyplus simulation file using the power of large scale computing power, these thousands of analyses leading to more exact optimisation settings for a range of “energy saving scenarios” applicable to each building.

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Appendix A : Required Information for DTM of Demonstration Object

1 Introduction

Deliverable 5.4 continues on from D5.3 and seeks to provide a behavioural simulation of the buildings as required by sub-task 5.3 (“energy profiling of the building based on the building thermal properties, occupants’ interactions (with the building), daily activities that take place within it…”) as well as an initial configuration of the building-specific energy management system. As discussed in D5.3 that provided the simulation for the Forum building alone, D5.4 will provide the simulations for the remaining Demonstration Objects, PICA and Blunet in Seville, HHS in The Hague and Mediatic in Barcelona.

To achieve this combination of showing user interaction and the relative importance of the services operational settings, such as run times, set-points and automatic controls (e.g. presence detection for auto shut off) Dynamic Thermal Modelling (DTM) was chosen. DTM can simulate the occupant use profile and the system set-point as well as be a realistic model of the thermal characteristics of the building. However, by itself DTM is only a system for assessing building energy demand per space, rather than consumption. Therefore, any assessment of actual energy use needs post-processing of the energy demand data to take account of the building services’ actual efficiency rates and Coefficients of Performance (CoP) of the plant installed.

From this thermal modelling the Basecase prediction of a standard annual consumption of electricity and fossil fuels will be gained based on the standard set-points, occupation levels and (average rather than extreme) weather conditions. However, the main benefit of the DTM process is that the DTM will provide a simulation to be iteratively run multiple times (in Energyplus) by the project partner Cardiff University. These iterations will find the optimum conditions in the building whilst maximising energy savings for a given set of simulation scenarios relevant to each building.

1.1 Dynamic Thermal Model Choice: DesignBuilder

The initial building, Forum building, Eersel, was constructed in a DTM in the code TAS (by EDSL Ltd – and included in Deliverable 5.3. This commercial software has a long history of use and was produced from modelling systems developed at Cranbrook University. Unlike the non-commercial codes available for DTM that have remained within the research community this has the advantage of being able to quickly render a 3d geometry of a building where no 3d model exists or information that could be gleaned from an IFC file - -as has been the case for all 5 Demonstration Objects in the project. However despite this software having a far greater linkage of post-processing macros and programmes to assess energy consumption than the Designbuilder software a move to this software was made for 1 critical reason. The multiple re-simulation work undertaken by Cardiff University could only be conducted through the freeware Energyplus.

TAS has no export facility to produce an Energyplus .idf file, however this option is available in Designbuilder as it can use the Energyplus calculation engine, despite the native DTM programme itself being more limited than TAS. Furthermore, the quality of the Graphical User Interface, linked room/zone profiles and its import facilities means that Designbuilder was not as useable a DTM choice in comparison to TAS when creating a new building model or setting up a new simulation run of the same model. Whilst this is performed more easily on TAS than Designbuilder, Designbuilder itself is a major improvement on Energyplus in its native format when creating building simulations as the latter is primarily a research software tool rather than a commercial code. In this instance, with multiple re-simulations of the buildings that will be required shifting to the duty of Cardiff University, Designbuilder provided a suitable “halfway house” i.e. a commercially available DTM code with which to construct the Demonstration Objects with the ability to export the required Energyplus .idf files that were the end requirement for the Knohol-em project’s methodology.

Therefore, in the first instance the full 3d geometry of the building that had been created for the Forum building with TAS had to be recreated in Designbuilder. This requirement was less onerous than the creation of the new models for the 4 remaining buildings as, though it was necessary to model the building in the same way as the prior TAS model e.g. to include the atrium’s full height to allow for the stack effect natural ventilation, the 3d geometry of the building could be easily exported to the new Designbuilder model and no additional effort was required in finding the input parameters (U values, CoPs for HVAC etc) for the building to be correctly modelled.

However, unlike the Forum building, where the inclusion of the atrium in particular made modelling of the whole geometry of the building a more logical choice, the DTM modelling of the geometry in the remaining 4 buildings needed to only focus on the areas solely used within the Knoholem project. In these cases a whole floor could be modelled of a larger building or (e.g. Mediatic) or a smaller section of even 1 floor (as per HHS). Therefore, as can be expected, where only the relevant floors or rooms of the remaining buildings are modelled with their immediately adjacent thermal boundaries (both internal and external), this provided a simpler geometry creation than the initial Forum building for the thermal models. However, these geometry modelling compromises could only be made where other requirements for precise simulation such as a natural ventilation strategy or shading methodology was not adversely affected, this modelling option of a single floor “Knoholem area” was also precluded in the PICA building where the whole building has been used within the project.

1.2 Granularity and Cross Comparison of DTM Predicted Energy Data and Metered Equivalent Readings

Unlike the real building the simulation models can be split into as many zones as required even where these are not physically differentiated in the real building, for example zoning within open plan areas which contain lighting systems with and without auto-dimming luminaires to maximise free daylight. Thus the comparison of actual energy consumption by zones will be limited by the metering strategy that may only record that metric such as lighting electricity use for the whole building or floor.

Furthermore, the granularity of the results may differ between the DTM and metered energy use over the time-step as well as the physical geometry of the building. The thermal simulation can be set up to output results typically at an hour interval for a year, though a smaller or larger time-step could be used. In contrast, the metered energy demand for the same zone could have a much better granularity (e.g. 5 minutes) or far worse as readings are only taken manually on a monthly basis. DTM was created as an energy prediction tool to look at buildings on a daily to annual basis rather than finite, smaller elements of time. These energy predictions are also strongly linked to the weather datasets that are included as a significant part of the data input to DTM. These meteorological datasets, whether to show an average yearly profile or more severe weather patterns are rarely found at below an hourly basis.

The DTM itself can only predict energy demand in a defined room or zone rather than its energy consumption. Therefore, further information about the efficiency of the HVAC and electrical services in the buildings must be known to convert these demands into energy consumption. Therefore, the approximation of the HVAC systems will be as important as the building if the actual energy consumption is wished to be compared and contrasted to the simulation results. In the Knoholem project the predicted energy consumptions could be compared and contrasted to the known, historic usage figures gained from meter readings that form part of Deliverable 5.1, however the simulations may not be able to replicate the consumption (as opposed to the demand) correctly. Whilst this consumption prediction can be simplistic e.g. energy demand for a "lossless" energy supply such as electricity to feed the ring-main or lighting system and can be easily converted from demand to consumption i.e. 100% of "supply" is used this is not the case for the HVAC systems that may have varying efficiencies. This will also prove difficult when multiple systems are used to provide the same end use, for example both the heating and cooling in HHS come from more than one system with a portion of cooling coming from the chilled/heated air in the mechanical ventilation which is then supplemented by chilled beams or under-floor heating when required. Such a technical system would also require simulation of the energy systems as well as the energy demand predicted by the thermal modelling.

Whilst the conversion to the actual consumed energy is readily done in commercial DTM, provided the system efficiencies and Coefficients of Performance of the building services plant is known and consistent, it also must be remembered that this consumption prediction is entirely that – a prediction - based on the possible optimisation techniques suggested by Knoholem being taken up by the Facilities Manager (FM) or other user group. The Knoholem project has been set-up to provide ontology based energy optimisation information to the Facilities Manager/User and is designed to keep their interaction as a fundamental element of this optimisation (i.e. the "user in the loop" approach). However, the Knoholem system does not enforce any automatic control or operation of buildings services to create this optimisation, though this control could be a future addition. Therefore, any optimisation routine foregone by the FM for a particular building will not be replicated in the DTM's prediction of energy use. Each simulation run in the multiple Energyplus modelling will portray a maximum possible energy savings scenario given a particular optimisation technique that is being tested, regardless of its actual take up in the real building. Therefore, very detailed information regarding FM/Users interactions with the buildings once the Knoholem energy management has been introduced will need to be known in order to contrast the DTM predictions' savings against "post Knoholem" energy meter information.

2 Requirements of Project Deliverable and BEM

As described in the project's Description of works task 5.3 will "establish an energy profiling of the building based on the building thermal properties, occupants' interactions (with the building), daily activities that take place within it, and overall performance of the existing building management system". The Building Energy Models (BEM) will be Basecase dynamic thermal models of each building in standard annual operation. Therefore, the BEM will be derived from dynamic thermal models informed with both accurate information regarding static metrics (e.g. fabric details) and accurate building occupation schedule. Therefore, for an initial Basecase to be produced the BEM requires that both dynamic metrics such as occupant levels within the building as well as the energy management system are successfully replicated within the model to adequately predict any possible energy savings. Given the complexity of such dynamic data in some instances this will necessitate multiple approximations in the model, some that have little effect on the energy consumption data (e.g. heating set-point values that change per season) and some that will produce more profound differences (e.g. synthetic average working day occupancy levels per room that applied throughout the year).

Such approximations are an inherent part of DTM in order to create the full breadth of input data to run a simulation, however the end result i.e. the multiple energy saving scenarios run by Cardiff University in the exported Energyplus models will all use the same input approximations, therefore applying the same level of estimation to all simulations allowing a clear comparison between energy prediction scenarios. Whilst the initial Basecase models from Designbuilder and TAS have some usefulness in the validation process of Work Package 5 it must be remembered that the creation of the BEM is to initiate an element of the research aspect of Knoholem – i.e. to provide the starting point of the scenario modelling in Energyplus for Cardiff University so that in turn these multiple, iterative runs can inform the Artificial Neural Network training the real time control unit at the heart of the Knoholem system.

2.1 BEM: Choice of Dynamic Thermal Models for Demonstration Objects

Dynamic Thermal Modelling simulates the dynamic thermal performance of buildings and their systems. This technique traces the thermal state of the building through a series of hourly snapshots, providing a detailed picture of the way the building will perform, The DTM approach allows the influences of the numerous thermal processes occurring in the building, their timing, location and interaction, to be properly accounted for. Dynamic thermal modelling allows; quantification of mechanical heating and cooling loads, calculation of internal temperatures, analysis of facades and their insulation (thermal performance characteristics) and analysis of natural ventilation options including incorporation of thermal mass techniques. Therefore, DTM was the only reasonable simulation approach to create "Building Energy Models" as required by the project. Other simulation methods e.g. CFD could produce in depth results of energy exchange in high detail but are static for a point in time and not suited to providing prediction results for days, months or years whilst non-dynamic methods such as the calculation engines demanded by EU legislation (e.g. SBEM Building Regulations certification in the UK) cannot adequately mimic dynamic building processes such as natural ventilation and are created with simplified input data sets governing occupation, fabric detailing etc.

Only a Basecase DTM of each building with realistic “as built and used” detailing could act as the BEM in the project for its later Variable Orientated Energy Simulation in Energyplus (created by Cardiff University to both create the optimization rules and inform these rules to calibrate them through multiple, iterative simulations). However, to gain such a versatile prediction utility for the initial BEM a vast array of information had be gained about the building in as much detail as possible. The required information from each Demonstration Object was formulated into several data gathering tables and has been included as Appendix A. Whilst for new designs some element of “rule of thumb” and estimation must be used, this information must be gathered for existing buildings (such as the Demonstration Objects in Knoholem) in detail from existing features. In this way a full, 3d geometry of the building can be created with each each window, door, ventilator or other aperture having its relative altitude and orientation automatically calculated to give a potential airflow network through the building. This means that natural ventilation can also be simulated – such as found in the Forum building.

Construction materials and glazing types and their relative thermal performance characteristics must also be created within the model. The relative operating procedures within the building must also be known such as the operating time of plant, its set-points such as heating and cooling temperature minima and any automated efficiency system (such as PIR control of lighting). In typical design use, Internal Gains from lighting, small power use and occupation of the building is also input manually into the DTM via generic data for types of room/zone or prescribed methods. However, in this instance given occupation schedules and equipment totals per room needed to be provided for each particular room. The final element that defines the BEM and is crucial to the heating and cooling demand is the climate data used to drive the simulation. As per typical design or Certification usage weather data is taken from “Example Weather Years”. However as these weather file derived conditions do not coincide with the metered energy use any comparison between simulated savings and metered results will need to normalize both data-sets for these weather conditions e.g. via the use of Heating and Cooling Degree Days.

Due to the somewhat limited nature of sub-metering and sensor information in the Demonstration Object buildings, as noted in D5.1, there may be an additional limitation caused by this for the contrast of predicted energy savings to the “as is” condition of consumption patterns in the buildings. The DTM can produce a model where each room can be separated out as a zone for analysis or even a single room turned into multiple zones (e.g. where only the window adjacent lighting as automated dimming) and thus has a very fine level of detail to which it can disaggregate the building. In contrast, although the Knoholem project only makes use of smaller portions of the building total, such as 350m^2 of the Ground Floor of the Forum building, these may not be sub-metered to such a high degree to allow disaggregation of their heating, cooling, ventilation demands etc. This would mean that the comparison is only possible by taking the energy use for a whole floor, zone or even building and applying it pro-rata which will induce a larger error band of the true consumption figure. In contrast the other Demonstration Objects are more complex buildings and therefore contain a higher level of metering to compare against the DTM predictions. For example, in the other Demonstration Object in the Netherlands, the HHS building, each room has its energy demand for heating, cooling, lighting and small power metered and can provide a similar level of fine detail of analysis as the zones created in the DTM.

2.2 DTM – Transition from TAS to Designbuilder for Demonstration Objects

As previously stated, Deliverable 5.3/4's BEM was required to produce Energyplus models due to the renewed project Architecture – an overview of which and has been covered in section 4.1 of this report. However, in so doing this has meant a shift from a more applicable, commercial DTM code, TAS, to a less robust system, Designbuilder, purely due to the requirement to export Energyplus input files (.idf) for the later variable orientated simulations by Cardiff University.

Whilst Designbuilder is a full commercial code DTM code that allows a 3d representation of the building and can produce results in its own native calculation engine (or use the Energyplus calculation engine) its pre-processing ability in both the 3d modelling system and the application of building fabric and HVAC systems lacked the power of other more widely used (and expensive) codes used commonly in industry such as TAS or IES. This more simplistic code therefore created several modelling/simulation problems as an attempt was made to replicate the complexity of the case study buildings. Whilst workaround solutions to many of these problems were possible so that a passable replication of the buildings was possible some details from models were lost/omitted that would have been achievable in other full commercial DTM codes. For example, CO_2 controlled ventilation rates in the HHS building could not be accurately replicated in Designbuilder and a simplified ventilation rate applied to per person in that zone. However, whilst some HVAC and other geometry detailing was required to be simplified due to the change in DTM this was far less than detailing lost and required simplifications due to the lack of building data. In converting the existing buildings to a thermal model not all input data for the DTM was able to be provided by the project partners resulting in inherent simplifications in the model so that they less accurately reflect the actual building. For example, despite only modelling the Knoholem section of the Bluenet building, details of the additional exhaust ventilation via natural stack effect through the atrium was required. With no roof details for the Bluenet building being provided this could not be replicated and the Knoholem model shows the building in full mechanical ventilation mode only. Where such deviation from actual building operation was forced to be used in the Basecase simulations for each building they will be noted per building in Section 3 below.

3 DTM: Demonstration Objects

It was envisioned during the Knoholem project creation that fully BIM compliant models of each Demonstration Object would be available, including IFC models from which the DTM could leverage the 3d model of the building geometry in a simple import exchange. This has not proved true for any of the 5 buildings within the study. Despite only partial areas of the building being used in some instances the 3d outline geometry of the full building had to be re-created within the DTM software chosen from existing CAD plans applying the real orientation and height of the building area chosen to realistically locate the building in relation to north and its altitude in order to correctly apply the solar gain to the building's facades (as the sun's height and position is taken from an applied weather file). By including the whole building in the 3d geometry, any self-shading of the building was also taken into account although, with the exception of PICA, only a limited number of zones were used for analysis purposes for each Demonstration Object. Naturally, for the specific "Knoholem areas" of the buildings a full 3d representation was created i.e. including fenestration, internal partitions etc.

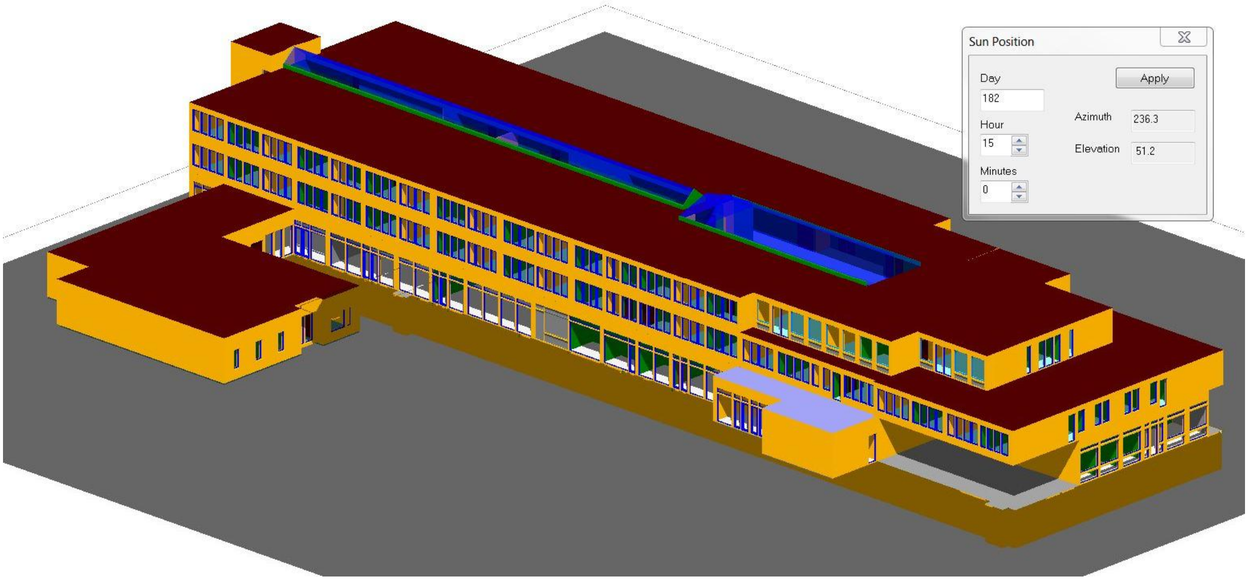
As described in Section 2.0, a large amount of information is required to create the DTM of the each building – CAD plans, HVAC services information, set-points and system operating times, thermal characteristics of the walls, doors and windows and system efficiencies to convert the predicted energy demand data into actual gas and electricity demand figures. A pro-forma table was created to collect this data in a consistent manner for each building and has been included as Appendix A "Required Information for DTM of Demonstration Object".

3.1 Forum Building, Eersel

As described in Deliverable 5.3 Forum building BEM was initially constructed in the code TAS, however due to the requirement to provide Energyplus .idf files the building was resimulated in Designbuilder. Whilst all the data had been collected for the Forum for the initial TAS model this work still necessitated time for the conversion process plus a small amount of design Workarounds" to run the model in the new programme.

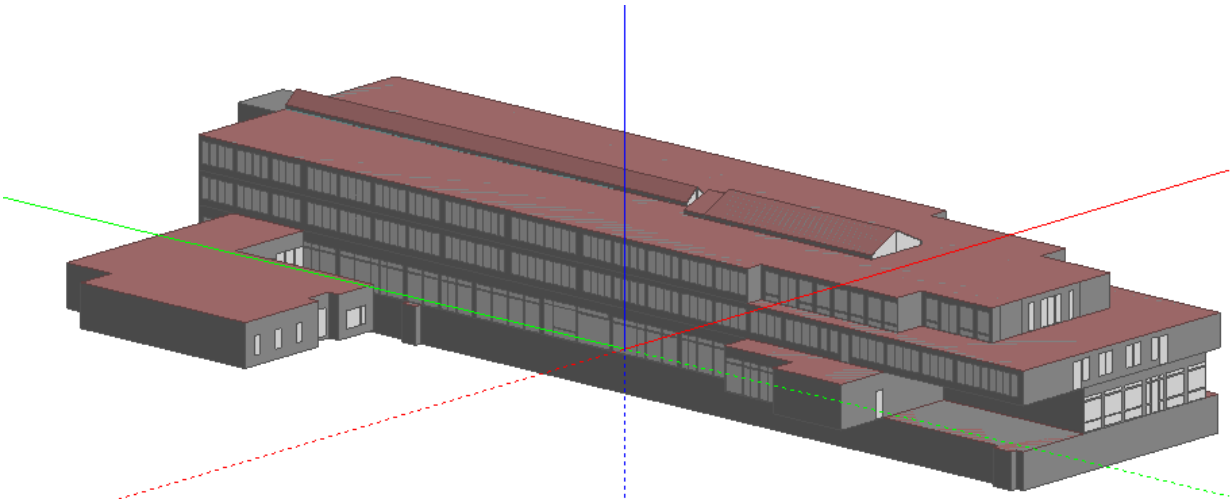
The 3d geometry of the building, initially constructed from existing CAD drawings, was easily exported into the new Designbuilder code at little time penalty, however each remaining item of input data to inform the thermal model (e.g. details of the building's fabric definition, occupation schedule and HVAC/services system) needed to be recreated. Despite this time penalty an equally detailed BEM as found in D5.3 was re-simulated in Designbuilder to also analyse the initial energy demands within the building, in turn providing a benchmark against savings due to the KnoHolEM approach can be compared. The completed Designbuilder BEM is therefore a comparable simulation to the initial system definition of the building ("as is" model) as created in Deliverable 5.3. No input variables such as occupation schedule and rate per room/zone, lighting and small power load, were changed and therefore will not be reported again in this Deliverable. Instead the Forum simulation zones will be briefly summarised and their imagery shown to give an overview of the new Designbuilder model shown below and its studied area consistent that is consistent with the prior TAS model.

Sun Position External View of the 3D Geometry of Forum Building - TAS



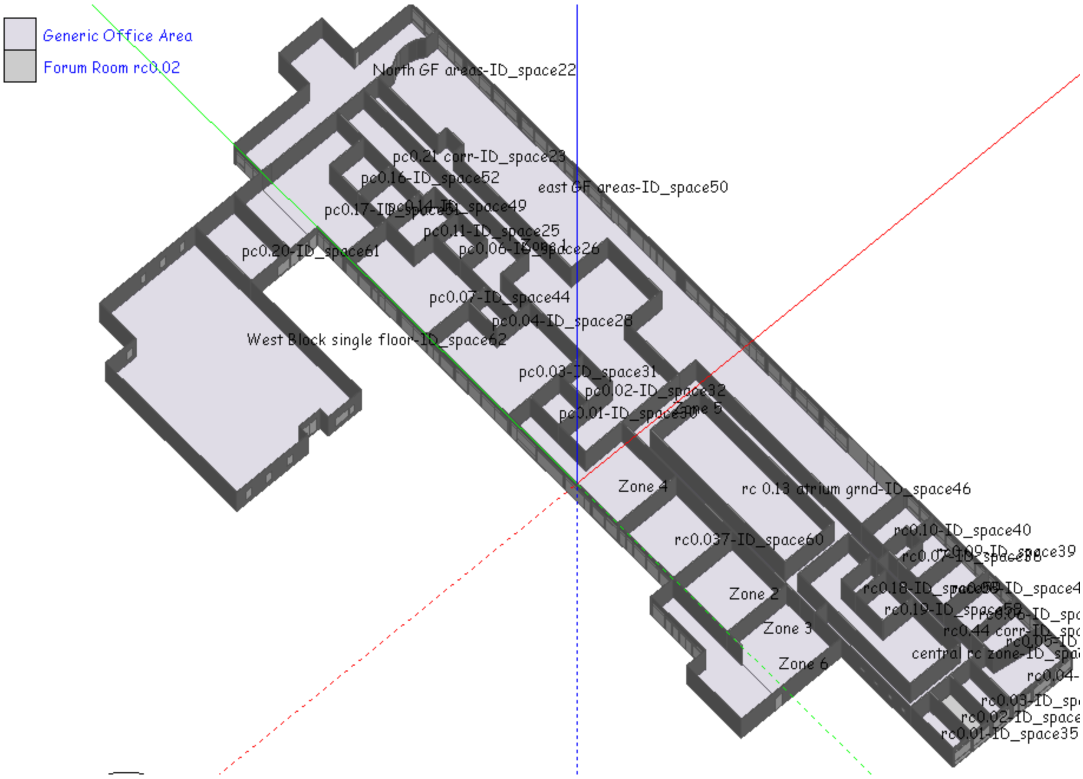
Day: 182
Hour: 15
Minutes: 0
Azimuth: 236.3
Elevation: 51.2

External View of the 3D Geometry of Forum Building (simplified rendering) - DesignBuilder



From the above 3d sun-position view of the building model it can be seen that the entire building has been re-modelled, this was appropriate due to a number of issues. Firstly, in this way the building will correctly self-shade and give a truer prediction of solar gains on facades throughout the year. More importantly, one of the areas studied within the building is the Ground Floor of the Atrium – the apex of which can be seen in transparent blue element in the 3d view – and part of its ventilation strategy is that it uses natural stack effect ventilation from the atrium to be drawn out at roof level. This required that the floors and spaces directly connected to the 4 storeys of atrium were also modelled. Finally, whilst the thermal boundaries of each space adjacent to the studied Ground floor areas are the only concern for simulation, due to the ease of replicating the upper floors (apartment sections) these could be added to the model at a very low time penalty and thus it was possible to create a full building geometry.

The following culled view of the interior of the Ground Floor of the Forum building shows the studied areas within the project – i.e. those given precise room notation numbers (e.g.PC0.17, RC0.03 etc) rather than generic names (West Ground, North GF) – in this instance with the specific room RC0.02 chosen for analysis. These project areas amount to approximately 350m^2 of the building.



The resulting Energyplus format .idf input file created by the resimulation of Forum in Designbulldder was the able to be passed on for multiple resimulations in Energyplus by Cardiff University as the reworked project methodology demanded. No zoning of the rooms or areas within the model were changed for this later simulation work and therefore there is commonality between the zones used both within the original TAS model, the resimulation in Designbuilder and the variable orientated simulations created by Cardiff University within Energyplus – simplistically, this is as a zone per discrete room.

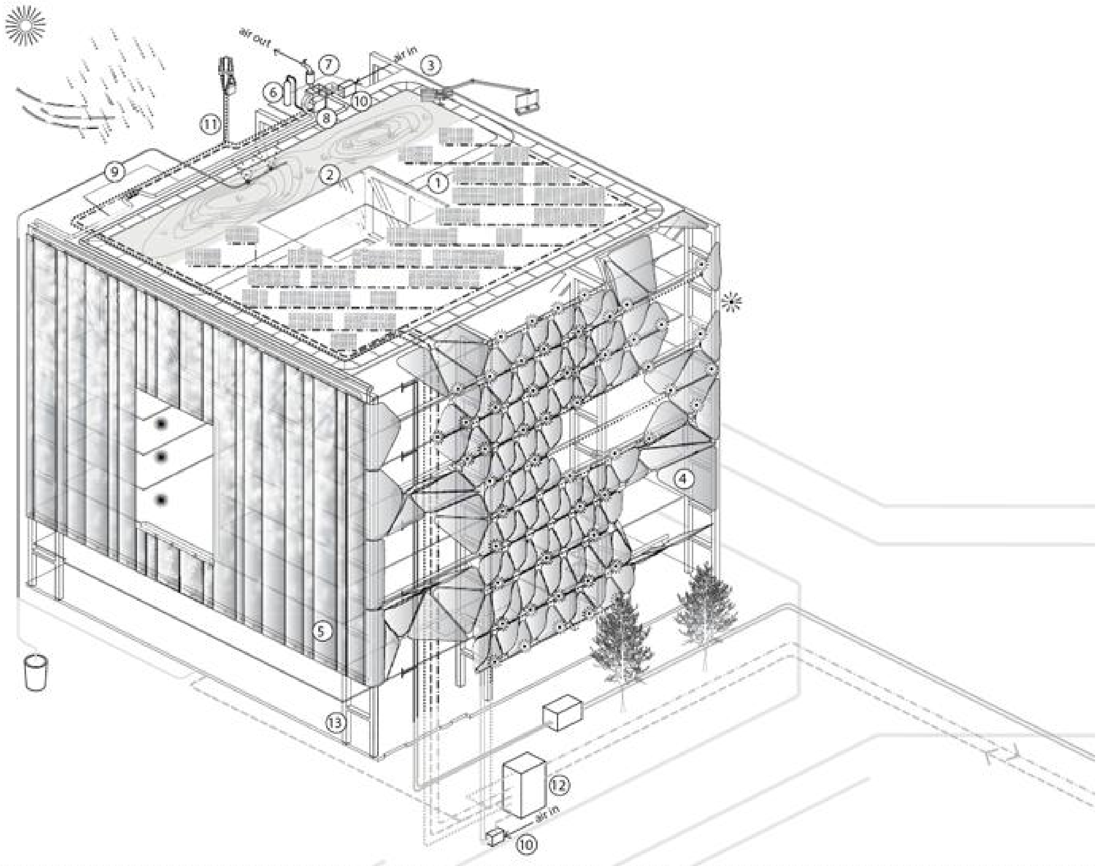
3.2 Mediatic Building, Barcelona

The Knoholem partner BDigital is an advanced technology centre specialising in the application of Information and Communication Technologies (ICTs) located on the 5th floor of Mediatic comprising approximately 80- 90 people**.** This section of the building alone has therefore become the Demonstration Object for Seville.

Briefly, the entire Mediatic Building consists of eight upper levels with various office facilities and a conference room, an extended multifunctional ground floor that includes a mezzanine level, and two underground levels used as parking spaces. The 5th floor is a largely open-plan office space comprising a separated circulation corridor and WC core space. Whilst the building has Photovoltaic solar panels with integrated controllers these are currently not in use. The building features a novel brise soleil manufactured from ETFE to protect its south and westerly facades from solar radiation - the system automatically activates itself based on the input from an internal temperature sensor network and external solar radiation sensor. Air conditioning includes the production of hot and cold water delivered through individual fan coil units allowing for free cooling air via mechanical ventilation with heat recovery in winter.

The air conditioning system is linked to the district heating and cooling network in Barcelona, DISTRICLIMA, to allow for even more carbon neutral services, though it cannot provide all the building heating and cooling demands and standard electricity fed heating and cooling plant is also utilised. The District-Heating building connection is done through two exchangers (hot and cold) and is connected with the heating/air-conditioning pumps. The water thermal exchange between these sources is established as 8.5 ºC for cold water (5.5ºC-14ºC) and 30ºC for the hot water services (90ºC -60ºC). DISTRICLIMA has been operating since 2004 to implement a district heating and cooling network for use in heating, air conditioning and sanitary hot water in Barcelona. The current number of buildings connected and its total constructed surface above the ground stands at (in the 22@ technological district) 41 buildings connected, with a constructed surface of more than 390.000m^2, serving more than 10.000 users. Situated in the warm Barcelona climate, the “Calenar” certification reported that heating makes up only 9% of the combined heating and cooling costs, thus the minimisation of this via the ETFE façade and Districlima network aids to produce a lower energy building despite the high cooling energy demand.

The main elements of the building’s low energy structure and services are shown in the building drawing and diagram below. However, whilst installed the PV array on the building has not been used to provide renewable electricity to the Mediatic building in reality. These are not in use and are no longer intended to be in operation due to financial subsidy changes.



DISTRICT HEATING AND COOLING

The Districlima project is the first district heating and cooling system in Spain. It derives its energy from a heating and cooling power plant utilizing renewable energy such as cooling sourced steam and a waste-to-energy heating source (steam).

FOTOVOLTAIC MODULES

① BP SOLAR mod. BP 3165S
Policristalin (SiN) 165 Wp
140 Units of 1,30m2
Peak potential of total instalation: 23,02 kWp

GREEN ROOF

② Green roof built-up as an inverted roof
Sedum plants

Rainwater collection
Containers are installed underneath the ramp of the car park. Rain water is used for watering the green roof.

③ Suspended working platform for maintenance and cleaning

ETFE FACADES

④ Air supply Sancho d'Avila facade
Sancho d'Avila façade (south-east facing):

-Type A cushions: 3 layer cushions with pneumatic sun shading, allowing to adjust solar transmittance to either 65% or 45%. Each cushion is individually operated by a light sensor. The programming of each cushion can be manipulated via an IP address.

-Type B: 2 layer cushions. Exterior layer print of silver circles, interior layer green tinted ETFE foil. Solar transmittance approx. 55%.

-Type C: 2 layer cushions. Exterior layer transparent, interior layer green tinted ETFE foil. Solar transmittance approx. 65%.

-Type D: 2 layer cushions. Exterior layer transparent, interior layer print of negative silver circles. Solar transmittance approx. 50%.

CAC façade (south-west facing):

⑤ -Solar sun shading is achieved via a system which injects fog into the cushions. This system provides a variable shading which reduces solar heat gain up to 90%.

Air supply CAC facade

Return fog CAC facade

Nitrogen Supply

⑥ Nitrogen cylinder

⑦ Oil mist separator

⑧ Fog generating system
Concept ViCount 180 Smoke System

⑨ Circular cased axial fan

⑩ Inflation unit

SENSORS

Luxometer
Operating sun shading

⑪ Directional luxmeter
Operating fog system

Light sensor
Operating interior lighting

Data cable

Supply of electricity to the grid

Consumption of electricity from the grid

⑫ Central Computer of Building Management System

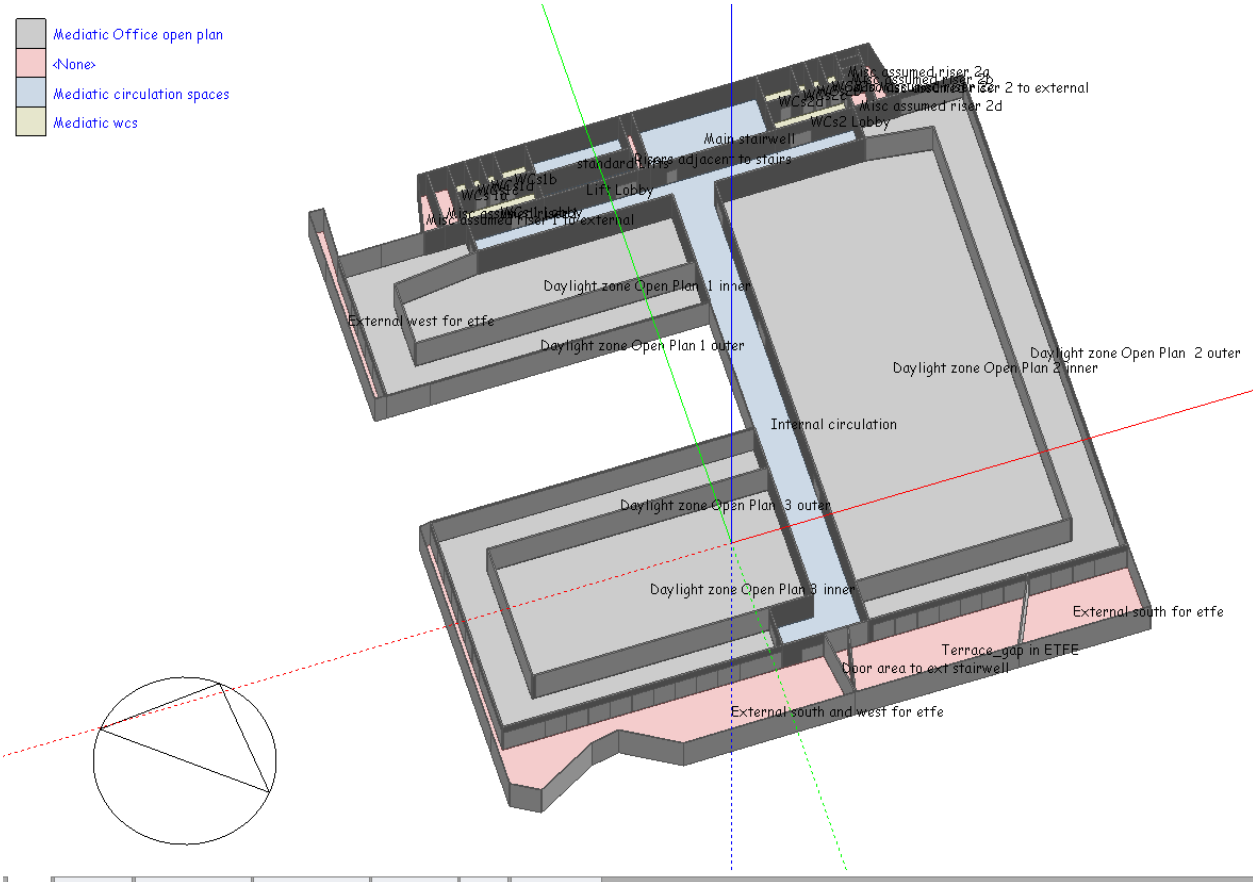
⑬ Bioluminescent paint applied to primary structure

Mediatic Building: Main Building Structure and Low Energy Devices and Sevices

3.2.1 Designbuilder Basecase - Mediatic Building, Barcelona

As described above, the Knoholem project concentrated on only the 5th floor of the Mediatic building and therefore only this was modelled in Designbuilder. However to correctly model the elevation of each façade dummy floors for Ground to 4th and 6th to 8th were also included in the 3d geometry. In this way the correct solar radiation levels would fall on each analysed surface. The modelled floor plan was zoned per open plan work area, however due to the addition of lighting control some "null" walls were added in the 3d model to separate the open plan zones out further.

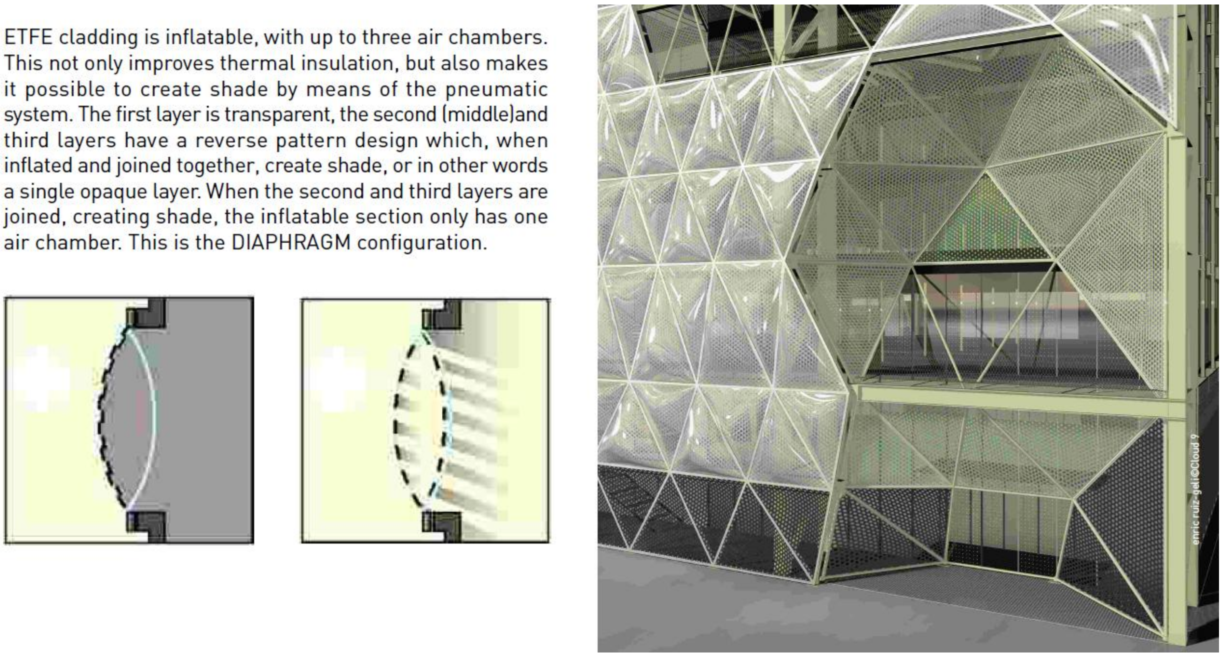
Designbuilder 3d geometry of Mediatic 5th Floor with Lighting Zone and ETFE false "walls".



However, the novel approach of the solar shading on Mediatic, the ETFE brise soleil, is difficult to replicate in a thermal model as its solar shading coefficient can vary dependent upon how many of its 2 or 3 layers are inflated. Whilst the correct material definition of ETFE has been applied in the model and it has been applied as an external façade the Designbuilder model leaves the ETFE at set shading percentages – alternative ETFE material definitions were also created with higher shading coefficients so that the materials could be swapped out as triggered by the needs of the subsequent Energyplus models. Therefore, one of the key optimisation scenarios (i.e. the increasing and decreasing solar shading) is created via the multiple variable orientated simulations by Cardiff University rather than this variable being built into the DTM as such. In practice, the dynamic nature of the ETFE is more limited than originally planned as one façade now remains with a static shading percentage as the "nitrogen fogging" system that opacified the

ETFE is not used in reality (i.e. modelled as a constant 40% solar transmission). Whilst the second façade using the ETFE brise soleil consists of both 2 and 3 layer forms of ETFE with only the 3 layer version inflating to provide varying solar shading percentages across the day – thus some areas have a 55% solar transmission factor constantly whilst “ETFE Type A” has a variable solar transmission in reality (between 45-65%).

ETFE Description and Mediatic Brise Soleil (from promotional ETFE catalogue)



ETFE cladding is inflatable, with up to three air chambers. This not only improves thermal insulation, but also makes it possible to create shade by means of the pneumatic system. The first layer is transparent, the second (middle)and third layers have a reverse pattern design which, when inflated and joined together, create shade, or in other words a single opaque layer. When the second and third layers are joined, creating shade, the inflatable section only has one air chamber. This is the DIAPHRAGM configuration.

ETFE Brise Soleil on both shaded facades (image from BMS Lighting GUI screen)

Funcionamiento Zona 1.1
○ Manual ● Horario
● On ○ Off
Horario

Funcionamiento Zona 1.2
○ Manual ● Horario
● On ○ Off
Horario Repassar

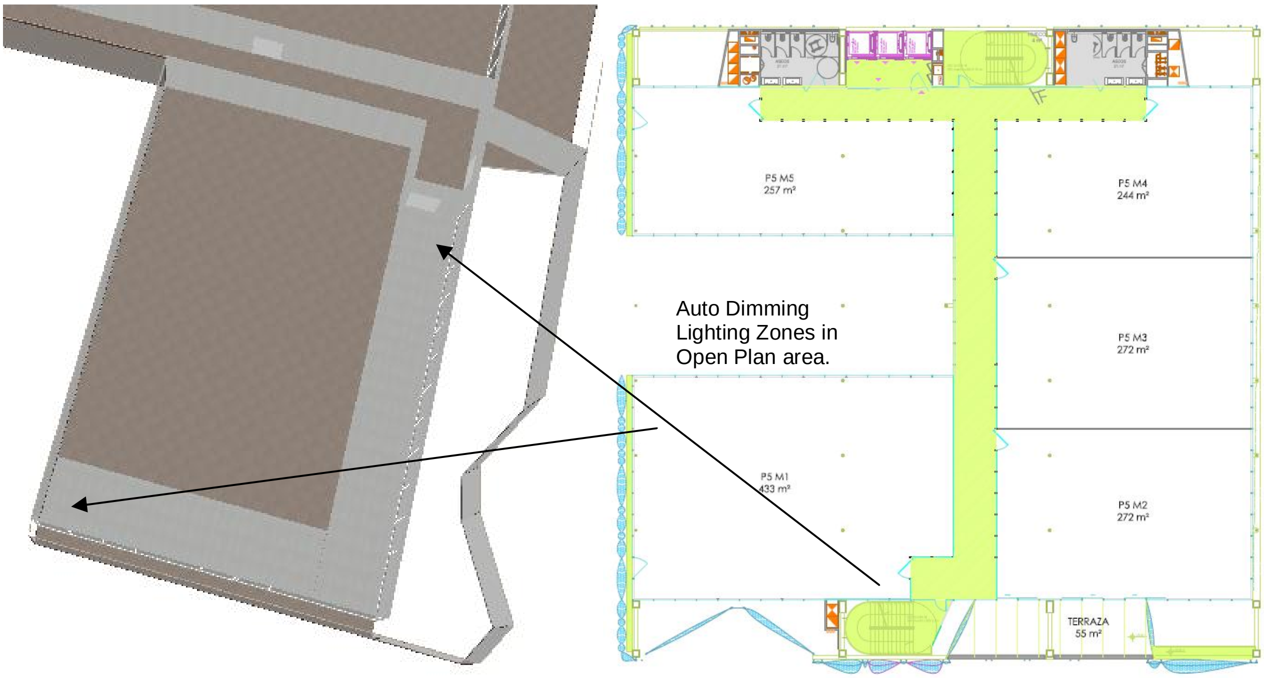
Funcionamiento circuito Reserva
● Manual ○ Horario
○ On ● Off
Horario

Funcionamiento Zona 2.1
○ Manual ● Horario
● On ○ Off
Horario

Funcionamiento Zona 2.2
○ Manual ● Horario
● On ○ Off
Horario

All other modelling parameters were able to be fufilled in Designbuilder after the receipt of the modelling information pro-forma (as found in Appendix A) from BDigital. This data provided the sufficent detail to allow the correct occupation rate to be set (generally 0.16 persons/m^2), the correct daily occupation schedule (09-1400 & 15-1800 Mon to Thurs and 09-1500 Friday), the correct environmental set-points (20°C winter, 25°C summer, 40-60%RH), ventilation rates (10 l/s/p at 25% fresh air), incidental equipment gains (approx 15 W/m^2) and of course the material definitions for each wall, floor and glazed element (taken from the Calenar certification). Furthermore, the correct total heating and cooling loads from the VRF system were able to be applied to each zone rather than an infinite definition, thus in the future Energyplus simulations an upper limit on the ability of the plant is included as occurs in reality despite alterations to set-points and gain rates. Although, each open plan and cellular room was explicitly modelled from the CAD plans the information provided also allowed the model to be re-zoned to allow the open plan areas to include lighting control zones. Whilst all artificial lighting in the building has PIR occupancy control, the model also simulates the actual inclusion of auto-dimming luminaires found in the space of the first 3m from the façade windows, thus realistic lighting energy use can also be simulated. The “lighting zone” is shown below in the Designbuilder model image contrasted against the CAD plan of the same open plan floorspaces.

CAD 5th Floor plan and DesignBuilder “Culled” Image Showing Additional Lighting Control Zone.



The maximum heating and cooling demand per fan coil unit were known so that a maximum potential cooling or heating could be modelled in each zone rather an averaged potential or an unlimited supply to meet the set-point point criteria (as discussed above). Thus apart from the ETFE workaround no other simplifications were required in the model to ascertain the energy demand of the 5th floor offices. However, the same does not hold true of building energy consumption. Fortunately for the modelled building the PV system installed is not in operation and does not have tp be allowed for. More importantly, the proportion of the heating and cooling supplied by Districtclima as opposed to that provided by the main electricity supply cannot be modelled to mimic reality as this will be a changing percentage. However, given information supplied that is used within the Calenar certification process to allow for supply via the distict network (Districtlima) the dual supply of the two systems can be combined into one overall

Coefficient of Performance (CoP) each for heating and cooling that could be applied to the building – thus should approximate reality when looking at annual consumption figures.

The full annual Basecase energy consumption prediction created by Designbuilder was produced as an Energyplus output file (.eso) and therefore could be used as a check against the same input file produced (.idf) if also simulated with Energyplus. However, it is this .idf export that is the main product of the D5.3/5.4 works and will now allow multiple re-simulation as described in Chapter 4.1.

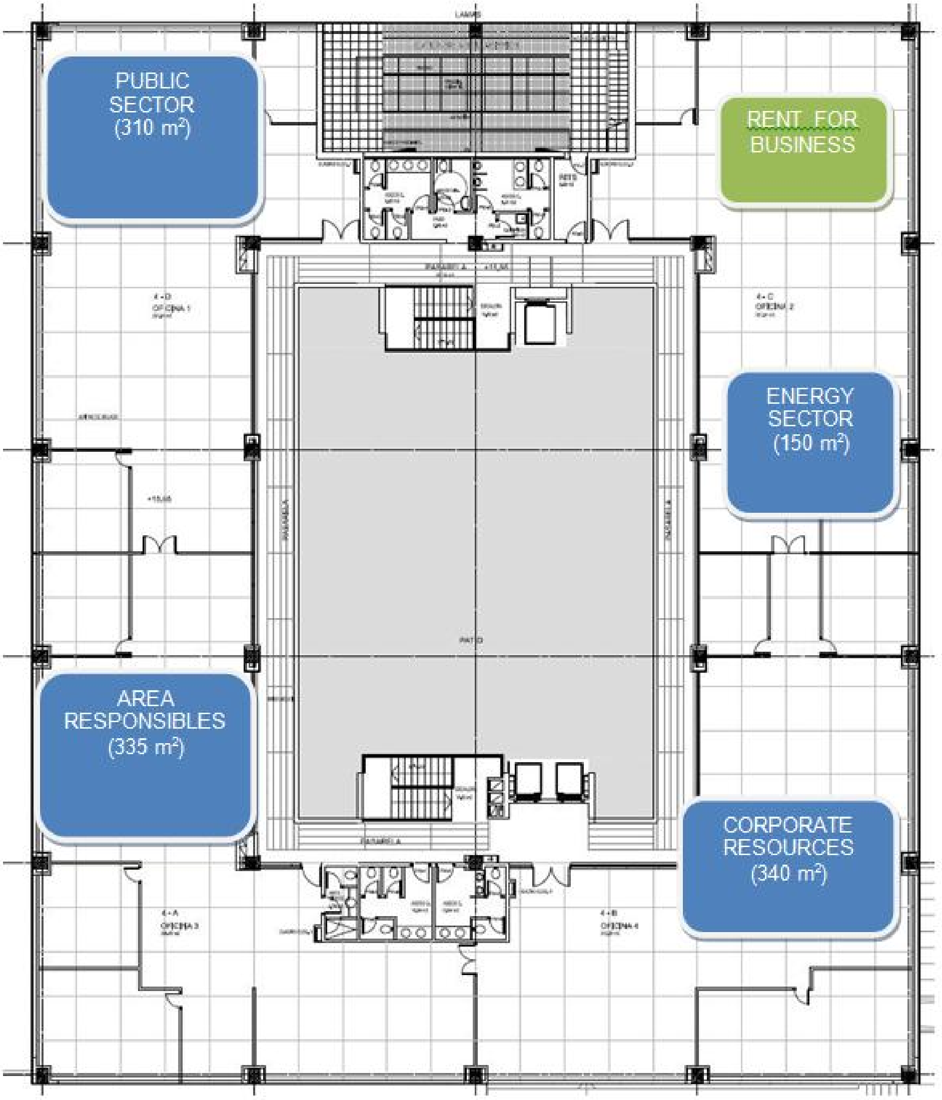
3.3 Bluenet Building 4th Floor, Seville

The Bluenet building in Cartuja Technological Park, Seville is an office building for businesses and governmental administration, focusing on Information Technology (IT) and energy. The building form is a glazed cube consisting of 6 floors, however the whole-height glazing external faced is misleading as only approximately 40% of the curtain wall glazing is tinted glass alone – the remaining is cladding over standard block construction. . The glazing, as well as being tinted blue to partially opacify it. is further treated to lower the solar transmission of heat gains into the building. The building internally consists of large open-plan spaces on each floor as well as common areas such as toilet blocks and circulation spaces that connect the individual open-plan sections together. The layout of each floor has been designed for maximum freedom of re-partitioning and mobility. Each floor centres around an internal atrium, the internal atrium's perimeter being glazed adjacent to the office core and containing a walkway and lift cores).

Bluenet Building – External View

In total the building is 19m in height and the occupied floors provide for a building of approximately 10,000m^2.Of the six available floors: two underground levels are used as parking lots and as common facilities (lecture room, kitchen/dining room and offices), and four above-ground levels accommodate the offices of different firms. The Knoholem project considered only the roof adjacent 4th floor which houses the project partner, Isotrol, this area is approximately 1580m^2, which although predominantly open plan contains separate work areas of 300-400m^2 each. The Isotrol offices typically have approximately 150 occupants, with a maximum of 186. A floor plan showing the named sections of each working area on the 4th floor is shown below along with an internal view of the Isotrol office, showing the extent of the internal atrium.

4th Floor Plan – Bluenet Building with Knoholem Project Areas



Internal View of Atrium Perimeter onto 4th Floor Façade and Roof Level.

The individual open plan sections of the building are monitored by a sensor network reporting to the BMS so that ambient temperature, light levels, PIR (presence detection) and electricity consumption are monitored at each point. In this way the building is finely zoned so that HVAC temperature set points and mode (heating or cooling) plus the light intensity level can controlled at these points. Thus in practice the temperature set-points can be modified by the employees in each area of the fourth floor down to each space served by an individual terminal unit.

Although there is a multiple indoor terminal system (installed in office false ceilings) in use, the building services are not modularised and the HVAC system is centralised with distribution of the Variable Refrigerant Volume (VRV) to the different terminal units provided via external and roof mounted plant-rooms. Despite the central external units the individual terminal units do provide the possibility of simultaneous heating and cooling of the building to different areas, should the condition arise, mid-season. The air-conditioning throughout the building is provided via DAIKIN VRV units, with varying units, ranging from 4.5 kW to 14 kW, used per floor. The cooled or heated air supply from these units is supplied to the office via ceiling mounted, rotational diffusers with a low average power consumption of under 2 W/l/s. The HVAC system supplies air at 12.5 l/s of air per person with a flow of approximately 2,500 l/s per floor (from which heat recovery is applied), though around 30% of this maximum rate is recirculated air.

The building also provides some provision for natural ventilation. A very small proportion of windows are openable per floor, however a mixed mode system has not been designed and these should not be in operation during full heating or cooling operation of the VRV air conditioning. However, the internal atrium also provides natural ventilation for exhaust office air. Internal openable windows linking the atrium to the internal office perimeter can be opened to naturally extract office air via the atrium by the stack effect to be exhausted at roof level. Whilst this operates in reality, no window opening details could be provided or any roof details so that this could not be replicated in the DTM. Therefore, the BEM of the building operates Bluenet as a mechanically ventilated building only.

To interact with the BMS, sensors actuators are distributed in each of the open plan office areas. This sensor network includes the lighting controls, which are provided by a proprietary system developed by Philips. These sensor nodes include light sensors, movement detectors and infrared receivers. There are two areas of the fourth floor controlled by a Digital Addressable Lighting Interface (DALI) system within the Knoholem, project area. No additional services of note are available in the Bluenet building and it does not possess any renewable energy sources or low or zero carbon technologies. Due to the requirement to minimise solar gain into the building, the heavily tinted windows ensure that maximizing daylight is not a priority and no automatically dimming lighting luminaires are present. However, the artificial lighting load is low with much use of recessed compact fluorescent ballasts in the office spaces and halogen lamps to light the circulation space and atrium. Occupation of the building is normally from 8:15 until 17:30-18:00, however with some late evening work the HVAC system is programmed to switch off automatically only after 20:00. Even with this given number of run hours for the building HVAC system it is possible for late working employees to be able to switch on the HVAC system again after 20:00, but it will turn off again after half an hour if not re-initiated.

3.3.1 Designbuilder Basecase - Bluenet Building, 4th Floor, Seville

The Designbuilder model only takes into account the 4th floor of the Bluenet building, however in a similar manner to the Mediatic model the prior floors were also modelled in the 3d element but not added to the calculation. In this way the correct height assignment of the 4th floor was transferred to the model i.e. the floor started at 15.65m rather than ground floor level, this then correctly applies the solar gain and illumination potential given the sun's altitude and azimuth from the applied weather file. The orientation of the model and its correct latitude and longitude were set in the model to correct for the CAD file imports that were created for ease of viewing and showed with no set orientation to north. It can be expected that the 3rd floor conditions will be a corollary of the 4th and the internal floor elements between the 3rd and 4th floors were set as adiabatic elements. This is a common modelling convention, however due to the paucity of data provided regarding the make-up of the internal floor to ceiling elements this was the only possible means of creating this boundary element.

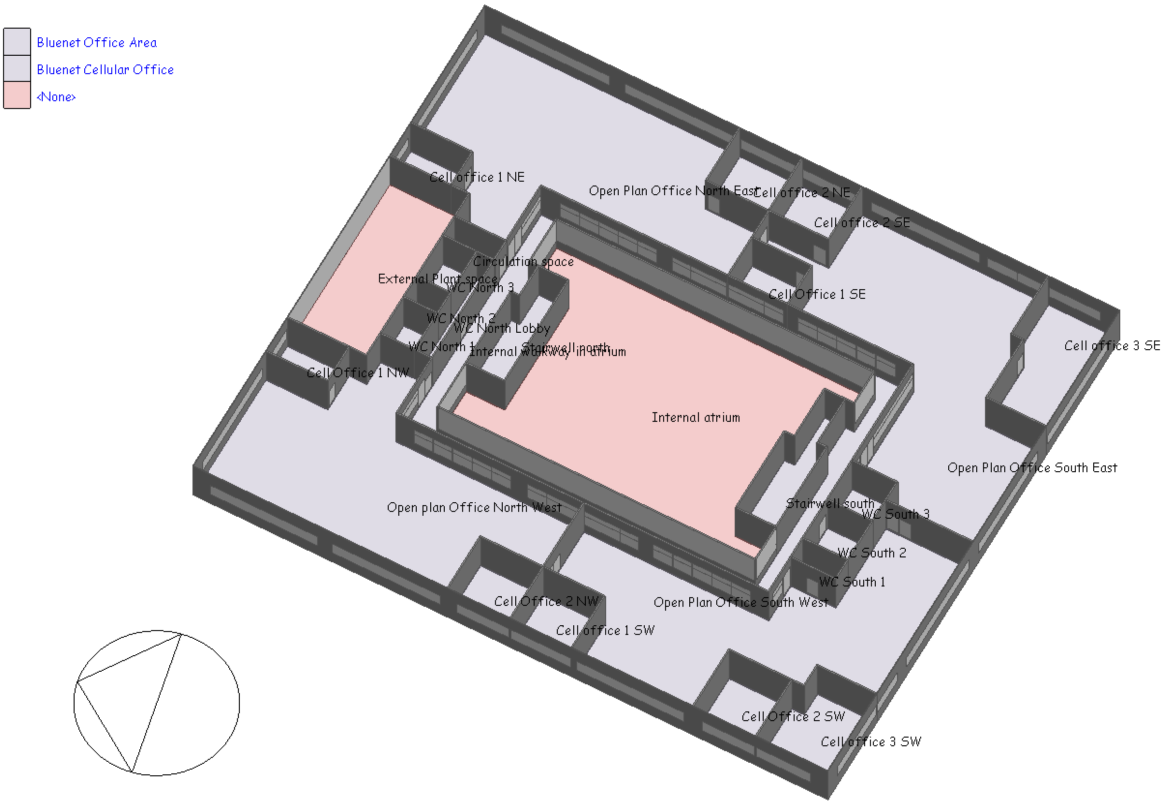
A far greater compromise was enforced due to the lack of details provided regarding the operation of the internal atrium. Whilst modelling the air flow through the atrium creates a more realistic model of the building as it operates insufficient details were provided by the Consortium partners to allow this. In operation, whilst fully air conditioned each floor has openable sections of windows into the atrium to allow some natural ventilation extraction of the office air. This air transferring to the atrium and exhausted via openings in the atrium's sealed roof. No CAD drawings showing the roof, its roof mounted windows or their openable percentage, their inavailablity meant that it was not possible to correctly model this activity. This would also have required the modelling of the former floors (Ground to 3rd) to correctly model the stack effect throughout the entire atrium. Therefore, the whole floor has been modelled as a sealed, fully air conditioned building i.e. the predominant operating mode of the building in cooling and heating seasons. However, this may not be accurate in mid-seasons with little or no heating/cooling demand where minor use of this additional natural ventilation is made.

This minor addition of a natural ventilation in a fully air conditioned building also meant that the small percentage of exterior opening windows could not be included in the model. Again, no details of the window opening or their percentage or schedule could be given. As the building does not operate on a "mixed mode" basis – i.e. with natural ventilation prioritised before heating or cooling demand becomes too great and the building is sealed and fully air conditioned – this could not be mimicked by a thermal model. The small number of window openings available are used on an ad hoc system by staff and are as likely to be used when the VRF system is in operation as when it is not. During a building visit it was stated that routine use of these windows should not be made, however it was noted that a small percentage were opened.

Despite the enforced use of full air conditioning mode for the entirety of the year which may not replicate small periods when the minor ability for natural ventilation is applied on the 4th floor few other deviations were required and the building was able to be modelled "as is" in its standard operation. The VRF system's peak load and appropriate CoPs for each zone were known so that the correct total load and system efficiencies were able to be provided for each zone. Lighting, occupancy rates and small power loads were also able to be realistically set although as a predominantly open plan space these loads were based on averages per square metre of the building.

The initial zoning of the building before it was converted to an Energyplus .idf model was a replication of the actual room numbering and layout, with zones being provided for each open plan space, the small number of cellular offices, WC blocks, stairwells, main atrium as well as the circulation spaces both internally and within the atrium. An image showing the 4th floor plan as zoned within the Designbuilder model is shown below.

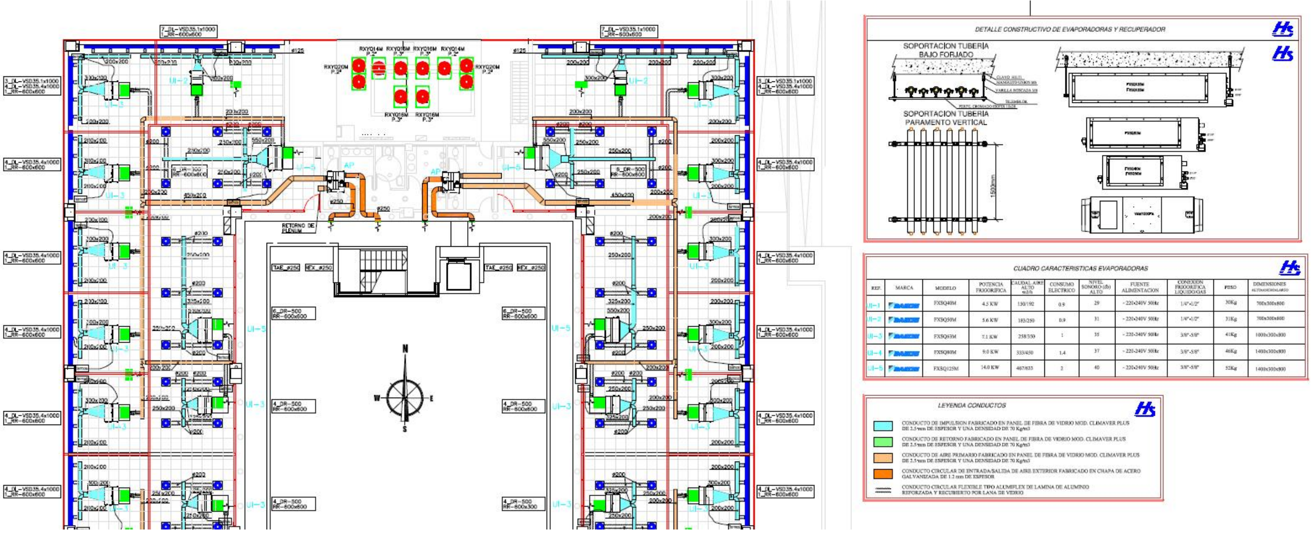
Designbuilder 3d Geometry of Bluenet building 4th Floor and Zoning



The input data regarding the HVAC, lighting and occupancy schedule and rate for the building was provided by the project partner Isotrol and was able to be replicated in the thermal model. Electricity and lighting schematics were made available to provide a corrected installed lighting load to each zone in the building. Principally made up of 3x 18w fittings for the office lighting to provide 500 lux, this load was turned into an equivalent load per square metre for use in the model (11.7W/m^2). The correct but differing average W/m^2 requirements were also applied to the additional areas such as the north and south circulation areas and the atrium walkway section.

Full HVAC drawings were sent that allowed the supplied maximum heating nc cooling capacities to be supplied on the 4th floor and averaged per zone from the number of VRV terminals that served that area. For example, whilst the 4th floor has a 252kw load this is spread more exactly per zone dur to the number of terminals that serve that area - with several VRV units of differing capacity being used in each zone (rated between 4.5kw and 14 kW). The information for the Daikin VRVIII system was also able to provide precise CoPs for heating and cooling efficiency (3.98 and 3.36 respectively). A section of the 4th floor HVAC layout is shown below, indicating the large number of terminal units in just the northern section of the 4th floor.

Daikin VRV Terminal Unit layout - Bluenet building 4th Floor



Occupant loads were applied at the given occupation rate (0.147 person/m^2) and attributed to the open plan and small amount of cellular offices alike for the schedule given by Isotrol in Section 3.3 above. This occupant level therefore determined the fresh air rate (30%) of the mechanical ventilation system (itself 12.5 L/s/p).

Although there was an element of simplification due to the removal of the atrium roof element and the inclusion of the floor as an adiabatic layer, the opaque roof element, external walls and windows were all applied with the correct thermal transmission values. Full U value details were provided for these elements as well as a break-down of the main central glazing panes so that a correct G value for solar transmission could be applied to it. For example, the main “Coolite” window system has a low G value and Solar transmission coefficient (0.21 and 0.24) yet a reasonably high U value allowing little insulation (2.5 W/m^2 K), whilst as can be expected for a primarily cooling led building the opaque element U values are similarly high (e.g. walls of 0.5 W/m^2 K, roof of 0.4 W/m^2 K). No further estimation of building element details were required for example internal floors as they were not used/adiabatic in the building model, Also, though appearing in the 3d geometry some non-serviced areas such as the external plant room could be omitted.

The full annual Basecase energy consumption prediction was simulated for the 4th floor within Designbuilder and also saved for comparison purposes as an Energyplus output file (.eso) as a check against the same input file (.idf) if also simulated with Energyplus. The EnergyPlus .idf export that is the main product of the D5.3/5.4 works was then available to allow multiple re-simulation as described in Chapter 4.1 by the project partner Cardiff University.

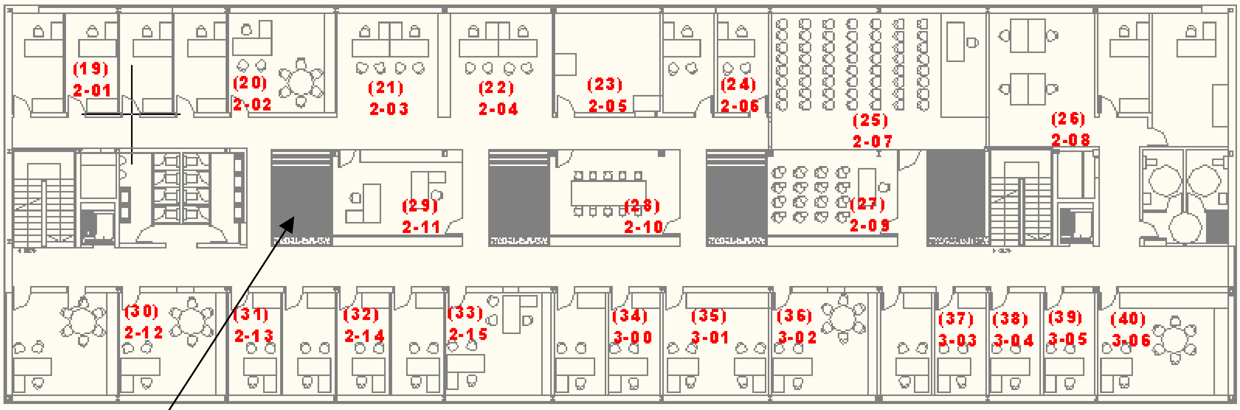
3.4 PICA Building, Seville

External view of PICA Building Façade

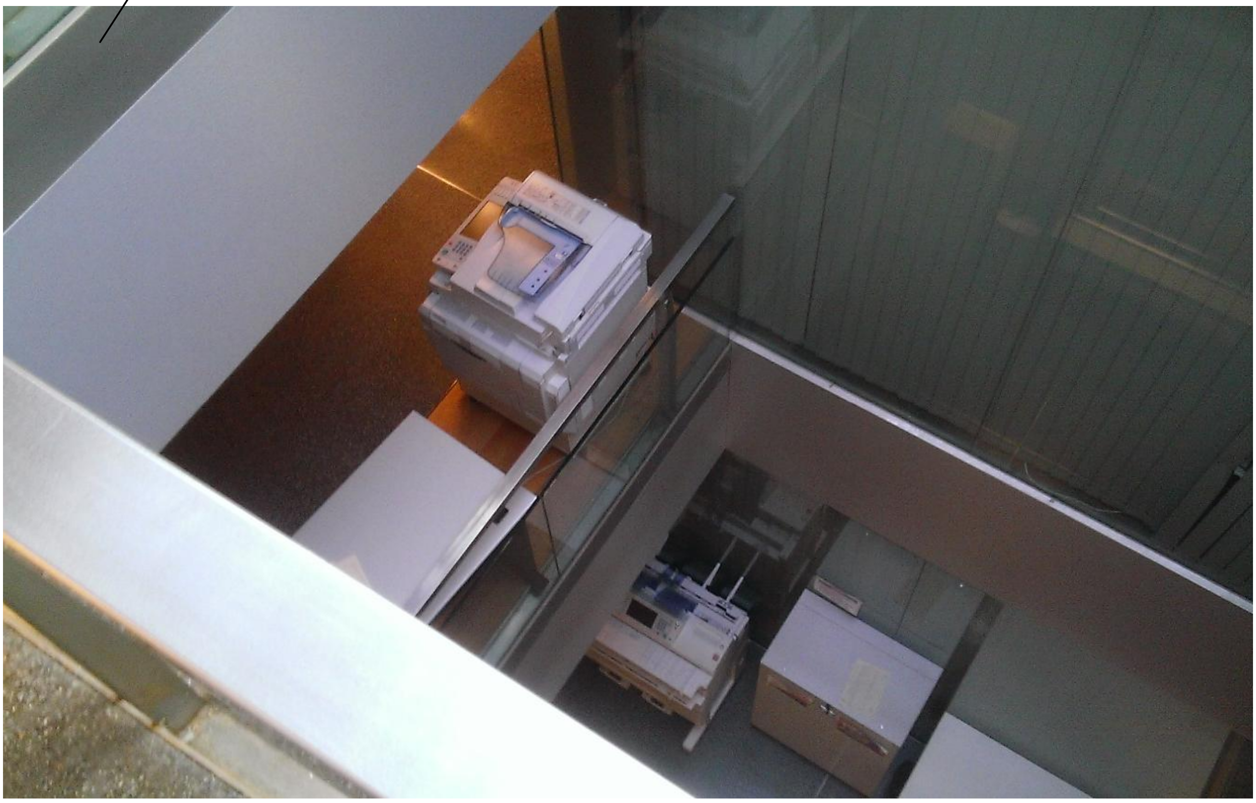
The PICA building has also been provided by the partner Isotrol and like Bluenet is located in Seville, however, PICA belongs to Seville City Council. PICA was a late replacement building to the project in 2012 due to the alternate Seville property (IDEAS building) yet to have any occupancy. PICA is a new-build office building situated on the Carretera Amarilla Industrial Estate and consists of 3 office levels above ground and 3 underground floors of parking spaces – however only the office floors are considered for the Knoholem project with no detail being provided for the unoccupied below ground floors. Though not the largest building in the project, the inclusion of all 3 occupied floors means that PICA is the largest study area of the Demonstration Objects to be considered in the project and consequently the most rooms to be analyzed and thus the most zones in the DTM were required to be created for it.

Internally the office floors are divided into three strips, two of them along the perimeters, which are the office areas, plus a central section which contains utility areas consisting of meeting rooms, bathrooms, GIS stations and communal areas for employees. Access to all floors is by two sets of stairs and two lifts which are located at opposite ends of the central strip (stairs and lifts also service the three parking floor levels) whilst the central strip also holds the internal circulation space between offices and small internal atria. The 2nd floor plan below highlights the 3 separate "strips" of the internal arrangement of the building and the image highlights the small central strip atria on each floor.

Floor-plan Layout for 2nd Floor Office – PICA Building



Central Floor-plan Atrium View from 2nd Floor Conference Room – PICA Building



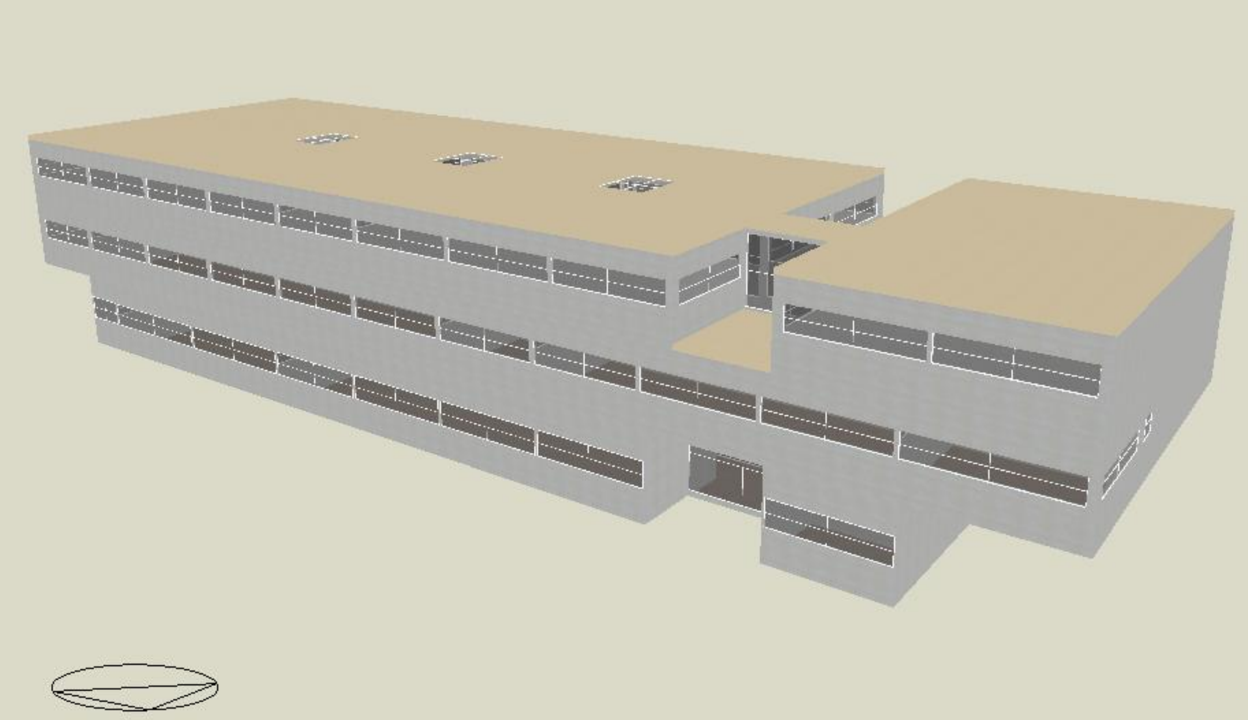
All office premises are fully equipped with air conditioning supplying fresh outdoor air and extraction for removing stale air. The air conditioning system makes use of individual fan-coil terminals with multiple terminals in each of the 3 longitudinal sections of the floor-plan per floor. The separation of these multiple zones by end use of room and/or workday schedule ensures that the BMS able to turn off the AC system in those premises or areas of the building that are unoccupied. This semi-centralised system, i.e. with multiple terminal units running from an outdoor unit is the same as applied to the other Seville Demonstration Object, the Bluenet building. This system heats and cools the spaces with the same Daikin Inc air-air heat pumps with variable refrigerant volume (VRV) technology, divided into sectors according to floor level.

The VRV system with its inherent variable flow of refrigerant allows for an efficient air conditioning system that can provide heating or cooling for multiple zones individually or in groups. The terminals are served by three outside units, one per floor level, thus allowing for some optimisation of the installed capacity. As the internal terminals serve isolated sections of the floor, some affected by direct solar gains whilst others are shaded (which naturally changes during the day), peak demands for each will occur at different times of day. The current HVAC set up allows one terminal to operate at peak demand from its outdoor unit whilst lower energy demands are served in other areas from another unit. This configuration also lends itself to mid-season scenarios where, though at low demand levels, simultaneous heating and cooling may be demanded in the building – e.g. a heating demand in the exterior facing offices whilst cooling is still required in the internal rooms that may have high occupant rates. Whilst the configuration does not allow users in the zone covered by a single terminal unit to switch between heating and cooling as this is controlled centrally, the temperature control will be available allowing for fine environmental control in small, discrete areas of the building, in some cases down to individual rooms. There is also an AC system independent of the main VRV system in the building, however this is purely for treating the server room on the ground floor and also contains humidity control, however this unoccupied zone has been omitted from the calculation

The mechanical air supply is also created through the ventilation units located in the terminal units found in the lowered ceiling. The one exception to this is the heat recovery unit which treats the primary air which supplies the meeting room located on the first floor. In the case of this unit and due to the high reciprocity between the primary air to be input and the total flow of the air being supplied, a heat recovery unit to ameliorate the heat demand from the exterior supply air from the outdoor unit was deemed viable.

3.4.1 Designbuilder Basecase - PICA Building, Seville

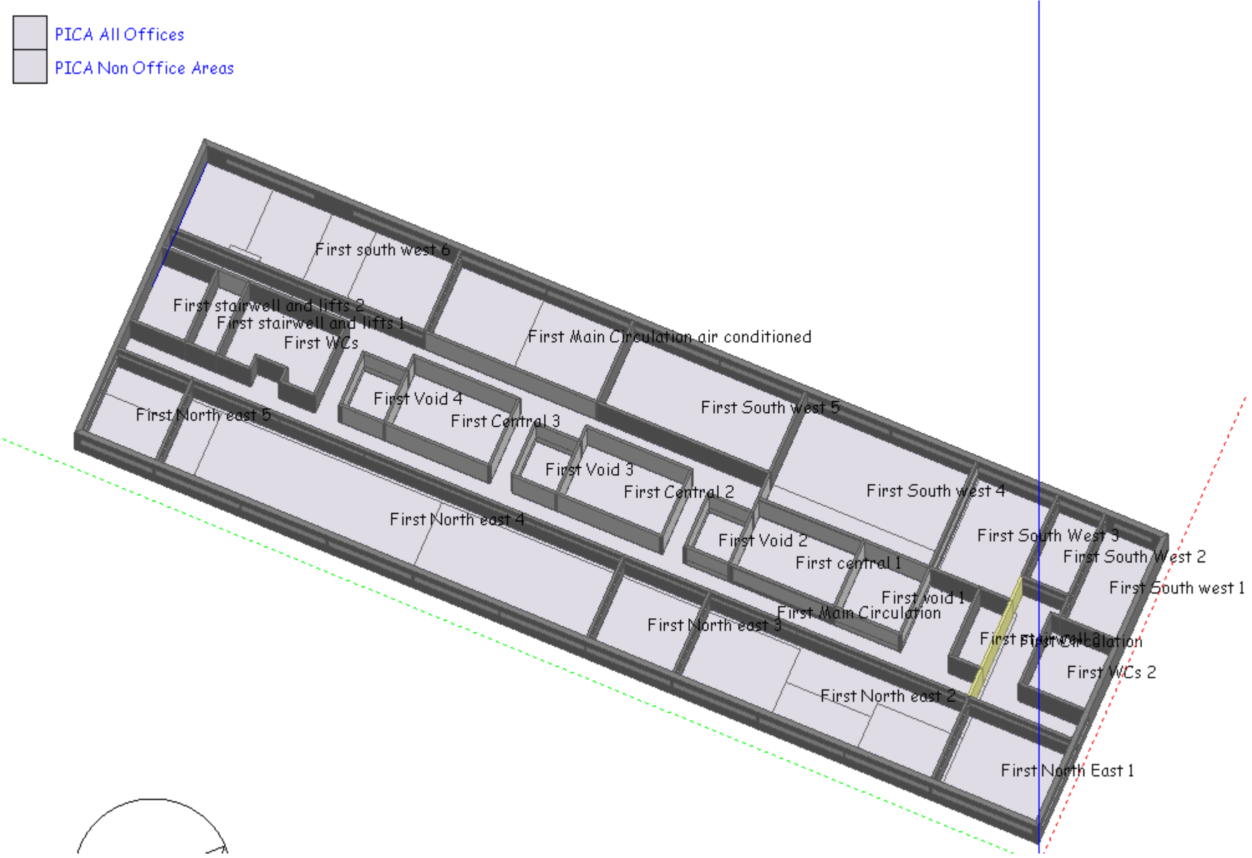
Designbuilder 3d Geometry of PICA building Ground to 2nd Floors based on Sketchup Model



As per the prior buildings the PICA building was recreated in 3d for the Designbuilder simulation. In this instance, only the 3 above ground floors of the building were replicated with the uninhabited 3 below ground floors omitted. To do this the thermal adjacent layer between the Ground floor and -1 floor was set as an adiabatic layer. This is a required simplification as no details regarding the servicing or environmental condition of the below ground floors were available. It is likely that, being adjacent to the serviced (heated/cooled) Ground floor but insulated from the earth temperature by 2 further below ground levels, the temperature regime in this floor should not greatly deviate from the Ground floor itself. However the conditions would be expected to show a greater degree of difference as compared to the serviced Ground floor in the main heating and cooling seasons and the use of an adiabatic border will introduce an element of inaccuracy when trying to replicate the building in use.

Only basic floor-plans in PDF format were available for the PICA building which could not be sized off whereas no elevations or sections were available at all. However, a full Sketchup .skp file of the main office floors of the building was available. The Sketchup model was used to size all elements in all 3 dimensions as the building was recreated freehand in Designbuilder's 3d geometry builder as there was no CAD plans to act as a guide to trace the perimeter and internal dimensions. This also meant that there was no indication of a "Northing" as no CAD plans existed, therefore the North orientation of the model was required to be taken from Google Earth, though this provided an adequate indication of building orientation.

Designbuilder Zoning of PICA building First Floor



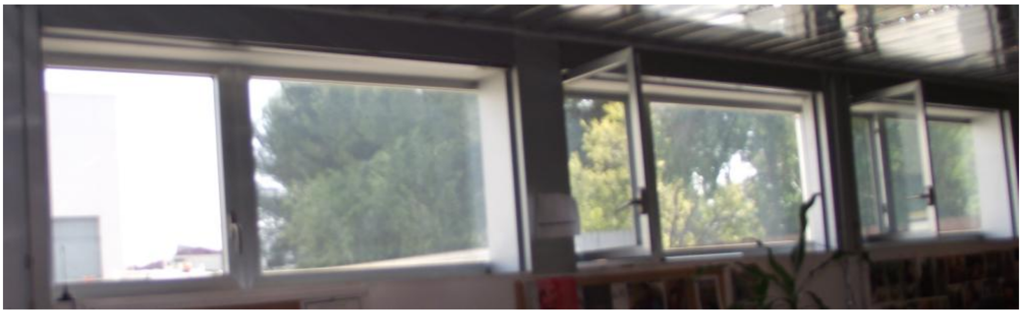
The model has been zoned so that each distinct room is a zone, whether an office area or an auxiliary area such as the central "break out" rooms, toilet core or circulation space such as stairwells and lift cores. In so doing this has created many zones, however in essence their applied internal gains and servicing are consistent between the two façade adjacent office rows on each floor and the central strip of atria/break out spaces/meeting rooms per floor – as per the building in reality. For the purposes of the project only the offices and central core break out/meeting rooms are of concern and the auxiliary areas are modelled, as standard, to correctly simulate thermal transfer within the building as a whole. The image above indicates the zoning of the First floor of PICA.

As per the other Seville located building the PICA building makes use of Daikin VRV units and full cooling and heating loads were able to be provided enabling each zone/room to have the correct maximum heating/cooling potential applied – terminal units sizes varying between 4kW and 25kW. The CoPs of the system were also gained from the Daikin installation notes so that the correct efficiencies could be applied in both heating and cooling mode, the differing outdoor units per floor requiring slight changes to each zone's CoP for both heating and cooling (ranging between 3.9 to 4.27 and 3.19 to 3.95 respectively). The set-points for these systems and their running schedule were also provided by Isotrol (21-23°C Summer and 22-24C winter).

No information was available regarding the infiltration rate of the building was provided and a generically low value to represent a recent construction was chosen. However, set mechanical ventilation rates were able to be set by the provided figure of 10 l/s/p. The ventilation rate was then modelled via occupancy rates as these were provided in detail fpr each room in the building via Isotrol – the total square meterage of each room being proved with its equivalent occupant numbers – thus in the model each zone is given an exact occupation figure (as persons/m^2) and the set ventilation rate applied as l/s/p to this rate per square metre. In typical office rates this equated to 0.134 persons/m^2.

As per the Bluenet building, whilst the building is fully air conditioned there was a minor portion of opening windows (of the available glazing) on the external façade that could be used for natural ventilation that were not designed for use in cooling or heating mode of the building. Once again, no details could be provided regarding the number of opening windows, the extent to which they open and most importantly their opening schedule in use meaning that this could not be accurately simulated in the thermal model. As with Bluenet building the ad-hoc use of these windows by staff is not controlled and ideally should not be used, however as the building does not operate in a Mixed Mode system it is entirely possible that these windows are manually operated during the heating and cooling seasons. The Designbuilder model therefore only reflects the PICA building as a fully air conditioned (and sealed) building and cannot make any allowance for this increased air exchange with outdoor conditions during AC operation or the minor element of free cooling gained by the natural ventilation during mid-season periods. The image below shows the openable windows in operation during a site visit, therefore it is assumed that some use is made of this natural ventilation despite the same office spaces also being fully air conditioned, which in practice would lead to needless, additional cooling and heating duty on the VRV units. Assuming that the smaller window pane sections are all openable this would allow approximately one third of the available fenestration on each façade to be opened to allow natural ventilation.

Image of PICA building First Floor Façade Window Opening



The remaining internal heat gains into the building were provided at a low level of detail and applied across the entirety of the office spaces that were analysed – e.g. an allowance of 20 W/m^2 for lighting gains linked to the occupancy schedule (07:00-14.30) was provided whereas no details regarding office equipment was provided and a generic standard assumption of 11.7 W/m^2 for the office environment was assumed. These levels of equipment heat gain are low with no major IT, manufacturing or catering rooms used within the building with far higher rates of internal heat gain and therefore the effect of these assumptions should be negligible.

Construction element details were provided that allowed the correct thermal properties of the main external wall, roof and window elements as well as the internal partitions to be applied. However, as discussed above the Ground Floor is assumed as an adiabatic layer as no details were available regarding the car parking level on the floor beneath it. Simple whole construction details were provided for the window and roof glazing (i.e. the U and G values of each) rather than the individual construction elements of the pane and frame units themselves. Therefore, approximate window elements were created that for a total “window + frame” unit combined to create the given U values (2.7 and 3.2 W/m^2 K for the wall and roof windows respectively) with the same given G value for the central pane glazing (0.54 and 0.78 for wall and roof glazing respectively).

In the same manner as all prior Demonstration Objects the full annual Basecase energy consumption prediction was simulated for the three floors of PICA containing offices within Designbuilder and the output file also saved for comparison purposes only as an Energyplus file (.eso) as a check against the same input file (.idf) if also simulated with Energyplus. However, the far larger number of zones in the PICA model, despite an equivalent floor area to some of the “Knoholem only areas” of building simulated for other Demonstration Objects, meant that a grouping or rezoning of the PICA building was necessary within Energyplus. The EnergyPlus .idf export that is the main product of the D5.3/5.4 works was made available to allow multiple re-simulation (as described in Chapter 4.1) by Cardiff University, however a decision was made to group similar small groups of rooms that have the same servicing method and orientation and are on the same floor to cut down the number of zones as created by the “zone per room” basis in Designbuilder. For example, the first floor zones that are contiguous offices and share a common orientation can be grouped together, this can be repeated on the ground and second floors. However further grouping of these 3 groups with the same façade orientation would not be recommended due to the differing heat loss perimeters of each group i.e. due to the adiabatic ground floor and exposed roof element. Conversely, grouping together the central rooms on the ground and first floors would be allowable as they are similarly unexposed to external conditions. The finalised extent of this rezoning, or rather groupings of zones, in the Energyplus model has been left to the discretion of Cardiff University, based on these logical criteria, so that zone numbers and simulation time can be reduced in the multiple Energyplus simulations.

3.5 HHS Building, Section of 1st Floor, The Hague

Architectural Impression and Final Finished Build Quality of HHS Building

The HHS-building was opened in 2009 and can accommodate more than 1000 students in its classrooms, computer rooms, discussion rooms and workshops, as well as provide office space for its scientific staff and educational staff. The building was designed to be highly energy efficient and comprises many building energy efficiency and renewable energies technologies. The final Energy Performance Certification (EPC) predicted that it would consume just 33% of the national standard (leading to HHS being nominated as the most energy efficient building in the Netherlands on opening in 2009). The building has 3 levels plus ground floor and basement level containing a bicycle parking space. The building also contains a large central atrium which is used as a natural ventilation strategy by collecting exhaust air from all areas. The upper windows of the atrium are opened automatically during hot summer days, to permit hot air to be exhausted The building has mechanical ventilation in its classrooms; however room windows can be manually opened if required. All areas of the building, including the atrium, have under-floor heating and chilled ceilings, this servicing is aided/supplemented by the heated/cooled air provided by the forced, mechanical ventilation system.

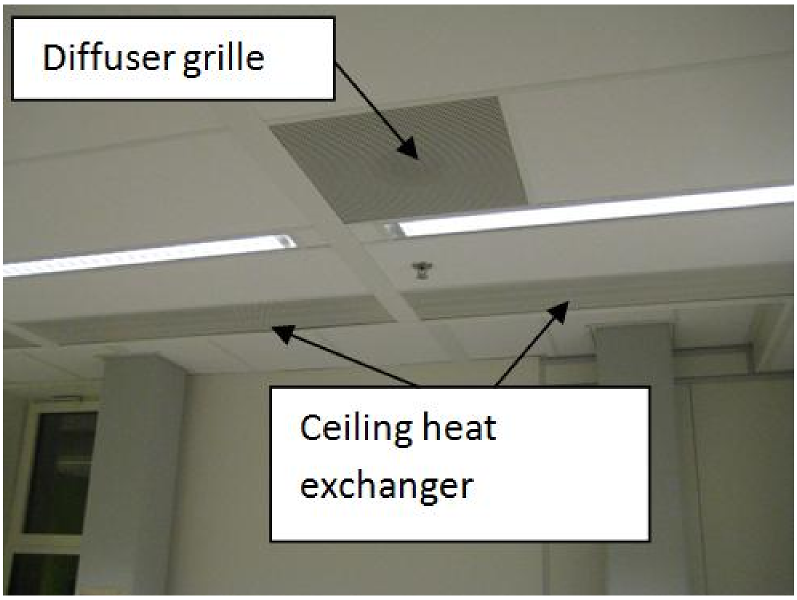
The main source for heating and cooling of the building is a heat exchanger, its thermal energy provided by a ground water source (well/aquifer system). The thermal energy is also partially reused through the heat exchangers of the ventilation system on the roof, where a recovery unit operates between the incoming and outgoing airflows. Therefore, the only energy consumption for heating, cooling and ventilation is created by the heat pump and the fan-power for the ventilation systems, in the form of electricity. However a number of gas-based backup boilers are available and situated on the roof, though these are not part of a bivalent system for everyday operation and only supplied in case of a system failure or very low temperatures in extremely cold winter days to heat up the incoming fresh air. HHS also has photovoltaic and hot water solar panels on the roof for the creation of some renewable electricity and thermal energy towards its total demand. Due to the very high efficiency of these renewable generating technologies, the renewable energy-based HVAC systems, the high performance glazing used, the large internal heat gain from electric devices (computers, printers, etc.) and the occupant heat gain from the high density of building users, the building uses, on average per year, 10 times less gas for heating than its predecessor building did.

Heating and cooling is provided via under-floor heating. The pipes carry the pumped water from the heat exchanger of the heat pump beneath the floors. The heat pump can deliver heated and cooled water simultaneously, in circumstances where some areas of the building require heating (at the end of the heating season), while other areas like computer rooms, workshops or highly occupied class rooms with high internal gains might require cooling. Valves regulate the water flow; however, 4 rooms are grouped to an area controlled by a group of valves. Therefore, it is not possible to adjust the floor heating/cooling individually per room but via a set of 4 rooms. For this reason similar building uses have been assigned to a group of rooms, to avoid conflicting requirements in terms of heating and cooling controlled by the same valves.

In practice, heating and cooling is via a partial radiant and partial convective system when required. Supplementary heating or cooling is available over that provided via the floor/ceiling mounted radiant system of each room. Each room's ventilation system has a heat exchanger (with its own valve) for the hot/cold water supply from the heat pump (I.e. the same pipes used to heat the floor above). When additional heating/cooling is required, air is absorbed through the ceiling and passes combined with fresh air to the heat exchanger. However, this system is only intended to supplement heating or cooling, or where the floor heating/cooling has been stopped due to no demand in the neighbouring rooms in its 4 room heating/cooling group, to provide heating or cooling for that specific room..

The image of the room below shows the ceiling mounted heat exchange units and the air supply grille The HVAC system's ventilation ducts are also placed beneath the ceiling, pumping fresh air into the rooms. The ventilation level is determined by the CO_2 level in each room. The walls to the inner corridors and/or to the atrium possess a very fine grid of grille openings through which the air from the room is exhausted due to a slight overpressure. This also requires that a fixed amount of fresh air is also introduced into the corridors and the atrium, as these have no CO_2 sensors. The stale air is then expelled at the roof level in the atrium where it enters the heat exchanger before being extracted to the outside. Despite the heat recovery, a varying portion of the building's heated or cooled air will be exhausted to prevent the mixing of stale air with the fresh incoming air, however this amount is dependent upon the CO_2 level of the exhaust air. In practice, the building has operated in a full fresh air mode due to much higher than expected CO_2 level of the exhaust air created by the 1,000+ building users during peak hours.

Internal View of HHS Room HVAC Systems



The atrium allows the possibility of natural ventilation as well as being the stack effect extract source for the forced ventilation system in the case of very high temperatures in summer time - hot air in the atrium's can be removed, again by the stack effect, by automatically opening roof windows. However, this natural ventilation potential is not used typically such as for night purge ventilation. The rooms analysed under the Knoholem project are not atrium adjacent and therefore this additional natural ventilation has not been required to be simulated. Also, some windows within each of the rooms can be manually opened, in this instance window frames sensors can determine this and provide an interrupt to the mechanical ventilation and heating/cooling. Although the building management system identifies an opened window, it cannot ensure its automatic closing, however can generate a malfunction report to ensure that the Facilities management can close the window (as, in its opened state, the now opened window will influence the temperature in the neighbouring 3 rooms due to their common floor heating/cooling system). As room based natural ventilation is an exception rather than a desired servicing method, the simulation in Designbuilder did not model this functionality and therefore the rooms operate as intended i.e. a sealed room that is mechanically ventilated and heated or cooled.

Illumination levels in the office and classroom areas are controlled by presence and light intensity level (lux) sensors. Luminaires are installed on the ceiling in two rows, close to the external windows front and close to the full-height, separating glass partition to the corridor/atrium. These rows are separately controlled to allow the switching off of the window adjacent rows when natural day-lighting permits. The presence sensors are able to detect human presence in the room and can be used for further automatic light switching. There are no presence sensors on the corridors and in the atrium, light stays permanently switched on during daytime. The building management system switches the lights on and off, according to a given schedule – however, these additional areas are not within the scope of the studied area and their lighting control can be ignored for the DTM simulation. The images below show the external facades of the Knoholem project areas indicating the amount of fenestration per room and the internal corridor layout.

External Views of HHS – Indicating fenestration Level of Knoholem Project Areas

Internal Views of HHS – Indicating Knoholem Project Areas fully glazed Corridor partitions

Due to the “4 room” basis of the HVAC supply, the mechanically supplied temperature and ventilation rates cannot be changed for each room by its occupants as it would influence the neighbouring 3 areas. The room heating/cooling set-points and ventilation rates are controlled in these groups by Facilities Management via the building’s BMS system to meet the given temperature minimum/maximum and CO_2 level maximum. The building utilises two building management systems, one to control the heat pump, roof ventilation and heat exchange devices, gas boilers, and one to supervise heating/cooling/ventilation and illumination in each room and area. Per room the building has a combination of presence and movement detectors, illumination (lux) meters, humidity meters and CO_2 level meters to aid optimisation of energy demand. However, as previously stated heating, cooling and ventilation are functionally combined and for energy efficient usage HVAC is considered for the entire building and control is via groups of rooms.

The HHS-building’ two independent building management systems, Priva and Octalix, have different control tasks to perform. Priva controls the heat pump (and its thermal storage), the roof-based ventilation system and its heat exchanger, the backup gas boilers and the solar thermal devices, the solar panels and the entire HVAC system on the general functionality level. Octalix controls the HVAC on room and area level, in connection with the temperature, humidity and CO_2 sensors and windows sensors. Depending on these readings and on the facility manager’s pre-sets, heating/cooling and ventilation is determined for each room and area of the building. Octalix also controls the entire illumination system of the building: rooms and areas and roof parking lot with presence and light intensity sensors, as well as the corridors and atrium with their fixed schedules from the facility manager as described earlier. Furthermore, the weather station on the roof of the building is also connected to Octalix. It's meteorological readings aid the relevant temperature pre-sets to be applied in the entire building. Octalix also controls the atrium roof windows opening and closing, depending on the readings of an internal temperature meter, as well as on the weather conditions. Naturally, due to the high level of inter-dependency between room/area HVAC control and the heat pump and roof ventilation/heat exchanger control, a connection exists between the Priva and Octalix systems. Therefore, the level of heat/cold extraction of the heat pump and the level of ventilation and air temperature exchange are strongly connected with the demand of the building (its occupancy and internal gain levels), and with the weather station readings.

Finally, both Priva and Octalix have web interfaces, as well as interfaces to connect other systems to it. This interface is used by statistical software - Monavisa[1]. This software reads all sensor readings and settings from Octalix and uses a set of indicators whose reference values have been calculated over a longer period and compares it with recent or real-time data, so that exceptional situations (energy wasting) in the building as well as malfunctions can be identified. Monavisa provides a remotely-accessible web interface to visualise statistics and live data, as well providing for the long-time data storage through a historic (SQL) database of BMS readings.

3.5.1 Designbuilder Basecase - HHS Building, Section of 1st Floor, The Hague

It is evident from the description above that HHS is a very complicated building to recreate due to its novel control and HVAC systems. However, the Designbuilder model differs greatly from the other Demonstration Objects simulations due to the very small portion of the building used within the Knoholem project. The replication of this small portion of the building is principal reasoning behind the large amount of simplification of the model as compared to the existing building. However, the highly novel HVAC system is also not able to be replicated within Designbuilder (i.e. either is CO_2 control mechanism for ventilation demand or the dual convective and radiant heating and cooling systems). Furthermore, a dearth of information regarding some required inputs meant that further simplifications needed to be made within the model. Therefore, the simulation model is only appropriate for the external facing rooms used within the small, Knoholem area itself – an area far smaller than any of the other case studies within the project. Furthermore, with no information regarding the level of whole building demand catered for by the solar water heating and PV system, this also cannot be replicated and a portion of this renewable energy creation applied pro-rata to the small area studied within the project.

The Knoholem project only takes into consideration 9 individual rooms on the First Floor for of the building. A slightly larger area than this has been modelled to decrease the number of adiabatic adjacencies. However, in essence the project is delimited to only Room 1.067 through to Room 1.078, the stairwells and corridor areas also not being considered for optimisation within the project. However, no CAD plans over and above the basic floor layout were available for the building therefore a Sketchup .skp model had to be used for the recreation of the building in 3d format within Designbuilder. Unfortunately, the Sketchup model, whilst being able to provide room floor to floor heights and fenestration details, was only for the extent of the Knoholem areas themselves and gave no information regarding the adjacencies to the further areas of the building. It was therefore impossible to accurately determine what building conditions lay beyond the westerly rooms and thus all of these rooms (1.062/1.064/1.072/1.074) had to be constructed

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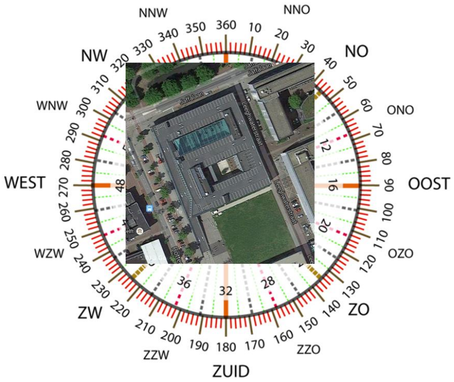
with the assumption of adiabatic conditions through their “external” walls. In addition, with no information regarding the extended building available both the floor and ceiling elements of the entire section modelled had to be defined as adiabatic. The latter condition applied should not be an issue, however, as the First Floor of the building is under consideration, therefore almost identical temperature regimes would be expected for the classrooms and offices both above and below the rooms simulated on the First Floor. The image below shows a simplified layout of the areas considered under the Knoholem project.

Rooms on 1st Floor HHS considered for Knoholem Project

Although many adiabatic surfaces were required to recreate the small portion of the HHS building as per previous Designbuilder geometries a dummy 1st floor was required to correctly set the height of the 1st floor studied from ground level so that direct solar gain was correctly calculated top each room. Building latitude and longitude was easily gained however no Northing of the building was available due to the lack of CAD plans provided for the building. In its place, HHS provided Google earth images of the building with the correct orientation overlaid to overcome this problem. The image below shows the plan image of the HHS building with the orientation overlaid as informed the thermal model.

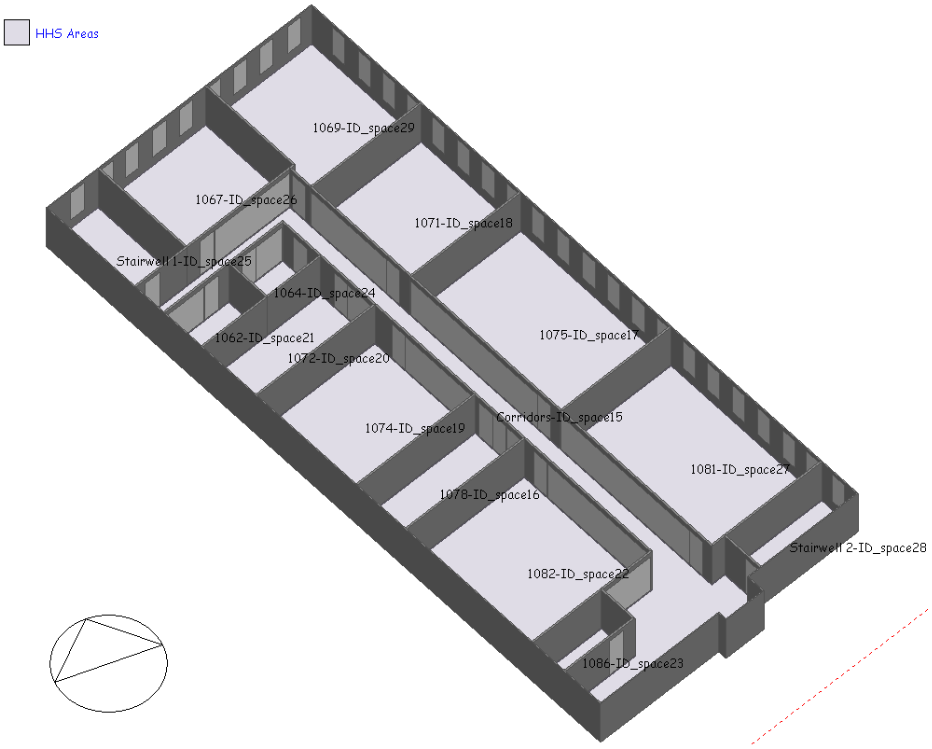
Orientation of HHS in Relation to True North



Due to the inherent simplification of the model and the small area under consideration no further alterations to the 3d geometry were required. The simplification process and the use of multiple adiabatic boundaries meant that only the 2 main construction materials were required i.e. external walls and windows plus the including partitions (glazed) and including their internal doors. No distinct make-up was available for each construction given layer by layer, however the general construction details were known as well as the overall U value from the building's EPC certification material. Therefore construction materials could be created and applied to the building with the correct thermal properties e.g. walls of 0.24 W/m^2 K and glazing of 1.7 W/m^2 K (with a solar gain G value of 0.25). As previously stated, each room was able to be provided with a zone and no aggregation of rooms was allowed combining rooms given the small portion of the building studied.

As well as the construction details, the EPC materials also provided the set infiltration rate for the building from the pressure test of the building post construction. Internal shading screens are also available on each internal window and were also included in the model. However, as these are manually controlled by occupants and no information was provided about their operation a general operation pattern was set to only allow their use for glare control and for internal temperatures exceeding the set cooling point should set cooling provision be insufficient. The final Designbuilder floor-plan indicating its zoning is shown in the image below.

Designbuilder 3d geometry; Zoning of 1st Floor Rooms used within Knoholem Project



Further simplification was required for the use of heating and cooling efficiency in the building. Whilst the set-points given could be set in the model for control purposes (e.g. 22°C) the use of a dual convective (via the air supply) and radiant services (via heated or chilled ceilings) could not be replicated in the DTM model. The set ventilation allowance is provided (10 l/s/p) with its inherent chilled or cooled air as well as a radiant cooling or heating allowance that is given its maximum potential duty. Due to the novel HVAC system the individual efficiency of each system cannot be supplied, however HHS were able to provide Coefficients of Performance (CoPs) for both heating and cooling in the building calculated from existing demand and energy consumption readings – i.e. 1.50 for heating and 3.37 for cooling along with the ventilation system's heat recovery potential (70%). In this way the heat/cool demand should match the energy consumption across the year though it is not possible to match the portion of that demand which is met by either the radiant or convective system alone.

Similarly, though the mechanical ventilation rate is known, 10 l/s/p, and the approximate occupancy rate and schedule has been given - the numbers of occupants changes per room but on a set weekday schedule – the actual control mechanism is via CO_2 levels. This is not possible to be replicated per se, as although occupants may be present given the low enough CO_2 levels fresh air not be required and simple recirculation may occur. In the model the given mechanical ventilation rate will only occur during scheduled hours (as per the building) and will be set pro-rata for each person at the 10 l/s/p level, occupancy set at a persons per square metre rate. A further reduction in the ventilation rate was allowed as HHS were able to provide an average percentage occupancy per room over and above its set maximum occupancy rate. This work-around will come as close to minimising ventilation as possible although does not strictly mimic the carbon dioxide control system (although CO_2 threshold levels that govern this ventilation rate were also not supplied were it able to be replicated).

As described above the occupancy schedule was given for the rooms studied (08:00-18:00 weekdays), a maximum occupancy rate was given for each room but also a typical occupancy percentage. In this way the internal gains from occupancy could be realistically applied to each zone. Further information regarding the other internal gains from lighting and equipment use was also provided on a room by room basis. These additional sources of incidental gain were then applied on the same occupancy schedule across the working week. Samples of this data supplied by HHS are shown in the tables below.

Room Numbers and Average Occupancy rates (as a percentage)

1.062	1.064	1.067	1.069	1.070
Spreekkamer	Spreekkamer	Kantoor	Kantoor	Verkeersruimte
Gemiddelde bezettingsgraad	Gemiddelde bezettingsgraad	Gemiddelde bezettingsgraad	Gemiddelde bezettingsgraad	Gemiddelde bezettingsgraad
47,5%	45,8%	48,7%	45,6%	-
1.071	1.072	1.074	1.075	1.078
Kantoor	Kantoor	Kantoor	Werkcollegezaal	Kantoor
Gemiddelde bezettingsgraad	Gemiddelde bezettingsgraad	Gemiddelde bezettingsgraad	Gemiddelde bezettingsgraad	Gemiddelde bezettingsgraad
47,8%	66,7%	47,2%	33,9%	70,0%

Internal gain, occupancy rates and power use per m^2 per room

Lokaal	Functie	Lichtbakken	Max. personen	Aantal vaste apparaten			% laptop p.p.	Totale warmte-afgifte personen [W]	Totale warmte-afgifte licht [W]	Totale warmte-afgifte apparaten [W]	Aantal m2 vloeropp.	W/m2 personen	W/m2 Licht	W/m2 Apparaten
				pc's	Beamer	Beeldscherm								
1.062	Spreekkamer	1,0	4	0	0	0	50%	400,0	30,0	120,0	9,9	40,6	3,0	12,2
1.064	Spreekkamer	1,0	4	0	0	0	50%	400,0	30,0	120,0	9,9	40,6	3,0	12,2
1.067	Kantoor	6,0	5	5	0	5	0%	500,0	180,0	700,0	46,1	10,9	3,9	15,2
1.069	Kantoor	7,0	6	6	0	6	0%	600,0	210,0	840,0	52,0	11,5	4,0	16,1
1.070	Verkeersruimte	12,5	20	0	0	0	0%	2000,0	375,0	0,0	121,8	16,4	3,1	0,0
1.071	Kantoor	8,0	6	6	0	6	0%	600,0	240,0	840,0	51,8	11,6	4,6	16,2
1.072	Kantoor	4,0	1	1	0	1	0%	100,0	120,0	140,0	29,2	3,4	4,1	4,8
1.074	Kantoor	8,0	6	6	0	6	0%	600,0	240,0	840,0	52,6	11,4	4,6	16,0
1.075	Collegezaal	8,0	41	1	1	1	33%	4100,0	240,0	1251,8	73,1	56,1	3,3	17,1
1.078	Kantoor	12,0	1	1	0	1	0%	100,0	360,0	140,0	73,1	1,4	4,9	1,9

The table above shows that each room can also be allowed a specific lighting allowance for artificial lighting as well as that for small power (equipment use). However, further breakdowns of electrical power for the HVAC system cannot be achieved i.e. for fans and pumps, however this should be included in the aggregated CoPs provided by HSS described above. The final minor simplification is the removal of any natural ventilation use as previously described. Due to the ad hoc nature of the natural ventilation system (i.e. it is unscheduled and on manual control by the room occupant as he/she opens a window) this cannot be applied as a mixed mode system despite window opening turning off mechanical ventilation in a roof. This is due to additional natural ventilation being an exception rather than planned servicing of the building and the notification system of the BMS allowing quick though not automatic re-closing of any opened window. Naturally, details of the duration and amount of window opening could not be supplied due to the minor usage of natural ventilation as an exception. Therefore, given the lack of any set schedule for this natural ventilation to operate, this means that it cannot be added in addition to the mechanical ventilation system and has been ignored in the model. As the rooms modelled are set to perform as fully sealed and mechanically ventilated zones this is likely to provide a more accurate energy simulation prediction than any “guesstimate” of ad hoc window opening across the year.

As per all prior Demonstration Objects the full annual Basecase energy consumption prediction was simulated for the 9 offices to be studied within the Designbuilder model and the output file also saved for comparison purposes only as an Energyplus file (.eso). However, despite the low number of zones in the HHS model and no grouping or rezoning of the HHS rooms being required in the Energyplus model, the adiabatic external wall rooms on the western façade were to be omitted for the re-simulation work. The EnergyPlus .idf export that is the main product of the D5.3/5.4 works was made available to allow multiple re-simulation by Cardiff University, however a decision was made to ignore the rooms without a simulated external wall heat transfer as their occupancy rate, servicing and end use was identical to the remaining rooms in the “zone per room” Designbuilder model. The finalised extent of zones studied in the Energyplus model has been left to the discretion of Cardiff University, however based on the criteria above, redundant zones that generate little more to the optimisation rules and simulation time can be reduced in the multiple Energyplus simulations.

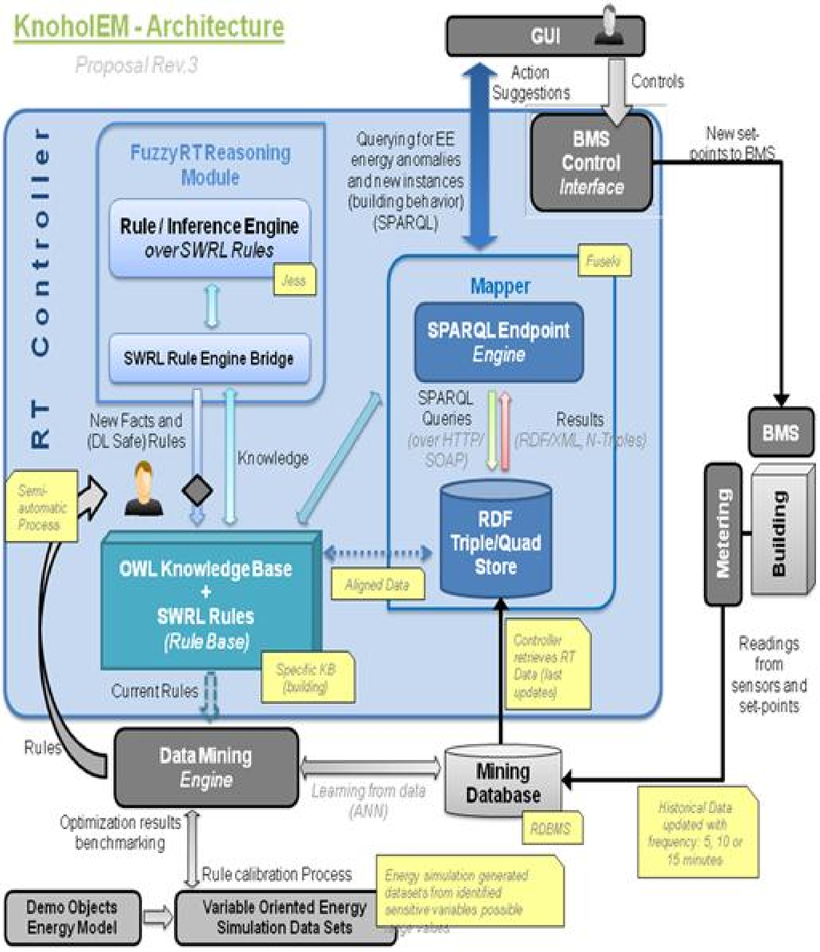
4 Project Methodology and Future Works

4.1 BEM applied to Project Methodology: Energyplus and ANN training

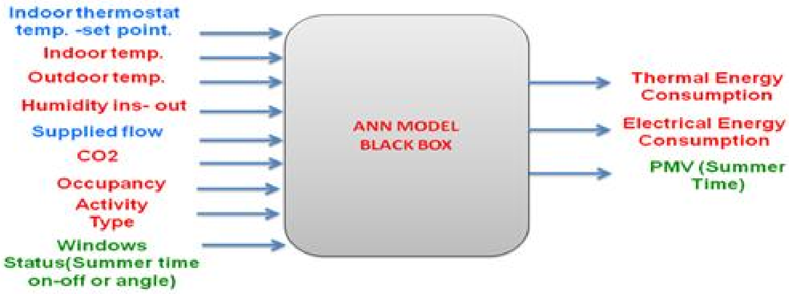
The requirement to create a BEM was predicated on the renewed Knoholem methodology from June 2013. This required the existing Basecase DTM models to be the basis of subsequent analyses (and therefore also shifted the DTM modelling to a lower order of commercial code Designbuilder). The move to the alternate methodology and its impact on the WP5 modelling is briefly described below and the renewed system Architecture shown diagramatically.

A pre-requisite for a successful KnoholEM solution is the understanding in each building of the variables that are sensitive to energy consumption. This is strongly related to the building envelop and fabric, the external and internal environment, occupancy patterns, efficiency of the energy generation and consumption equipment as well as a wide range of building specific parameters therefore this is best achieved by an energy simulation model, in this instance via Dynamic Thermal Modelling. The renewed methodology stated that:

"In that respect, WP5 should provide: (a) the scope of the data used for the data mining (rule-generation) activity. Ideally, all sensitive variables should be captured in the data mining database.(b) a reliable basis for energy saving rules generation.(c) baseline figures for rule calibration through a benchmarking exercise against simulation data."



The renewed methodology means that two work packages will now deliver the building specific ontology or "knowledge base" that embeds building specific energy saving rules and provides real time energy consumption accounts. Rules are generated from the data mining process from real time sensor information and simulated data from analysis of the modelled building. These rules will not be automatically triggered when they meet specified conditions to alert about anomalies but via a suggestion through an automated dialogue with the Facilities Manager (created in WP4) for energy saving plans. The data mining exercise should help understand how a number of sensitive input variables impact on other output variables. The diagram below illustrates this using an Artificial Neural network (ANN) “Blackbox”: The ANN Blackbox will be trained using multiple simulation runs in Energyplus, the initial model data coming from the Designbuilder “Basecase” model. (WP5).



Briefly, in terms of the overall system architecture, the Energyplus modelling will iteratively model variable inter-dependencies and from this the energy saving rules can be easily derived. Thus in the Architecture diagram above the Demo Objects Energy Model (DesignBuilder) provides the initial “Basecase” BEM as an Energyplus input file (.idf). Energyplus is run iteratively, for many designated energy saving scenarios, one variable at a time (such as heating set-point) and data is produced per simulation run i.e. the Variable Orientated Energy Simulation Data Sets. These data sets will provide the Rule Calibration process as the combined single variable orientated simulations are holistically analysed together to provide the optimum running conditions of the building. In this way the energy savings rules that seek to optimise all inter-linked but variable functions (e.g. cooling set-points, window blind use and ventilation rates) are “trained” via simulation to the way the building operates even before the launch of the Knoholem system. These rules are then refined in use by building sensor data providing feedback to the data-mining database, ensuring the continued improvement and evolution of the energy saving rules by the Knoholem system – in so doing aiming to achieve the simple aim of the project i.e. to reduce energy consumption in the public buildings by up to 30% per annum.

4.2 Future Improvements

The Project was structured assuming BIM (Building Information Modelling) models of each Demonstration Object would be available providing a vast quantity of required information on each building in a set schema such as IFC (Industry Foundation Classes). The initial hope for buildings providing such IFC compliant building data with inherent 3d geometry information and thermal characteristics of construction materials has not proven true for any building within the study. Naturally, gathering the data and replicating this information in other BEM such as a DTM has a large time penalty added to it. However, given the successful data collection in the main for the case study buildings, providing sufficient detail to complete a full BEM for the studied areas, an initial, working model of each Demonstration Object could be completed. However, in future scenarios where full IFC models of buildings exist much of this data will be held in that file system and the creation of a DTM may be foregone.

Given the complexity and scale of inputs required for a DTM to be performed, it is likely that some elements used as DTM inputs may not be contained within the building's BIM in its IFC schema, such as distinct heating and cooling set-points. However, it is likely that these elements are exactly the same metrics that would be altered during the Variable Orientated Energy Simulations to create the required data sets as discussed above. The vast majority of data regarding the building, its U-values, wall dimensions, occupancy level, heating system capacity and efficiency etc will be contained within the IFC data in the BIM model and therefore can be leveraged from it without the need to construct an initial thermal model. Therefore, in future cases where multiple simulations are required for optimisation rule calibration an automated system could be applied leveraging the required inputs directly from the BIM of each building. Here the simulation (in Energyplus or another system) would only have a user interaction as the input variable required to generate each data set is applied – for example, allowing the building to run iteratively between heating set-points of 16 to 24C°.

Whilst BIM may be beneficial in aiding or replacing the use of DTM for future iterations of the Knoholem system, the current DTM Basecase could be improved by the occupancy data gained via WP 3's online occupancy profile created by TCD. Whilst as accurate as possible an indication of occupant numbers per room and their occupation schedule has been provided for each building by the Consortium partners, the web based system developed by TCD would allow staff themselves to fill in their actual occupation times. Given sufficient respondent numbers to this web format and its application over a suitable duration of time, far more accurate schedules and occupant numbers could be provided to the DTM basecase. The inherent simulation technique would still require the creation of artificial working day and working week schedules in the model, however these input schedules could be applied per room for the most accurate, yet typical, assessment of occupant occupation patterns and durations available. Unfortunately, the works to create these occupant profiles and the required web based graphical user interface in multiple languages was concurrent with the works to create the DTM of each building in Tasks 5.3 and 5.4 and their inclusion was not possible. Furthermore, current low respondent rates to the occupancy profiles for the 5 Demonstration Objects would have provided little additional data to create the room specific occupancy schedules in Designbuilder – however, for future application these could easily be added into the Basecase simulation (should the occupancy data exist) swapping out the current occupancy profiles currently used and described in detail in Section 3 for each building, with all other input parameters remaining the same.

4.3 DTM prediction against Future Monitored Energy Consumption

The first issue, as with comparisons against the historic, "as is" energy consumption of the building is the dearth of sub-metering in some buildings as discussed earlier. Therefore, whilst room by room heating, lighting, cooling demand may be gained for the most modern and innovative of the buildings, such as HHS, this may be not be available in the remaining buildings as the metering does not provide for this granularity of data. As has occurred in the Forum building, in these instances further sub-metering and stand-alone data-logging could be added to increase the quality of this data. Again this is most easily achieved on direct electricity consumption, such as via the Plugwise system, actively sub-metering or otherwise discerning room/zone based heating, cooling or ventilation may be harder to achieve and a requirement to pro rata down from a larger area may be required.

The second issue affecting comparisons of future, optimised energy use versus predicted data from simulations is that there will need to be a quantitative assessment of Facilities Management (FM) or others' optimisation actions taken. The current project methodology means that whilst energy optimisation advice/techniques can be placed in front of FMs enabled via the visualisation tool created within the project there is no assurance that these control changes will take place. The energy optimisation could therefore be implemented in full, in part or not at all and it is exactly this control regime information that would need to be quantified if it is to be contrasted against the simulated data. Where this information is implemented in part, such as heating set back temperatures only being changed in certain rooms or for a less frequent period than the DTM simulation, the predicted data can be normalised/used pro rata for more accurate comparison or even re-simulated with the real, “FM control regime”.

5 Conclusions and Project Enhancements

As described in Section 3, in detail for each Demonstration Object, the initial Basecase has been completed using Designbuilder dynamic thermal modelling software, this process providing an initial simulation of building energy use in its ,eso output but also an input for import to Energyplus software. Whilst the Basecase energy prediction is important and can be compared to the monitored level of energy use in the building its primary purpose was to follow the revised Knoholem project methodology and provide an Energyplus .idf input file to allow multiple, variable orientated re-simulation of the same building by the project partner Cardiff University. With the BEM set up and ready for multiple, iterative re-simulation, the energy optimisation procedures identified as suitable for each building within the project can be identified. This modelling providing a parallel approach to the optimisation rules generated primarily through the building specific data mining from the set sensor network in place.

The Knoholem project has made an attempt to tie this Basecase energy model into the behavioural characteristics of the building and make allowances for user influence, however currently this is still at the level of standard thermal modelling practice as the typical occupant schedule and occupant numbers per zone/room are entered into the model. However, work was also initiated within the Knoholem project to simulate user defined occupancy profiles within the Demonstration Objects via altered inputs derived from occupancy profiles created by respondents within the building via a web based format. To gauge these occupancy changes, the current schedules could be replaced by the web based scheduling tool which has been created by TCD. In turn, these DTM scenario results can feed back into the visualisation display of the building created by TCD also (within Work Package 2). However, due to the concurrent work of the web based occupancy tool and the DTM Basecase of each building, plus a sufficiently poor respondent rate for each building, the Basecase model of the building has been set with the more standard input patterns (work day schedule and room maximum rate of occupancy) for each DO, however due to the small size of the HHS model some attempt has been made to simulate typical occupancy rates as a percentage of total rather than the room maximum occupation rate.

Given the repeatability of the Energyplus DTM system, multiple simulation and re-simulation of these scenarios is a far quicker process than the initial process of building a usable and accurate computer model (in TAS, Designbuilder or other software) which requires a large degree of data gathering, 3d model creation and model population with thermal characteristics, occupancy profiles, internal gains etc. The large time penalty involved in the creation of the original DTM of the building in whatever software format and its 3d geometry, due in great part to the input data gathering process rather than the modelling per se should be removed in future generations of the Knoholem system where this data can be leveraged directly from the BIM model of the building. However, to this point this has not been possible as not one of the 5 Demonstration Objects chosen for the project had any BIM compliant information or even a 3d geometry in a suitable format that could simply imported into the simulation software used.

Whilst the DTM energy consumption predictions will show a maximum potential saving given the energy optimisation technique simulated of greater influence will be the effect of the Facilities Manager or other user group that is in control of this energy optimisation. The Knoholem project does not create an automatic control system to optimise energy consumption within the building, instead highlighting these savings to the FM for action (or not). Therefore, without the key information of the actions taken by the FM in applying the possible optimisation approaches, it would not be possible to normalise the metered energy use for comparison against the maximum potential displayed by the re-simulated models. Therefore to correctly compare the energy savings predicted by the Energyplus simulations a methodology must also be established to collect this “FM Activity/Interactions” information.

Appendix A : Required Information for DTM of Demonstration Object

PROJECT INFORMATION : Demonstration Object Thermal Model Requirements.

3D Model Geometry

Please provide scale drawings in Autocad DWG format including:

Plans of every floor to be included in the simulation	Including roof and basement if present
Sections giving floor to floor heights	For all internal height variations
Elevations showing makeup of building facades	For each viewpoint/orientation of the building
Colour Coded Plans indicating servicing method for each space (i.e. full air conditioning, mech. or natural ventilation)	i.e. marked up .pdf or other sections showing extent of HVAC system where multiple systems occur in the building.
Site Layout with Indication of North direction	On dwg or .pdf
Schedules for window/louvre opening & Openable proportion of window	Plans indicating number of opening windows if natural ventilation used Indication of opening restrictions on any windows if natural ventilation used
Dimensions and position of external shading devices (if present)	Are external overhangs/other brise soleil shown on elevations where present. Elevation drawings need to show these in place and an unobstructed view of façade behind them.

Building Services Information Please provide the following information:

Servicing Type Present (Natural ventilation, Mech. ventilation, AC or combination)	See Internal Conditions Sheet Attached. .
Servicing Method (heating system method and cooling system method if applicable)	See Internal Conditions Sheet Attached.
Heating Setpoint	See Internal Conditions Sheet Attached. (if applicable)
Cooling Setpoint	See Internal Conditions Sheet Attached. (if applicable)
Air movement:	See Internal Conditions Sheet Attached.

Mechanical ventilation supply rate	(Supply and Extract Rates required)
Internal conditions: Occupant, lighting and small power loads per m^2.	See Internal Conditions Sheet Attached. 1 sheet will need to be filled in for each change of room use or load e.g. general office, meeting room, entrance area etc.
Building element details Please provide for each construction type Material types Material thicknesses Required construction performance (U value, g value etc)	Please See attached Construction Materials and Glazing Sheet 1 sheet will need to be filled in for each variation of wall, window or external door.

Details of Building:

1	**Opaque Fabric details**:(or refer section drawing of the building giving detailed information about external walls, internal walls, roof, ground and intermediate floors - the insulation type, thickness,heights etc	For example: *External wall based on* *100mm Block* *50mm Celotex Insulation* *50mm air cav* *100mm Brickwork* *dense plaster finish*
1a	U-value if known	Where the above detail is not known
2	***Main External door types and construction details***	*Fully or partly glazed.* *U Value for the main external door*
3	***Glazing and Frame detail:***	**For example** *Velfac 6/14/4 Glazing =* *Velfac Sun1 6mm low emissivity glass* *14mm Argon filled Cavity* 4mm Clear Velfac glass *Frame to glazing ratio if not shown in detail on drawings.*
3a	***Glazing U value/G value/Light Transmission Value***	Light transmission and thermal performance of glazing if detailed construction information from “3” above is not available.

Zone	<u>XXXXXXXXXXXXXXXXX</u>

Internal Gain

Gain/Ventilation rate	Unit	Value	Hours of Operation	Notes
Infiltration rate	Air changes per hour		Constant	If unknown, a default rate can be used (e.g. at 10m3/m2/hr @50 pa where a pressure test was done)
Mechanical Ventilation	Air changes per hour or Litres/second			Naturally ventilated spaces will be calculated within the thermal model
Lighting Gain	W/m2			Lighting load for areas to be modelled or full lighting plans showing luminaire numbers and their rating (in watts)
Occupancy sensible gain	W/m2			Or simply numbers of occupants per room if unknown. A default value for office workers will be used
Occupancy Latent gain	W/m2			Split 2/3:1/3 Sensible to Latent heat gain if figure unknown and the simple occupancy rate is used
Equipment sensible gain	W/m2			A default value for offices can be used where the equipment load is not known

Cooling Emitter Type	Notes
	e.g. chilled beam, vrf/vrv, fan-coil, none

Heating Emitter	Notes
	e.g. LTHW radiators, under floor heating, radiant panel

Thermostat

Set-point	Unit	Value	Typical Hours of Operation (Schedule)	Notes
Cooling Set-point Upper Limit	°C			No upper limit where no cooling exists
Heating Set-point Lower limit	°C			Minimum heating set-point.
Humidity Upper Limit	%			If present
Humidity Lower Limit	%			If present