Building Simulation 2003

Eighth International IBPSA Conference
Eindhoven, Netherlands
August 11-14, 2003

INTEGRATED RESOURCE FLOW MODELLING OF URBAN NEIGHBOURHOODS: PROJECT SUNTOOL

D Robinson[1], S Stankovic[1], N Morel[2], F Deque[3],M Rylatt[4], K Kabele[5], E Manolakaki[6], J Nieminen[7]

[1]BDSP Partnership, Summit House, 27 Sale Place, London W2 1YR, UK (co-ordinators)
[2]LESO-PB, Ecole polytechnic Federale de Lausanne, Lausanne, 1015, Switzerland
[3]Departement Seve, Electricite de France R&D, 77 818 Moret-sur-Loing, France
[4]Inst. Energy and Sustainable Development, De Montfort University, Leicester, LE7 9SU, UK
[5]Faculty of Civil Engineering, Czech Technical University, Zikova 4, 166036, Prague 6
[6]IDEC S.A., 96 Iroon Polytechniou Str., 185 36, Piraeus, Athens, Greece
[7]VTT Building and Transport, PO Box 1800, Lampomiehenkuja, 02044 VTT, Espoo, Finland

ABSTRACT

Environmental masterplanning is an increasingly vibrant area of research and development activity. Design tools to support environmental masterplanning can be loosely categorised as simulating (i) microclimate, (ii) resource availability, and (iii) resource flows. Much progress has been made in respect of (i) and (ii) but the latter category – simulating resource flows within the urban neighbourhood – is at an embryonic stage. There is also a dearth of guidance for designing and managing sustainable urban neighbourhoods. This paper describes a new EC funded research project that was conceived to fill this important niche: Project SUNtool.

INTRODUCTION

At the scale of the urban neighbourhood district co-generation becomes economically viable, renewable energy technologies are more economically attractive and it is possible to optimise their utilisation natural resources (e.g. solar radiation and daylight) and to create a pleasant external microclimate. Rainwater collection also becomes viable, as does the possibility of deriving energy from waste products. In essence, sustainable urban neighbourhoods are within our grasp. Consequently, developers, municipalities and research and development funding bodies are increasingly turning their attention to sustainability considerations at the scale of the urban community. However, for this sustainable urban neighbourhood potential to be realised (i.e., to optimise the mix of building uses, their layout, the mix of sustainability technologies etc) requires a new generation of design tool that simulates the associated resource flows (energy, water, waste) in an integrated way. Project SUNtool (*S*ustainable *U*rban *N*eighbourhood modelling *tool*) is a new EC funded research project that was conceived to fill this important niche.

To be of use at the conceptual stage of the masterplanning process this tool should be rapid and intuitive to use, offering comprehensive information in a non-technical way regarding resource use, emissions, costs etc to support optimisation of the site layout, mix of uses, range of sustainable technologies etc. – all the while shielding the user from the associated modelling complexity. It is this integrated resource flow modelling in an urban-sensitive way whilst shielding the user from the associated complexity that is the real challenge for Project SUNtool. This paper describes our approach to this challenge and how we aim to help overcome related socio-technical barriers to more widespread adoption of sustainability principles at the community scale.

MODEL SCOPE AND STRUCTURE

Ignoring for the present time industrial processes and transportation, a given urban neighbourhood would consume resources to operate buildings and perform the activities that they support. This would also lead to the production of waste water, human waste and refuse. These processes define what we might loosely term a consumption domain and this is integrated with a production domain, to supply energy and water, possibly using some of the by-products of the consumption domain.

The consumption domain has at its core a transient heat flow solver (Figure 1). By dynamically resolving heat flow within the building and between the building and the ambient environment, loads for heating and cooling (sensible and latent) are defined.

Now, urban neighbourhoods are comprised of multiple buildings that inherently view a sky of anisotropic radiance distribution. These buildings also shade one another (from diffuse as well as direct radiation) to varying degrees. The urban fabric also has a relatively low solar albedo and longwave radiation exchange is relatively inhibited. Local air temperature is correspondingly different from that measured at a nearby meteorological station and this temperature difference may be exacerbated by heat island warming/cooling. Properties of local wind also vary and this too has an impact on local temperatures as do anthropogenic gains and variations in vegetation (which also affects local humidity). These climatic differences alter the thermal loads acting on urban buildings and so it is important that our resource flow modelling tool is sensitive to this urban context. For this reason *microclimate* is defined as a separate family of model. On a related note, interior daylighting is sensitive both to the urban context and to the varying luminance distribution of the sky, so that *daylight* is also identified as a separate class of model.

The production and consumption of resources within an urban neighbourhood is strongly influenced by occupant behaviour. It is also the source of greatest uncertainty in current building simulation programs. To resolve this uncertainty a new generation of stochastic models is required. For conventional simulation programs these need only consider processes which impact a building's heat balance (and incidentally its electrical power use). In relation to urban resource flows, these need also to consider water use and refuse and human waste production.

Developing a suite of *stochastic* models that could be reliably employed to analyse individual buildings (and the range of common building types) would be the subject of a large scale project in its own right. The purpose of this aspect of SUNtool is then to develop a first approximation of these models which predicts behaviour reasonable reliably at the community scale. This will lead to predictions of casual heat gains and any associated electrical power loads, water (differentiating between hot and cold) and waste (human/refuse) production which if aggregated produce reasonable means and variances (compared to say a repeated casual gain profile).

Outputs from these models (which will be developed in a form that is amenable for later refinement) will be integrated with the transient heat flow solver and either directly or indirectly with post-processing routines to collate the resultant resource flows. The lighting model will take as input the results from the daylight model to define light switching due to timer and photoresponsive controls as well as occupant interaction.

Once reliable heating and cooling loads have been defined it is necessary to translate these into energy consumption, by considering equipment efficiencies and heating/cooling medium transport power use. It is presently envisaged that a very simplified approach would be adopted, based upon empirical evidence. For example, by collecting combustion efficiencies for different boilers, CoPs for different chillers and specific fan powers for different fan types. Some simplified models may be developed to handle low energy heating and cooling plant. For example, using ground source heat pumps or absorption chillers. These energy consumptions together with those defined by the occupancy models will define the total energy delivered profile (inherently split by use). The remaining aspects of the consumption domain (e.g. waste) are produced by the occupancy-related models implicitly.

The production domain will consist of a series of sub-models which predict thermal and electrical energy generation and rainwater collection, in certain instances with feedback from the consumption domain. For example, in relation to microclimate, rain and waste water recycling and energy from waste. Models of the following are planned:

- Photovoltaics, wind turbines and fuel cells for electrical power production.
- Solar water heaters for embedded hot water production.
- Rainwater collection and grey water recycling (incl. associated electrical power consumption).
- Combined heat and power plant, including energy from waste.

The guiding principal for the development of the integrated solver will be that its composite models are *appropriately complex*. We do not want models that are excessively onerous – computationally or in input terms. By the same token they need to produce sufficiently accurate simulations. This will be the key test that will be applied during the initial review stages of the project when the technical specifications for each family of model are defined.

USER INTERFACE

As noted above, it is crucial to the success of this project that the user interface is easy and intuitive to use, that the user is shielded from the underlying numerical complexity and that the solvers results are presented in a readily accessible way. Following from this rationale, a significant proportion of the software development effort will focus upon composing geometric descriptions quickly, automating routine attribution tasks and defining accessible results presentation formats.

On embarking on a new project the user will be invited to identify the region of the country within which the site is located to select the climate file. Following from this, the user will have the flexibility to define and analyse the problem according to their own preferred route through the software. For simplicity we describe the interface by way of a sequential problem definition and analysis process.

In the first instance, a geometric description of the site will be developed using a simple 3D sketching tool (e.g. vertical extrusion of a 2D polyline). The user will then be invited to define the type of activity that the building supports (e.g. from the principal categories office, residential, school, or *obstruction*; and sub-categories such as low internal heat gain, low internal illuminance datum). These descriptors will then be used to access appropriate default values (iDefaults) from the database relating to fabric constructions, occupancy profiles, internal equipment and lighting gains, the façade glazing ratios (given the site's global coordinates) and building services. A series of rules will then be employed to zone the building. At its most basic level this will follow the rationale of the simplified design tool the LT Method (Baker and Steemers, 2000): splitting the floor plate into non-passive and orientation-specific passive zones. At a more complex level, rules will be employed to zone for environmental control. A further tier of spatial sub-division will relate to mixed uses, again via a series of rules (based upon a more detailed definition of the building's activity via the GUI).

The user may also intervene, at this point or later, to more accurately attribute the building and indeed to add new entries to the attribution database for example relating to fabric construction (a facility will also be introduced to import climate files).

With the basic building attribution complete, the user may then proceed to define particular resource production and management characteristics. This will be achieved by associating icons within the resource management toolbar either with particular buildings or the site. In the latter case for example, this may automatically create links between central co-generation plant and each building. In the former case PV panels may be associated with particular building surfaces (facades or roof).

With the input process complete the user may then proceed to invoke the solver. By default the software will produce a single solution for the basic description that is parsed to the project database. However, it is planned to develop a parametric engine. This will simply be a mechanism for choosing a variable to parameterise, the lower and upper bounds and the increments by which the parameter will be varied. This could be relatively straightforward in the cases of percentage internal heat gains and façade thermal transmittance or more complex in the case say of varying urban street canyon proportions. This mechanism may apply both to individual buildings and to the site as a whole. If successful it will be a powerful building and urban design tool.

When complete the solver will parse raw and partially-processed results to the database, which may be accessed from the results analysis module of the user interface when the solution is complete. It is envisaged that the user will be able to plot one of three standard sets of charts at any one time as well as charts constructed from user defined variables. The standard results sets may be categorised as summary, detailed and parametric.

The aim of the summary results facility is to provide an a-priori overview of the performance of the site, each building within the site and how the site's performance compares within previous scenarios. One useful tool for providing performance overviews has been coined a `community resource signature` - for example taking the form of a horizontal bar chart with the bar subdivided into resource types (energy, water and waste) and positive and negative x-axes referring respectively to production and consumption. Successive bars on this chart relating to different neighbourhood scenarios would then help the user to identify a solution that is approaching the resource use optima.

The more detailed analyses are intended to give a view of the temporal variation of resource flows – both site-wide and for individual buildings (once selected) – for a user defined time period. The parametric study results will be similarly split; in which the sensitivity of individual resource flows can be analysed at the site, building or zone scales.

These standard result sets may be viewed simply as a report process. The user defined results analysis facility will take the form of a standard simulation program - with e.g. var-var or time-var graphical options and the ability to export results in test file format for more detailed analysis – but with an additional layer of spatial granularity: the site.

DEVELOPMENT AND APPLICATION

Project SUNtool will develop a unique integrated resource flow modelling solver and this will entail innovations in many of the contributory models. The most fundamental innovations from Project SUNtool however, will be in the development of the stochastic models and procedures to quasi-automatically attribute the geometric building descriptions. Both of these will be informed by a concerted data collection exercise, with Europe being split into regions and different project partners being responsible for data collection from within their region.

Development of the deterministic models will be comparatively straightforward – being based on reviews of existing models and solution techniques. Some of these models will nevertheless be complex, as will some of the stochastic models, and this raises the important issue of testing (or validation) – the subject of a dedicated project task.

As each model is developed this will be tested in isolation by an independent partner by comparing output either with analytically derived results or with proprietary software (e.g. a Monte Carlo based lighting simulation program in the case of the daylighting and solar radiation models). Significant differences will then be reported to the developer for bug fixing and the process repeated until satisfactory results are achieved. A similar process will be repeated once individual models are coupled with the integrated solver. When this testing stage is complete and the model parameterisation method has been integrated the project will proceed to application.

The purpose of this final stage of the project, which will involve application to case study sites and (whether manual or automated) parametric studies, is two-fold (i) to evaluate the tool's efficacy in use, and (ii) to develop masterplanning guidelines. This latter will then inform the complementary educational tool.

Besides the testing of models, it is also important to determine whether the software as a whole is fit for its purpose. For this a user steering group has been established and this group is responsible for (i) defining users' requirements, (ii) policing the delivery of these requirements, and (iii) ultimately testing that the completed tool is fit for its purpose – both in terms of functionality and ease of use. The outcomes from this final phase, carried out as part of the application stage described above, will feedback into the development process shortly prior to project completion.

EDUCATIONAL TOOL

The quest for the holy grail of sustainable communities may be viewed as a three pronged process: (i) demand minimisation, (ii) renewable resource supply, and (iii) efficient delivery of outstanding resources; and the resource flow modelling tool is almost expressly developed to support this. However, the process of identifying sustainable optima must be placed within a pragmatic socio-economic framework if proposals are to have a good chance of being adopted in practice. The financial appraisal aspect of this decision support will be part of the modelling tool. The qualitative aspect will be accommodated within a complementary educational tool.

The educational tool will have two facets. It will on the one hand provide advice for overcoming barriers to the more widespread uptake of sustainability technologies and related considerations, covering e.g. (i) socio-technical barriers (aesthetics, noise, etc) including technical summaries of different technologies, (ii) technical issues such as maintenance, performance monitoring and optimal ongoing resource management, and (iii) nurturing a more sustainable-minded community spirit.

There are also some important issues related to sustainable masterplanning that are beyond the remit of the modelling tool and associated decision support. Examples are (i) transport planning, (ii) constructional materials, and (iii) approaches and supporting tools to optimise pedestrian comfort. On a related note, guidance on approaches to minimising net resource use will also be a valuable adjunct to the tool; covering issues such as site layout, mixes of building uses and technologies – many of which will arise from parametric studies. Both this and item (iii) above will be supported with case study material collated during the application stage of the project.

CONCLUSIONS

The rationale and proposed structure for the development of an integrated resource flow modelling tool to support sustainable community (re) design in complex urban settings has been described. This will lead to innovations in daylight and solar radiation modelling, translating meteorological measurements to the local urban scale for energy simulation, stochastic behavioural modelling, and rapid attribution of building geometries. These disparate models will then be coupled with an integrated solver and this will include a facility to parameterise certain simulation variables and subsequently to conduct multiple simulations. This together with case studies will inform the development of a complementary educational tool. This tool has the brood objectives of helping the user to overcome real or perceived socio-technical barriers to the more widespread uptake of sustainability technologies as well as advising on approaches to optimise community sustainability and the local pedestrian microclimate.

Project SUNtool is due for completion early in 2006 and throughout this time regular updates will be posted on the project WWW site.

ACKNOWLEDGEMENTS

The funding for Project SUNtool by the European Commission's DG TREN is gratefully acknowledged.

REFERENCES

N. Baker and K. Steemers, Energy and Environment in Architecture: A Technical Design Guide, Routledge, 2000 (ISBN 0419227709).

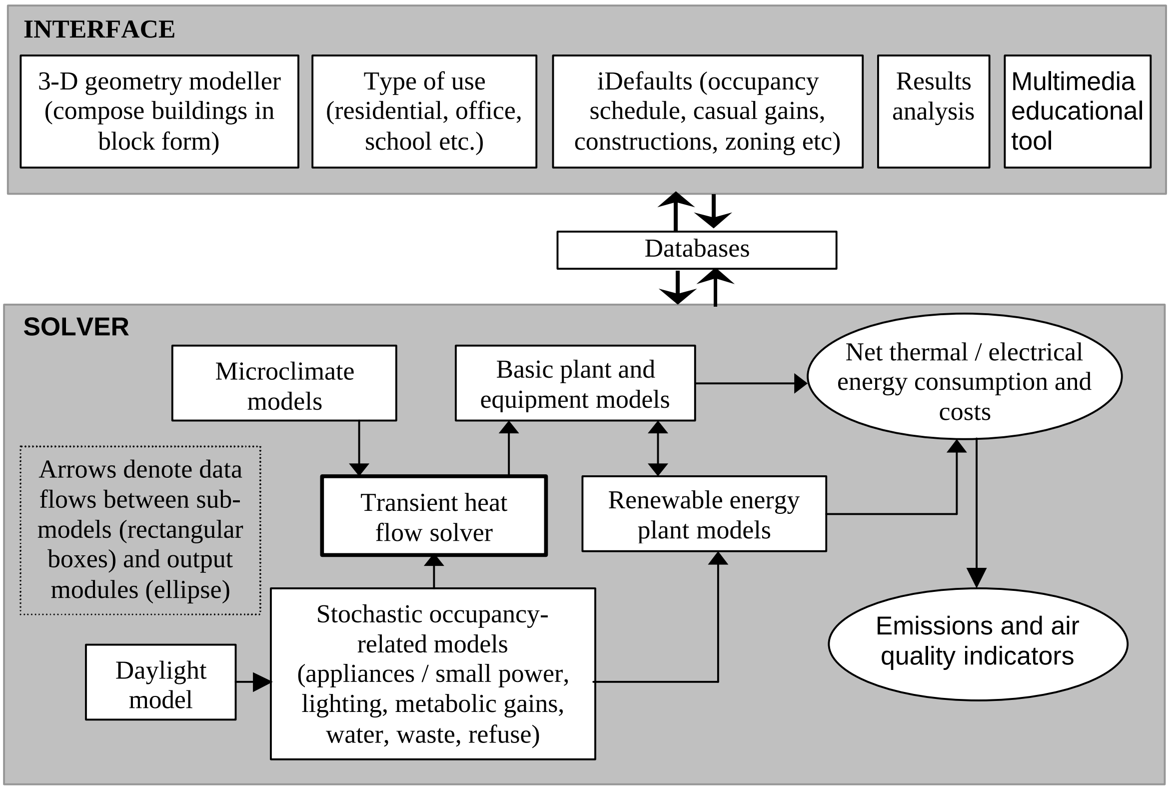

Figure 1 Structure of proposed modelling software