ENVIRONMENTALLY FRIENDLY CITIES, Proceedings of PLEA'98, Lisbon, Portugal, June 1998
Pages 341-344

The simulation of adaptable components in the external envelope of a building

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Abstract

This paper considers the building's envelope in the design phase. Energy related decisions during the design phase have great influence on the life cycle cost of the building.

Since sunlight and climate are changing factors, the envelope is equipped with mobile and adaptable components (shading devices, movable insulation, opening window schedules...) which can react to climatic conditions.

Architects use computer aided design tools to describe a building and its envelope. A lot of objects and parameters for the *heating, cooling, lighting, ventilation and acoustic* simulations during the design process are already specified in the architect's computer model of the building.

With a few *test cases* the data exchange between the architect's software tool (e.g. AutoCAD, Speedikon) and the building physics software for the different application fields (Trnsys, ESP-r, Radiance, Raynoise...) is analysed.

The main goal is to obtain a good performance for each of the mentioned disciplines. Several simulations are performed to evaluate the effect and the sensitivity of the adaptable components (changes from season to season, or from day to night) on the efficiency of the building.

Based on these studies a conceptual data model can be presented to support integrated studies in the preliminary design stage.

INTRODUCTION

The envelope of the building is like a skin.

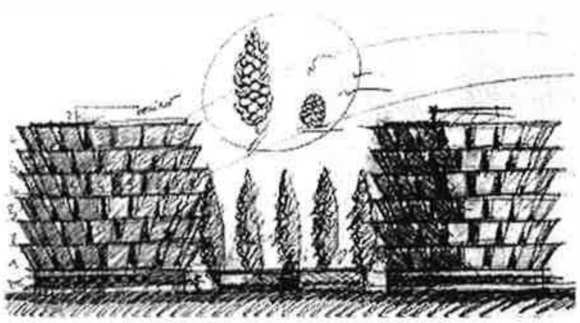

Figure 1. The envelope protects against traffic noise [8]

Sunlight and climate are changing factors. The envelope of a building could be equipped with mobile and adaptable components (shading devices, movable insulation, and window opening schedules...) which can react to climatic conditions and still ensure comfort.

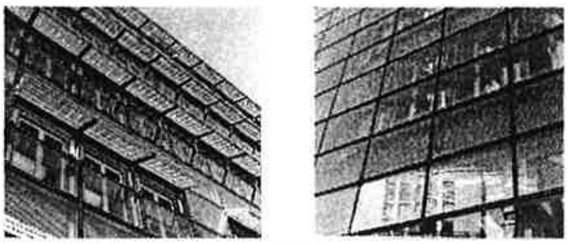

Figure 2. Adaptable components

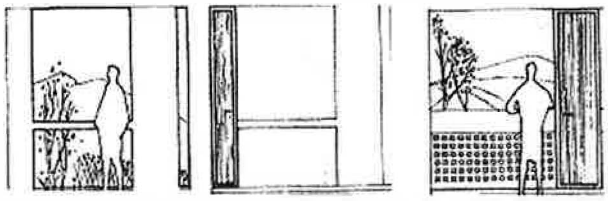

Figure 3. Lighting, ventilation and visual comfort [9]

COMPUTER AIDED ARCHITECTURAL DESIGN MODELS VERSUS SIMULATION SOFTWARE.

BUILDING PHYSICS SOFTWARE

Architects use computer aided design programs (AutoCAD, Speedikon) to describe a building. If they built a 3-dimensional model they generally specify both geometry and materials for objects like walls, windows, plates, roofs or overhangs. The computer model could be re-used to extract the geometry, zone's, floors, walls and windows for the hygro-thermal simulations (ESP-r, Trnsys). These programs use a simplified definition of the building together with specific input like climatic data, comfort temperatures per zone, characteristics of the glazed surfaces and so on.

In all simulation software a building consists of *objects* (like *rooms*, *walls, windows...*). Objects have *attributes*: a wall has an *axis* with *begin-* and *endpoint*, a *thickness*, a *height (may be different at begin- and endpoint)* and is made of a specific *material*. Zones can be *heated or not*, a room can be a *veranda,* a *void* or a *covered patio*. Relations link objects: a zone *consists of* rooms, a wall *contains* windows (1/more), a room *can contain* schedules for ventilation, and internal gains...

In a first study [6] a pre-processor *Autotrans* was implemented within AutoCAD: dedicated menu-tools were added to the standard drafting and modelling functions. These new commands like *insert {wall, window, orientation, roof, floor and climate}*, *make zone* or *modify {wall...}* enable the user to draw and create simultaneously entries in the building database. The information to be transferred (by a *save*) to the building physics software (Trnsys) is stored in this database.

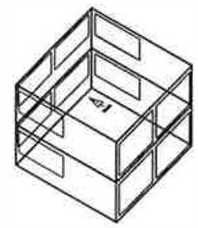

Figure 4. Autotrans model (largest windows are south).

The disadvantage of this approach is that the model is drawn twice: a first time by the architect and a second time by the engineer preparing (this time with a graphical feed back) the energy calculations. Modifications on the other hand can be performed more easily in the AutoCAD environment than in a text editor.

A more appropriate step is to translate the architectural model from Speedikon into a text file by the High-Level Interface (HLI) export. An interface is being implemented to translate both geometry and material data for walls, windows, plates, roofs or overhangs into the data required by Trnsys (or ESP-r)[4]. A really automatic translation is not possible: the orientation and climate data need to be added by the engineer. Also the geometric model has to be screened: a wall can be at the same time an *external wall* and a *wing wall* for a nearby window, a *plate* can become an *overhang* for an underlying window...

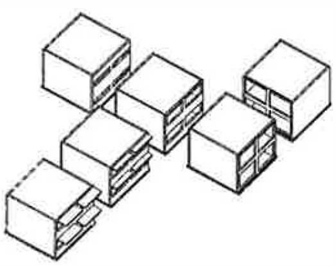

Figure 5. Different windows and overhangs in Speedikon.

RADIANCE.

This software simulates the lighting in a building. It can use data defined by an AutoCAD-dxf file. Materials (faces) with the same material are drawn on the same layer. A specific material database is required [2,5].

RAYNOISE.

This software simulates the acoustics in a building. It also uses data defined by an AutoCAD-dxf file. Results are presented in [5].

DESCRIPTION OF THE TEST CASE.

A small building (see Figure 4) with a plan of 9m by 9m, and a height of 6m is chosen as a test case. We allow the building envelope to be adaptable to ensure the hygro-thermal comfort. Wall panels, with a modular size of 0.8m by 4m can replace window panels. An overhang of the same size can be placed above a window with south orientation.

Table 1. k-values.

k-wall:	0.42	W/m²K
k-roof:	0.33	W/m²K
k-floor:	0.43	W/m²K
k-window:	1.30	W/m²K

For all windows triple-glazed panels are used.

Different layouts have been generated within Speedikon and calculated by Trnsys. While preparing these models they have been checked (rule of thumb) to make sure that optimisation for heating and cooling is not performed on units which require a high level of artificial lighting.

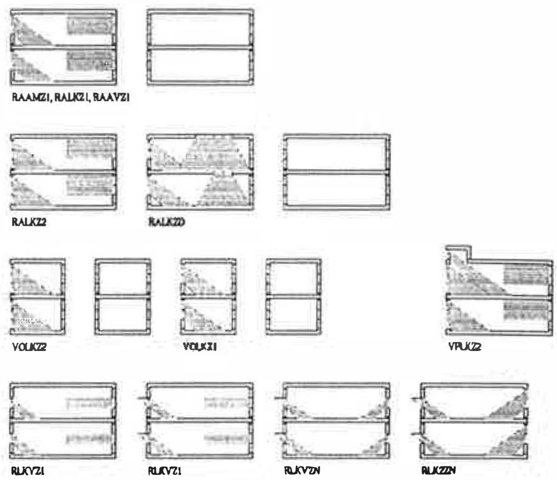

Figure 6. Day-lighting for the different configurations.

Three different climate conditions are considered: a Typical Winter day with a Cloudy sky (TWC), with a Sunny sky (TWS) and an Average Summer day (AS). For thermal comfort, heating and cooling conditions have been set to 18°C and 22°C respectively.

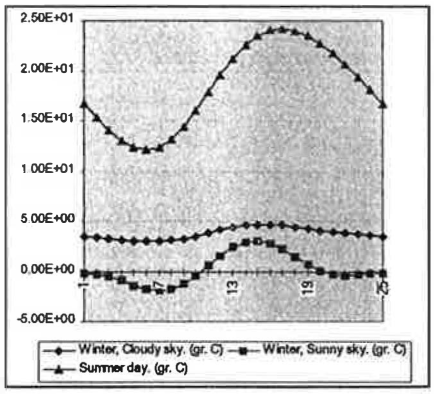

Figure 7. Temperature outside for TWC, TWS, AS (gr.C)

Table 2. Global K for the most closed and open configuration.

k = Sum (k_i * $Surf_i$)	RLKVZ1	37.0
/Total $Surf_i$	RALKZ2	45.3
K = 300 * k/(C + 2)	RALKZD	49.1

The present simulations have been performed with Trnsys. The input consists of the volume per zone and areas linked with orientations and materials. The consistency of this data is left to the responsibility of the engineer. The use of the HLI export from Speedikon calculates the zones and the orientations and areas of the walls (in the plane specified by its axis) *automatically* from the 3D-model [4]. Schedules for the adaptable components have been added *manually*. The same configurations are being processed with ESP-r[3].

The first reference configuration has no windows at all while the second has a window size of 4 times 6.4m^2 in the southern and 2 times 6.4m^2 in the eastern and western façade (no windows north). Both are calculated for the three above mentioned weather conditions (TWC, TWS, AS).

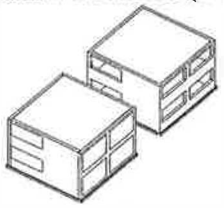

Figure 8. The first two reference configurations.

From the diagrams for a Typical Winter day with Cloudy sky (TWC) it is clear that shutters can be closed during the night to reduce heat losses. On a Typical Sunny Winter day (TWS) solar gains reduce the required heating.

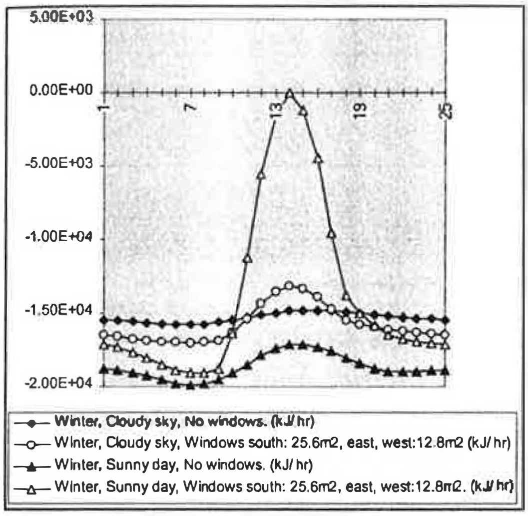

Figure 9. Energy consumption: TW (models Figure 8).

If all windows are shutters for the whole summer day, no cooling is required, but artificial lighting is.

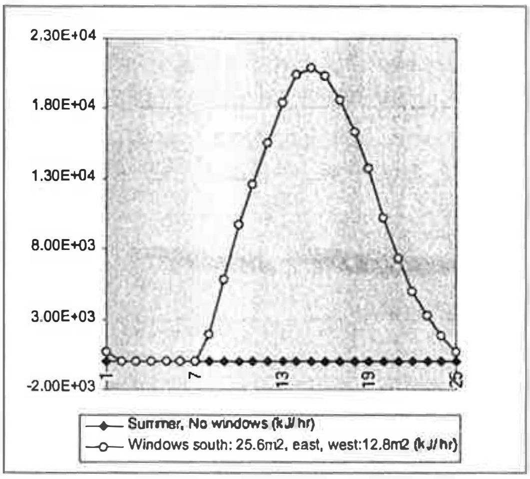

Figure 10. Energy consumption: AS (models Figure 8).

ANALYSIS OF THE TEST CASE.

TYPICAL WINTER DAY WITH A CLOUDY SKY.

The test case (see Figure 4) with a maximum window size of 4 times 9.6m^2 in the southern façade, 2 times 6.4m^2 in the eastern and western façade, and 4 times 6.4 in the northern façade is calculated under different conditions (see Figure 11). Both day and night configurations are drawn.

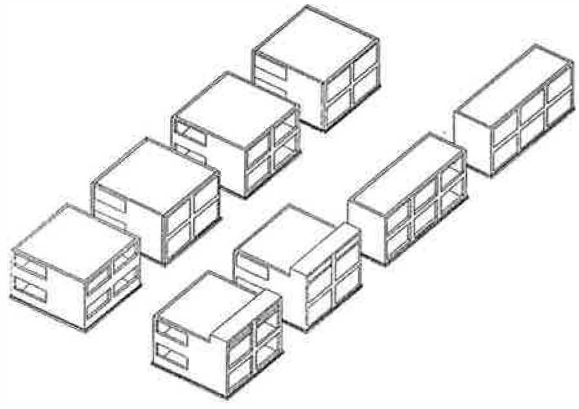

Figure 11. Configurations for TWC simulations.

As a basic rule all windows have shutters, which are closed at night-time (during winter). The ventilation can have an important influence on the energy consumption. For the simulations during the winter period ventilation is set to 0.3 volumes/hr (for the whole building).

Even when the sky is cloudy, the windows on the southern façade allow some thermal gain. A 50% increase in window size in the southern façade has only a minor effect.

The third model has an extra 9m^2 of glass in the southern façade and an extra volume of 2mx1mx9m on the roof. The benefit during daytime is reduced by transmission losses during the night. On the other hand, if the total *living space (heated space)* could be transformed into a smaller (still compact, x0.75) unit with a larger southern façade (x1.5), the benefit is ensured during the whole day.

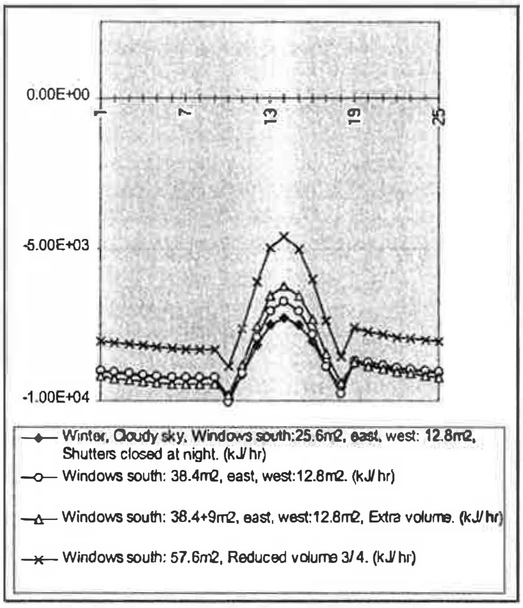

Figure 12. Energy consumption: TWC (models Figure 11).

A large glazed area in the roof could be necessary for lighting, but increases the energy consumption for heating.

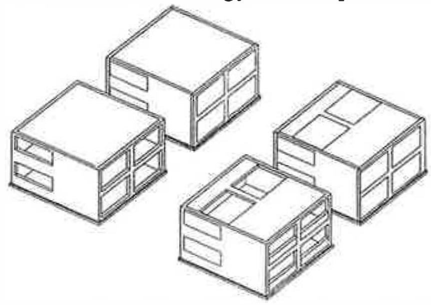

Figure 13. Configuration with a glazed area in the roof.

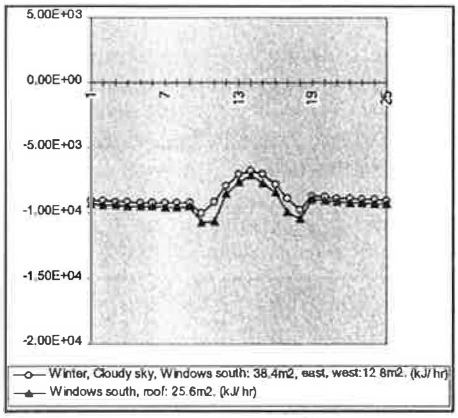

Figure 14. Energy consumption: TWC (models Figure 13).

TYPICAL WINTER DAY WITH A SUNNY SKY.

Again all windows have shutters, which are closed at night-time (during winter). Three models have been considered.

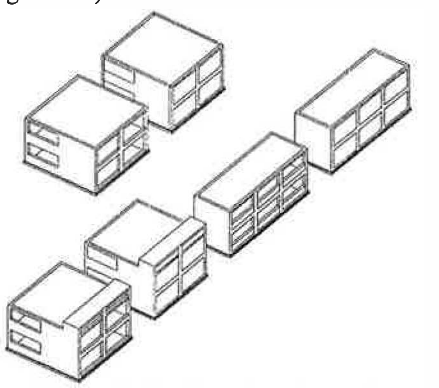

Figure 15. Configurations for TWS.

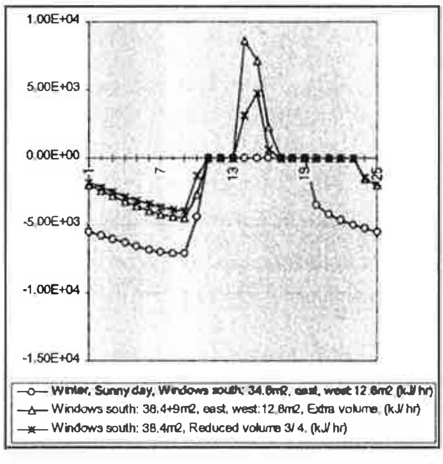

Figure 16. Energy consumption: TWS (models Figure 15).

The second model (with an extra $9m^2$ of glass, see TWC) causes a (small) overheating during daytime, but is beneficial during the night.

If the total volume is transformed into a smaller unit (see TWC) the overheating becomes too important. If all windows are reduced by 2/3, the benefit is ensured (a bit of overheating during the day).

AVERAGE SUMMER DAY.

The models are shown in a mirrored position to visualise the north side. For the summer conditions (AS) permanent shutters are installed to reduce the southern w.ndow size, overhangs are added, and ventilation rates are scheduled (3 volumes/hr during the night, 0.3 volumes/hr during the day). The third model gives the best solution (if only thermal comfort is considered).

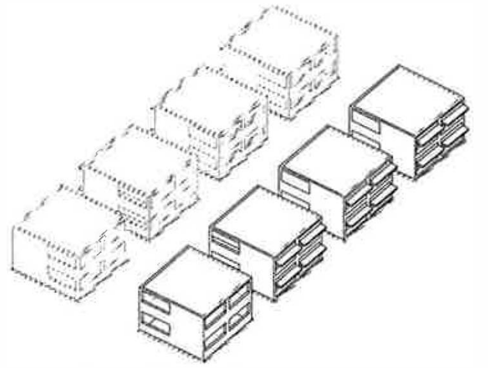

Figure 17. Configurations for AS.

Having $6.4m^2$ windows on the eastern and western façade and no windows at the northern façade gives almost the same result as no windows on the eastern and western façade and $12.8m^2$ windows in the northern façade.

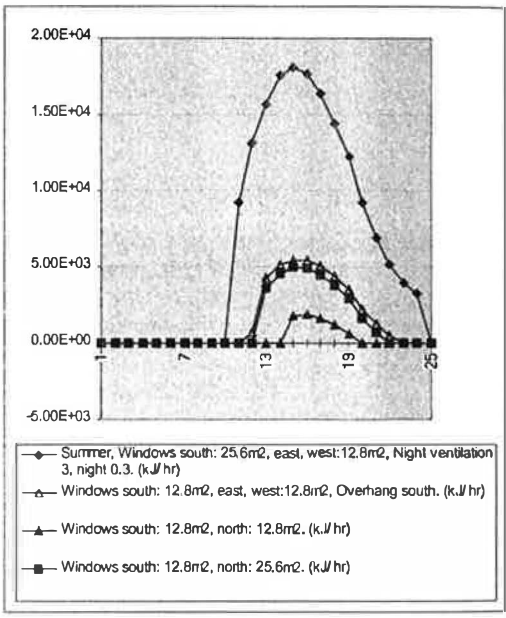

Figure 18. Energy consumption: AS (models Figure 17).

This very simple example illustrates that for energy reasons the same building block could have different configurations depending on the season or the daytime. Different layouts can have almost the same performance.

Further investigations could consider the influence of sloped roofs, sloped walls and windows and different orientations (see Figure 1). Also for mid season the best layouts should be analysed.

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