THE USE OF SIMULATIONS TO SUPPORT THE RETROFITTING OF A DUTCH MONASTERY, LISTED AS A HISTORIC BUILDING AND BEING RE-USED AS AN OFFICE BUILDING

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ABSTRACT

This paper describes the use of simulations to support the renovation process of a monastery, that is listed as an historic building and is being re-used as an office building. No simulations were used in the creative phase of the process, partly because no suitable simulation tools are available. In the other phases of the design, several software tools were used to answer different kinds of questions. The paper describes the ways in which these tools were used and makes recommendations for consultants and software developers.

INTRODUCTION

Monastery ‘De Weijert’, located in Apeldoorn (the Netherlands) is included on the national register of historic buildings in the Netherlands. It was built in 1932 as a minor seminary and it was bought in the 1970’s by the Ministry of Housing and Construction to house the Dutch Police Academy. The building is in need of renovation for several reasons:

- The quality of the indoor climate must be substantially improved. Problems with indoor draught make it is impossible to maintain a comfortable temperature inside the building during the winter.
- The Academy would like to house all of its teaching institutes, which are currently dispersed throughout the country in ‘De Weijert’. This will increase the number of people working in the building nearly five-fold and necessitate many more building functions.

The renovation of this historic building faces complex, often contradictory constraints. For example, although the Police Academy would like the building to have reasonable energy performance, drastic improvements to the façade or windows are not allowed, as this would alter the original construction. The quality of the indoor climate must be substantially improved, even as the number of people working in the building increases five-fold. This paper is written from the point of view of the consultant for building equipment and energy. It describes the design methods and processes that have been applied in order to perform the desired renovations and focuses on the use of simulation methods to support the creative ideas of the architect and consultants. In each stage of the design, different methods were used to answer different kinds of questions.

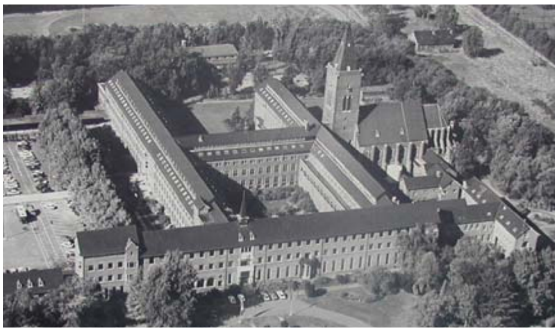

Figure 1 Monastery ‘De Weijert’, before renovation

DESCRIPTION OF THE BUILDING

Figure 1 gives an overview of the building in its original state. The renovation will change the inner courtyard into an atrium, and a new entrance and kitchen will be built next to the church. The church itself will be used as a restaurant.

The walls of ‘De Weijert’are brick and have no air cavities or insulation. The roofs are also not insulated. The window frames are steel with single-paned glass windows. The rooms on the first floor are approximately five meters high. The rooms on the second floor are approximately four meters high and the rooms on the other three storeys are around three meters high. Each wing has a central corridor, with rooms facing the outer garden on one side, and rooms facing the inner courtyard, which is to be transformed into an atrium, on the other.

PHASE ONE: SELECTION, OR THE CREATIVE PHASE

Current procedures for selecting consultants often involve competitive processes. Prospective consultants must therefore gain the trust of a potential client regarding their professional and financial ability to lead their part of the project, while also presenting original ideas to distinguish themselves from their competitors. The short selection procedure and the high level of

uncertainty about the outcome allow little time to invest in searching for original ideas.
Paradoxically, the choice of a consultant implies the consideration of their design choices, although neither the feasibility nor the consequences of these choices have been assessed. No simulation instruments are available to assist consultants in this initial stage. The following paragraph describes the process of creative thinking that was applied with regard to the renovations of 'De Weijert'.

During a brainstorming session, it was decided that the guidelines for the design principles should make full use of the qualities that already exist in the building. Although the indoor climate in the building's present state does not comply with modern requirements, it does form a sound basis for minimal requirements:

- There are no moisture problems.
- There are no superheating problems in the summer.
- High infiltration rates and tall storeys provide plenty of ventilation.

Tall rooms

- They are an advantageous with regard to air quality.
- Energy costs can be minimized by heating only the lower living area.

Insulation

- Outdoor insulation of walls and replacement of windows are not allowed.
- A minimal level of insulation of the walls can be provided inside the building. This insulation should cause neither moisture problems nor superheating in the summer (the occupancy rate in the building will increase considerably after renovation, making superheating in the summer a potential problem).
- Because of the cold radiation from the windows, an additional glass panel should be placed in front of the existing window. It should still be possible to open the window, however.

Infiltration and draught

- Because of the type of construction, infiltration could be responsible for most of the heat loss and discomfort.
- Because of the type of construction, historic components and costs, little can be done to reduce infiltration losses by sealing cracks.
- Overpressure ventilation, which increases pressure in the building, may offer an efficient low-cost option for drastically reducing the infiltration losses, thereby increasing comfort and decreasing the amount of energy used for heating.

Ventilation

- The current amount of natural ventilation through infiltration and windows is satisfactory for the building's current usage, but is probably insufficient for the planned increase in occupancy.
- Some mechanical ventilation will be needed .
- The application of mechanical air intake only could limit draught and save energy.

Heating and cooling

- Because the building will not be tightly insulated, some form of high-temperature heating (such as radiators under the windows) will be necessary. Because this would make the use of heat pumps difficult, high-efficiency boilers will be used instead.
- Because of the low insulation grade and large thermal mass of the building, along with the moderate sea climate, the cooling demand is expected to be relatively low. Some cooling must be provided, however, because of the expected high occupancy rate. If mechanical air intake is applied, cooling can be supplied to the air.
- High-efficiency generation is a logical option for improving the energy performance of the building without making major changes to its structure. Cold and heat storage in the ground could be used to ensure air-cooling and to provide a minimum level of heating to the air that is blown into the rooms.

The same brainstorming session resulted in the following proposal, which was selected by the client (see Figure 2):

- Minimal building insulation on the inside
- Additional glass panel in front of windows
- Overpressure ventilation, with mechanical air intake and natural air exhaust through infiltration spaces and windows
- Basic heating of the ventilation air
- Additional heating by radiators
- High-efficiency boiler for radiators
- Cold and heat storage in the ground for air heating and cooling

This first phase, in which the entire concepts for ventilation and energy were decided, was not supported by simulation, because there are currently no simulation tools that can support this type of creative process. This may explain why consultants are often reluctant to make innovative decisions;

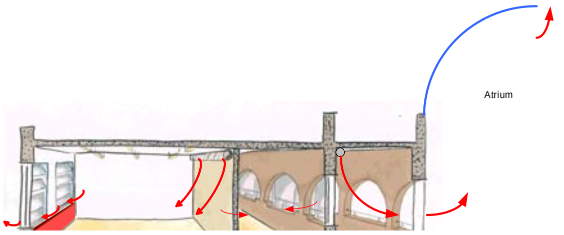

Figure 2 Working of the overpressure ventilation system

they must make such decisions without being able to verify the correctness of their assumptions.

In the following phases of the design, the major uncertainties of the proposal were gradually addressed in such a way that the proposal could be steered and modified where necessary, without frustrating the development of the project. In this way, the consultants and clients hoped to avoid discovering in a later phase that some design choices had not been well considered

<u>THE MASTER-PLAN PHASE</u>

In this first phase, which took place concurrently with the architect's functional study, there were three main concerns. The first concerned whether insulating the façades only slightly, at a level below the current standards, could be justified. The second concern was whether overpressure ventilation with natural air exhaust was possible year-round. The third concern was whether the ground structure near the monastery was capable of supporting seasonal heat and cold storage.

No simulation techniques were applied to analyze the third concern. Instead, a specialized firm conducted a study of the ground, based on existing boreholes in the neighbourhood and existing underground charts. The results of this study showed that seasonal heat and cold storage was feasible.

Simulations of the overpressure system concentrated on the feasibility of operating the system at the recurrent wind speeds of the area, in order to determine how the system would work during the main part of the year. Because wind speeds up to five meters per second occur during more than fifty percent of the year, the simulation was made to test the ventilator's ability to create enough overpressure in the building in the presence of corresponding wind pressure of five meters per second on the facade. These simulations were made by hand without using software

The decision concerning the degree of insulation focused on increasing comfort and saving energy. Considerations of energy savings involve all energy usage, and not just that which is used for heating. The energy use of a building also depends on the behaviour of the occupants. To determine the optimal solution, simulations were made using the software tool h.e.n.k., which was developed to support the first design stage (Itard, 2003). The number of entries is limited to data that are known at the start of the design. Additional data have standard values, but the software accounts for all physical processes within a building, including dynamics and the behaviour of its occupants. The software is based on energy and mass balances for the whole building. Figure 3 shows the results of the simulation. The first stack shows the actual energy consumption of the building, which is equipped with an outdated boiler. Replacing the boiler with a new one would sharply reduce energy consumption, but would not improve comfort (stack 2). Insulating the facade in accordance with current standards and sealing the cracks (stack 3) would greatly decrease energy consumption, but the costs are very high and the plan would be likely to encounter problems from the Historic Building Council. This measure would also increase the demand for cooling, thus necessitating an extra cooling system. Stack 4 shows the amount of energy consumed when using ground storage instead of a boiler and cooling machine. Insulating only the roofs and the lower parts of the wall (under the windows and behind the radiators), placing additional glass panels in front of the windows and reducing infiltration losses by applying overpressure would increase the total energy demand but would decrease the cooling demand (stack 5). The use of heat and cold storage (stack 6) could produce a reasonable level of energy performance, which would approach the performance level required for new buildings. Although the last option does not use the least energy, it represents an optimal balance among energy use, costs, comfort and historic value. In this phase, comfort level was evaluated by allowing the indoor temperature to vary between 20 and 24 degrees in the simulations, and by calculating the surface temperatures of walls and windows by hand.

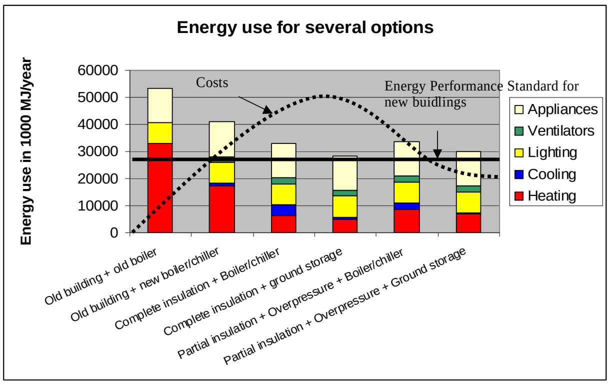

Figure 3 Energy use for several options in relation to Energy Performance Standards and costs

The results of the master plan showed that partial wall insulation in combination with overpressure ventilation and heat and cold storage in the ground would be feasible.

THE INTERIM DESIGN PHASE

The aim of this phase was to make an initial translation from design concepts to practical solutions, thereby identifying and finding possible solutions for the problems encountered during materialization. The use of simulations in this phase concentrated on the following aspects:

- Determination of heating and cooling loads, as well as the respective parts of the boiler and the ground storage facility.
- Testing the year-round working ability of the overpressure system.
- Assessing air quality and comfort in the rooms.

Determination of the heating and cooling loads

A risk analysis of the heating and cooling load was conducted using h.e.n.k. software. This analysis was necessary, as conventional designs calculate the heating load under the assumption that the building is empty and that it must be maintained at a temperature of 20^{o}C. These assumptions generate a high and unrealistic heat load, which is a barrier to the implementation of sustainable energy systems, which are generally more expensive. A more realistic heat load can be obtained by simulating the building under real-use conditions, although use conditions can never be precisely determined. It is therefore preferable to work with a range of values rather than with standard values. The main uncertainties arise from the determination of the occupancy rate and the internal heat load. With respect to occupancy rates, the effects of nominal values that are lower than those specified in the program requirement (20% and 80%, respectively) were studied. This was due to uncertainties concerning whether all of the teaching institutes would be housed in this building. A range of 50% was chosen for determining the internal heat load. Several combinations were simulated, the results of which are shown in Figure 4. The least efficient scenario requires a heat load of 2700 kW. Calculations performed according to the national standards generate a heat load of 3200 kW. Because ground storage is designed primarily for cooling purposes and has a long run-in period, it was decided to install a boiler that would be large enough to meet the maximum heat demand calculated with h.e.n.k. The combined capacity of the boiler and the heat storage would provide be sufficient to meet the standard requirements.

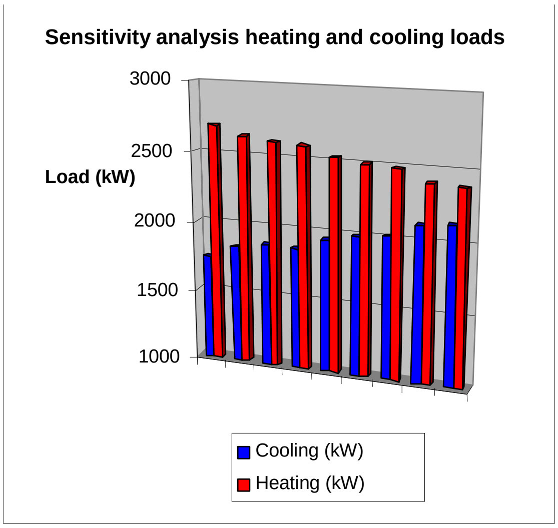

Figure 4 Sensitivity analysis for the heating and cooling loads

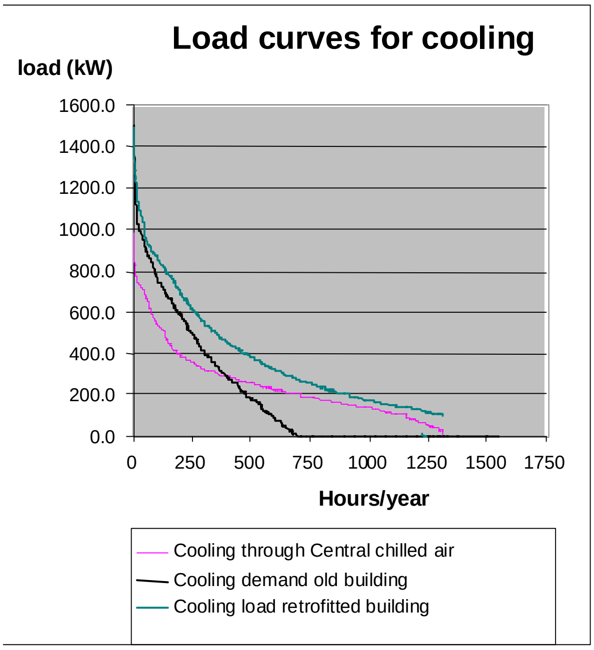

Figure 5 Load curves for the cooling demand

Load curves were calculated to estimate the cooling load. As shown in Figure 5, the retrofitted building would require cooling for a greater portion of the year than would the non-retrofitted building, with its lower occupancy rate. Only part of this demand could be fulfilled through central air chilling. The remaining cooling demand would not be satisfied. The cooling demand of the building in its present state is also not satisfied; there is no cooling at all. There are few complaints, however, as the building can be kept comfortable by opening the windows. Because opening the windows will remain a possibility, no extreme problems with too high indoor temperatures are expected.

The overpressure system

The calculations for the analysis of the overpressure system assumed extreme wind speeds, and the distribution of pressure on the façades of the building was calculated with the Computational Fluid Dynamics (CFD)-software Phoenix (see Figure 6), in order to determine the conditions under which the system could operate. If the wind pressure on the facade is too high, air exhaust through vents in the facade or through the windows is not possible. The air will flow out through other façades that are under lower wind pressure. In that case, the airflows would no longer resemble those represented in Figure 2, but would be as shown in Figure 7. Therefore, it was decided to install vents that would shut automatically when the pressure inside the building is lower than on the facade, thus minimizing draught and the infiltration of cold air.

Figure 6:Wind pressure distribution (height 7 m) for a west wind of speed 5m/s.

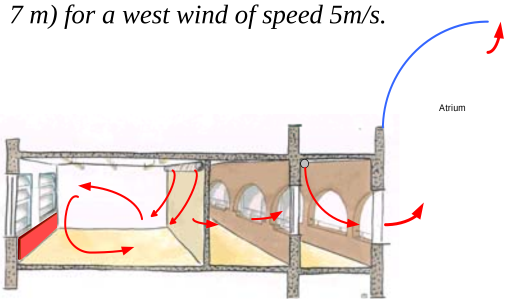

Figure 7 Air flows when the wind pressure on the outer facade is too high

Figure 8 illustrates the proposed combination of additional glass panels and vent openings

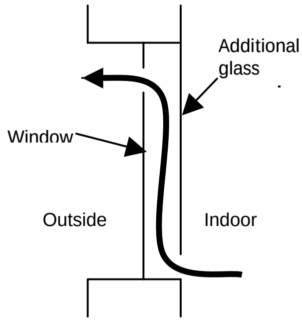

Figure 8 Exhaust air system

Quality of air and comfort in the rooms

The major concern here was determining the feasibility of ensuring favourable levels of air quality and comfort using the systems described in Figures 2 and 7. CFD calculations were made for both situations, assuming winter, spring and summer conditions in a typical first-floor room. Rooms on the first floor were assumed most critical, due to their height. Temperature, velocities and the dispersion of breathing air were studied in order to identify potential problems in the design.

Air stratification was observed under winter conditions in the room. This required specific attention to the way in which air would be blown into the room. By trying several different flow directions and velocities at the room's air-inlet grille, solutions for ensuring an appropriate level of comfort were found. Cold draught was also observed near the window (see Figure 9). A brief sensitivity study showed that this problem could be solved by creating a better balance between the temperature of the air blown into the room and the capacity of the radiators.

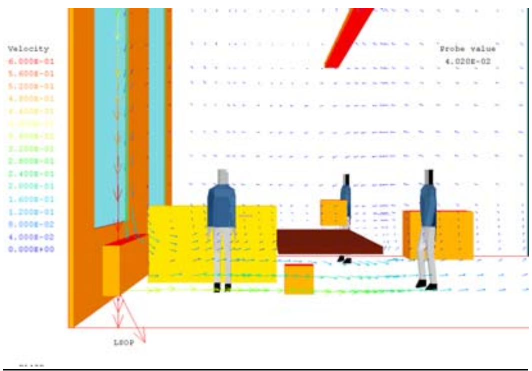

Figure 9 Air velocities and cold draught in the winter

Under spring or autumn conditions, the exhaust vents will be often closed due to high wind speeds (see Figure 7). The main concern in this situation involves ensuring proper ventilation throughout the room and the absence of an air shortcut from the inlet to the corridor. This is possible, as long as the locations of the air-inlet grille and the overflow opening to the corridor are well chosen. Figure 10 shows the dispersion of breathing air in this scenario.

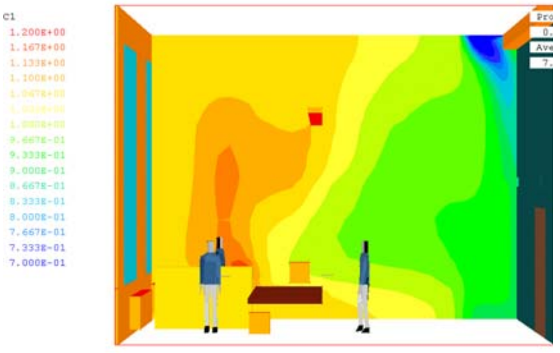

Figure 10 Dispersion of breathing air when the exhaust vents in the façade are closed

Critical results were obtained under summer conditions, where the temperature can reach 30 degrees for approximately sixty-five hours each year. Larger airflows cannot be applied, because of the limited size of the air ducts. A lower temperature for the air blown in is also impossible, because of the limitations presented by the temperature of the cold ground storage. Because this problem is present for only a limited period, however, night ventilation can provide a suitable solution. One problem encountered during these simulations was the inability to account for the positive effects of the building mass on the CFD calculations.

THE FINAL DESIGN PHASE

At the end of the interim design, it was clear that the complete system was feasible, and that all necessary design changes had been identified. In the final design phase, the simulations focused on

- Determining the right type and position of the air-inlet grilles for each type of room
- Determining the appropriate position of the air exhaust vents for each type of room, in order to avoid draught and to ensure good air quality throughout the room
- Determining the best positions, temperatures and capacities of additional heating equipment. Depending on the room type, additional heating equipment will consist of radiators, radiant panels or heating through the concrete floor, activated by low-temperature water.

These simulations were conducted using a combination of CFD simulations and VA114 (a simulation tool that is widely used in the Netherlands). The latter generates the wall temperatures needed for the CFD calculations as well as weighted degree hours, which are often prescribed in Dutch Programmes of Requirements. Weighted degree hours give the annual number of hours in which a certain temperature is exceeded during the summer.
Both simulation tools were customized for this project. A new module in Phoenix was created to take the building mass into account. Although the absolute results from the two software tools did not always agree, they showed similar tendencies. These tendencies were also consistent with the analysis performed in the first stage using the software tool, h.e.n.k. Figures 11 through 13 show the results of some of these simulations.

As a final check, a test-room will be implemented on site to validate the design choices. The aim of the measurements will be to check the performances of the system in terms of air quality, room temperature and draught.

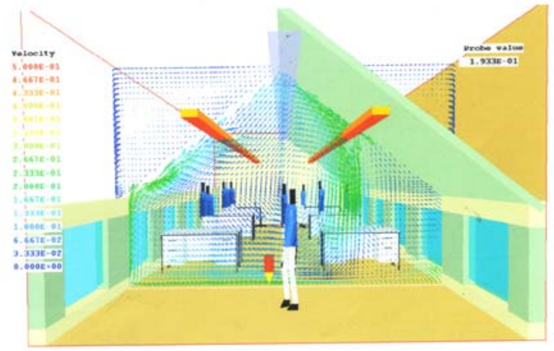

Figure 11 Air flows and velocities in the roof- level rooms under summer conditions

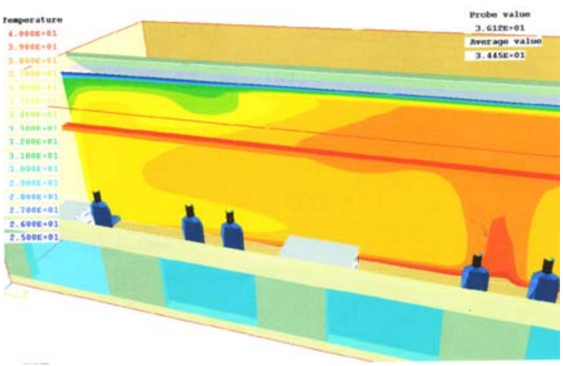

Figure 12 Temperature distribution in the roof - level rooms under summer conditions

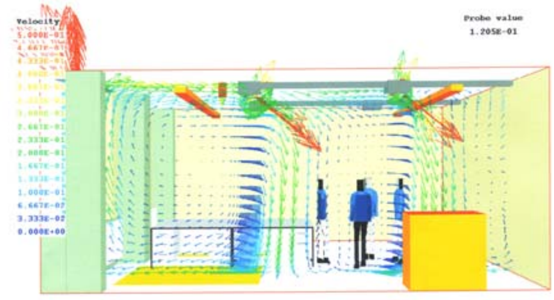

Figure 13 Air flows and velocities in the first- floor rooms

CONCLUSIONS AND RECOMMENDATIONS

This paper described the use of simulations to support design activities related to the refurbishment of the monastery De Weijert. Three concluding remarks can be drawn from these descriptions.

The first refers to the use of simulations for design activities. The major obstacle that a consultant must avoid is performing overly detailed simulations too soon. Otherwise, too much time will be spent on details that may have to be changed later on, and major items will often be overlooked. At the beginning of the project, therefore, a consultant should have a clear idea of which items must be checked during which phases of the project. The sizing of ducts is not the only important activity during the design process; making the right decisions at the right time is often much more important.

The second concluding remark refers to the implementation of innovative ideas. Innovative ideas are often difficult for consultants to make, because they bear the responsibility of design and innovative ideas that have not yet been fully proven. The example provided in the paper shows how risks can be reduced by performing simulations. Risks can be avoided, however, only if the consultant has enough knowledge to deal with complex simulation tools in the right way.

Finally, the availability of the right software tools in each phase of design remains a problem. There are enough simulation methods for the later phases, but few software tools are available for the phase of the master plans. This problem has already been stressed by many authors (de Wilde 2004, Itard 2003, Augenbroe 2001, Hensen 1993). Paradoxically, no software is available for phases in which the major decisions are taken. Because the trend of selecting consultants on a pre-design is likely to persist, it is of great importance to develop tools that can assist in the creative phase of the process.

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