Creating healthy buildings: early design stage and handing over are crucial

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ABSTRACT
Regrettably, buildings often do not perform as expected or wanted by the users. Especially with regard to indoor environment, dissatisfaction is occurring frequently. Based on an investigation of two office building projects, an analysis of causes for the mismatch between user requirements/expectations and the performance of buildings and systems has been made.

The investigation consisted of an analysis of the development of building and systems, based on documents and contracts, an interview of the building manager, an occupant questionnaire, measurements, calculations and interviews with stakeholders.

The early design stage (pre-design) and the handing over of the building are found to be critical for the performance of the building (including systems) with regard to indoor environment.

Due to assuming a fixed user pattern of the building the chosen concept for the building and systems often is not able to cope with changes during the use of the building. It is proposed to exchange this traditional approach for a ‘strategic’ design concept, wherein flexibility of the design is the main goal.

In the handing over phase, there is not sufficient monitoring of the functioning of the HVAC system, resulting in insufficient tuning of the system and late reaction on malfunctioning. Automatic fault detection and diagnosis using a Building Management System could play an important role in the monitoring of the HVAC system.

INDEX TERMS
Building process; HVAC design; Office building; Performance; Strategies

INTRODUCTION
The indoor environment is the result of the design of the building and the HVAC system. A good performance is achieved only when there is a good combination of design, installation and management. In the Dutch building industry this is often neglected, resulting in many problem buildings where the performance does not meet the expectations of the principal, tenant and/or user. The changes in required performance during use (e.g. as a result of more stringent requirements, changed use or changed lay-out) are assumed to play an important role. Already during design and construction, requirements change intentionally or unintentionally. The design process is often organized in such a way that consequences of a design decision for one aspect for other aspects are not explicitly made clear. The hypothesis made at the start of the project is that the mismatch between supply (building and systems) and demand (required performance by the occupants) is due to these changes during design and realization.

Because of costs and the fact that often in a new building project a co-operation with new/other partners takes place, there is almost never a feedback from realized projects to the design phase in the Dutch building industry. It is expected that such a feedback could lead to higher quality buildings.

Based on an investigation of two office building projects, an analysis of causes for the mismatch between user requirements/expectations and the performance of buildings and systems has been made.

METHODS

The investigation of the two building projects comprised of the following activities:

- Documenting building and systems and the use of the building, using a questionnaire for the facility manager of the building, analysis of design documents and a visual inspection of the building.
- Interview with the facility manager about experiences with building and systems.
- Determination of the opinion of the occupants using a questionnaire.
- Inventory the (development of the) requirements with regard to the indoor environment and decisions/choices in the different phases of the project (brief/design/specifications/construction), using documents.
- Verification of the performance with regard to indoor environment in the building using calculations and measurements.
- Interview with stakeholders of the building project (initiator, design parties, consultants, contactor, manager) focussing on the process aspects (project organization, quality control).

The buildings have been investigated during normal occupancy.

The aim of the analysis is to find out if the buildings meet the requirements in the brief and the actual demands by the occupants and the organization. The hypotheses that the mismatch between supply (building and systems) and demand (required performance by the occupants) is due to changes during design and realization is tested. For both projects, discrepancies between requirements/choices in different phases of the design and construction process are mapped.

Characteristics of the investigated buildings (located in Amsterdam and The Hague, The Netherlands) are presented in Table 1.

Table 1 Characteristics of the investigated buildings

Aspect	Building A	Building B
Floor area (m^2)	±12 500	±27 000
Number of floors	5	21
Conditioning	Heating, cooling, humidification	Heating, cooling
System	VAV, reheat	Ceiling induction system, reheat
Individual control	Yes (room thermostats)	Yes (room thermostats)
Rooms	Cellular/multi-person/landscape	Cellular/multi-person (4–6)
Windows	Not operable	Operable
User	Owner	Tenant

RESULTS

During the design and construction of building A there have no been no major changes from the initial design. Remarkably, in the early design process there has been no comparison of different HVAC systems. Already in the pre-design phase, a VAV system has been chosen.

The occupants complained about high temperatures, low temperatures/draught (locally), high noise levels, insufficient personal control and unsatisfactory reaction on request for changes. Satisfaction in the landscaped offices was clearly lower than in the one to four person rooms.

A common cause for insufficient temperature control was defective VAV boxes. Despite the presence of a building management system, this kind of failure was detected when occupants complained about temperatures in their working rooms.

The individual control of the indoor climate in building A claimed for in the brief has not been accomplished. There are several causes for this mismatch:

- Insufficient airflow rates per room, in combination with a high internal heat load due to a higher occupancy rate and use of equipment (PCs).
- Insufficient flow rate for the building as a whole; the system was designed based on the assumption that the flow rate should be sufficient to cope with 80% of the total heat load of the building.
- The chosen layout (more complaints in multi-person rooms and landscaped offices).

In building B, a careful selection of the HVAC system has taken place, comprising a full-scale test in a laboratory. At the end of the design phase, a rather drastic change in the design was made. Instead of passive chilled beams, ceiling induction units (active chilled beams) were chosen as the terminal unit. The occupants complained about low temperatures/draught, insufficient personal control, insufficient use of operable windows and high noise levels. The highest levels of complaints were found in the multi-person rooms (more than four people in one room).

Low temperatures were found to be caused by an insufficient air tightness of the facade (windows) and insufficient control of the supply air temperature, as was shown during measurements. There had been no tests of the air tightness of the facade during the construction of the building. Like in building A, despite the presence of a building management system, the insufficient supply air temperature control was not seen timely.

In both projects, there was no structural feedback from user phase to design phase.

DISCUSSION

At the start of the project, a hypothesis was postulated that a large number of changes of the design/ building between brief and use would lead to a mismatch between supply and demand (see Introduction). Based on the results of the investigated building projects this hypothesis could not be confirmed. The number of changes was limited. The changes that were made in the plans were not the cause for failure. The design teams evaluated consequences of changes of one aspect on other aspects.

There was no structural feedback from the use of the building to design and construction by the organizations involved in the design and construction of the building. After handing over, there is no evaluation of the performance of the chosen concept/solutions. This means that the experience gained in the project is not used to improve the design and construction of future buildings. From the interviews with the stakeholders it can be concluded that is a common approach in the projects of the associated stakeholders.

Specifically in building A, the specifications could not be met due to a different use of the building than assumed during design. This is a well-known phenomenon (Rutten and Trum, 1998). The changing performance requirements in time of a building (including HVAC systems) are difficult to predict. The design process is often characterized by a tunnel vision (see Figure 1).

Based on expectations about the early use of the building, the brief is drafted and a prediction of the optimal solution for this set of requirements is made. When the actual use differs from this predicted use, e.g. a higher occupancy rate resulting in a higher internal heat load, the user is confronted immediately with the limitations of the ‘tunnel’ design.

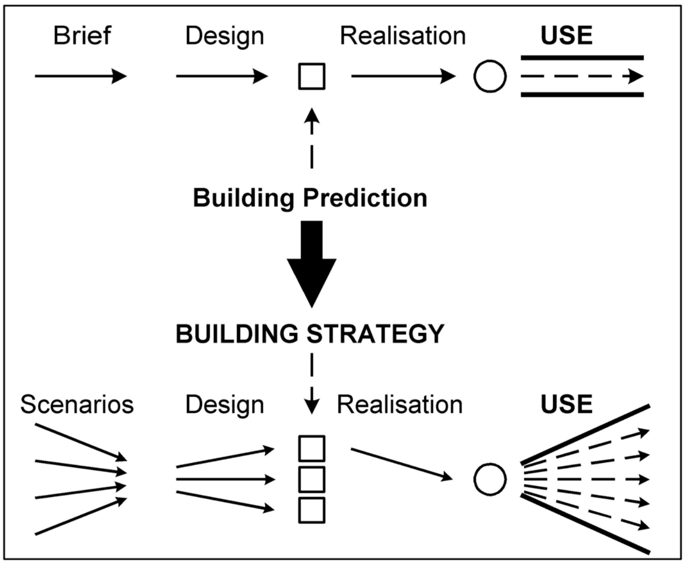

Figure 1 Building prediction versus building strategy oriented towards future use (Rutten and Trum, 1998).

In contrast to this traditional approach it is preferable to develop a number of scenarios of use that comprise a broad spectrum of possible future use. The design then leads to a building strategy that is capable to support a wide range of use. The result is a flexible, robust building design.

'Collaborative design', sometimes also called 'strategic design', could be an appropriate way to organize the design process (see Figure 2).

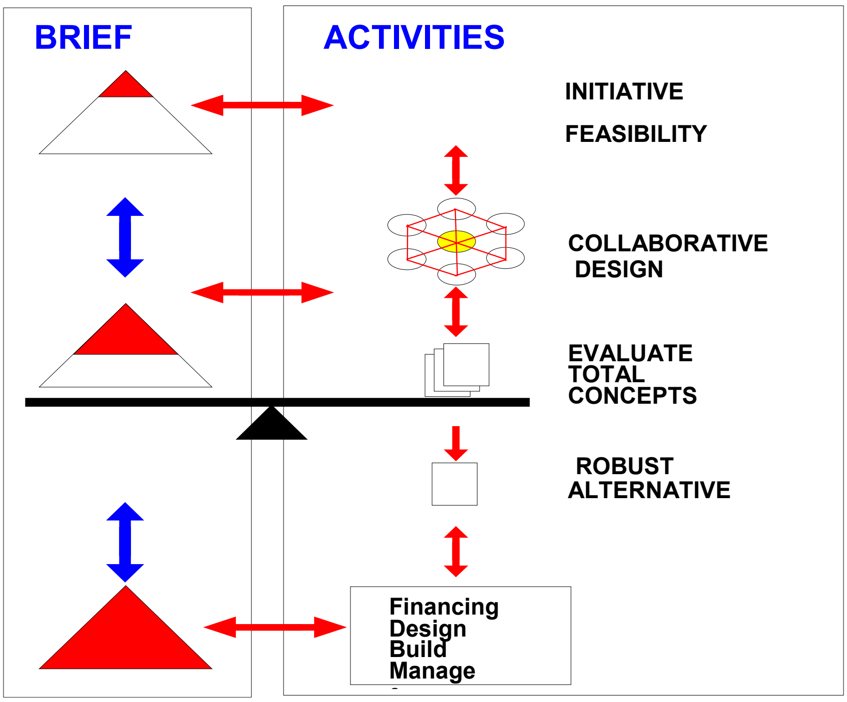

Figure 2 Schematic view of the collaborative design process (Rutten and Trum, 1998).

When making choices for the control of the indoor environment, the layout should also be taken into account. As in other studies (Leaman and Bordass, 2001), it showed that the indoor environment in rooms with more than four persons is rated less than in rooms with less persons (e.g. cellular offices). Specifically, indoor climate, noise and personal control were rated lower. Personal control is an important condition for a high appreciation of the indoor environment. In multi-person rooms or landscaped offices an existing local control (room thermostat) does not really provide personal control. In the new office concepts, with communication between workers as important motive, large-scale multi-persons rooms are more and more common. The eventual increase in productivity due to the more efficient communication might be counteracted by dissatisfaction or complaints about the indoor environment. Personal environment system or task conditioning systems, with local air supply (e.g. incorporated in the desk or via the floor; Baumann and Arens, 1996; Wyon, 1996), might be a solution but until now is rarely implemented. Several studies (Baumann and Arens, 1996; Wyon, 1996) have shown a positive effect on the perception of the indoor environment and as a result on the productivity of the workers, using this kind of systems.

Despite intensive attention, HVAC systems are still often the cause for complaints, as was the case in building B. Partly this is due to trivial mistakes in design or calculations. Quality control of design and construction (commissioning) can prevent these causes for malfunctioning. In the Netherlands, commissioning is still not very common in building practice, but gets a growing attention.

A second important cause for the complaints is simple malfunctioning of the systems. Despite the fact that building management systems were present in both investigated buildings there was no early warning in case of defects. In Leaman *et al.* (2002) it is stated that the higher the technical complexity of the HVAC system the higher the level of management that is required. It is estimated that this investment (in time and money) will be repaid by less failure or quicker repair of failures with less absenteeism, complaints and production loss.

The correct functioning of the HVAC system, with its dynamic behaviour, can be tested or proved during the real use of a building. By monitoring the occupation of a building, e.g. with help of a building management system, a fast response to deviations of the required performance is possible and ‘fine-tuning’ of the system can take place. Automatic fault detection and diagnosis with a building management system could play an important role.

In the UK, attempts are made to make Post-Occupancy-Evaluation (POE, referring to an audit during normal occupancy) a standard part of a building project (Jaunzens *et al.*, 2002). According to the initiators, this POE should be carried out in the first year of occupation of a building. The design and building team can evaluate how everything works, finetune the building and system and learn lessons for future projects. The users can better understand how the building is thought to function, leading to improvement of the performance and lower costs for use. Problems can be identified sooner and be handled more effectively in a spirit of co-operation instead of blaming the others. The authors point out that the problem of liability has to be solved to prevent a culture of fear, blame and conflict. It is expected that the cost for carrying out the POEs will be more than compensated by better performance of the building, prevention of problems and disputes and quicker learning of parties involved (Jaunzens *et al.*, 2002).

CONCLUSIONS AND IMPLICATIONS

The hypothesis that a large number of changes of the design/building between brief and use would lead to a mismatch between supply and demand in the finally realized buildings could not be confirmed based on the results of the investigated building projects.

This investigation has shown that the early design phase and the handing over phase are crucial with regard to the match between supply and demand with regard to a building and systems.

In the early design phase, the focus should lie on the development of a flexible, robust building design that can cope with a broad spectrum of scenarios of use. The design should lead to a building strategy able to provide the required performance for this broad range of use. A way to achieve this might be a 'collaborative' or 'strategic' design process.

Despite broad attention, HVAC systems in buildings are still a major cause for complaints. Partly this is due to design and construction faults that could be prevented by a better quality control e.g. by implementing commissioning in the building process. To date, this is seldom done in the Dutch building industry.

A second important cause is the simple malfunctioning of systems. This malfunctioning is not detected timely enough, leading to high numbers of complaints. Building management systems, which are present in many buildings, are not used for automatic fault detection and diagnosis. It is estimated that the time and money investment in for better monitoring will be compensated by timely repairs of defects, leading to less complaints, absenteeism and production loss.

Monitoring the performance of a building and its systems is especially important during the occupation of a building.

In view of the growing number of new and often more complex buildings and systems, structural feedback from the user phase of a building to the design phase is supported. Integrating this feedback into the building process would lead to—structured—learning from factors for success for creating healthy buildings.

ACKNOWLEDGEMENTS

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