

36 STUDY OF BUILDING SERVICES AND INSTALLATIONS

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36.1 INTRODUCTION

36.1.1 Building services: objective and means

The purpose of building services and installations is to support the building functions, so that buildings can fulfil their functional demands. They can also be a means to ensure that buildings answer economic or societal purposes. Finally, technical installations can be a formative factor in determining the shape of the building. In that case, contrasts between styling and functionality can come into being and should be balanced against each other: a subject of research.

36.1.2. Scope of the research

Examination of building services and installations entails a wide range of purposes, subjects, applications and methods, from technical studies focused on development of equipment and systems to investigations relying on specific methods to measure the effects of such installations on people. One aspect of the application study relates to the design of installations as part of the design process of buildings. ‘Technical’ studies with aspects of social sciences focus on problem solving in the case of complaints and on development of diagnostic methods. Study centring in methods from social sciences is the exploring and hypothesis formulating study needed in order to know installations as they relate to the building and building occupants as a risk factor. Ultimately study also serves improvement of building installations and their application and to improvement of the design process.

36.1.3. Problem-solving studies

Such studies normally take place in response to specific complaints from building occupants. If it is suspected that the cause may lie in technical installations, it is customary for investigation to be carried out by maintenance technicians. Such first line surveys are often performed in response to an ‘explanatory complaint’, in which people do not say what is bothering them, but what they think is causing the problem.^a First-line investigators normally do not know what to do with complaints about headaches, dry skin, contact lens problems and such. In order to change their situation, affected people tend to mention a cause, like “the air conditioning does not work properly”, because technicians will respond to that. If these complaints are taken literally, it is likely that the wrong track will be followed and the real cause will never be found, also because the appropriate experts may not be employed. Complaints on head-aches and such-like can have many causes; as do causes hailing from the building, type of work and the complainers themselves. When a situation has developed with a great many unexplained complaints the idiom ‘Sick Building Syndrome’ may well be used. In order to prevent originating that syndrome and to lower the number of unexplained complaints, diagnostic methods have been developed for first-line investigations.^b This teaches researchers to take complaints seriously, but not literally.

Questionnaires are used in order to ascertain what is ailing complainers and what they experience. The conditions prevailing in the building pass muster systematically with the help of a checklist to make an inventory of possible causes of complaints. The investigator must try to find a likely solution by matching the list of complaints with the list of possible causes.^c

If the first-line investigation does not yield results, specially trained second-line investigators can be called in. They frequently work as described above, but are more knowledgeable and experienced, and can carry out measurements. In case this inspection also does not yield results, the survey can be extended and the building investigated in its entirety, taking into account risk factors in the surrounding area, the work place and the organisation. This type of inves-

36.1	Introduction	327
36.2	Climate control	330
36.3	Transport installations	335
36.4	Electrical installations	335
36.5	Sanitary installations	336
36.6	Communication installations	337
36.7	Façade maintenance equipment	337
36.8	Preventing risks of complaints	337
36.9	Difference between classroom and practice	338

a Schalkoort, T.A.J. (1987) *Sick Building Syndrome, bewonersklachten, mogelijke oorzaken en oplossingen*.
b Schalkoort, T.A.J. (1988) *Wat wordt verstaan onder ‘Sick Building Syndrome’ en hoe moet met het daarbij behorende klachtenprobleem worden omgegaan?*; Schalkoort, T.A.J. (1991) *Ontwikkeling en behoud van gezonde kantoorgebouwen - Studie naar het ‘Sick Building Syndrome’ en de mogelijkheden van het terugdringen van bewonersklachten in kantoorgebouwen*.
c Kurvers, S.R. (1994) *Handleiding voor de aanpak van gebouw- en werkplekgerelateerde klachten*.

tigation is similar to 'Building in Use' evaluation and methodologically comparable to 'Post Occupancy Evaluation', see also paragraph 36.2.5.

36.1.4 Hypothesis-forming

Hypothesis-forming is carried out on the assumption that there is a relation between certain aspects of buildings and specific health complaints. This type of examination is often carried out as an epidemiological study. Many of these studies have been executed in order to gain insight in the causes of the 'Sick Building Syndrome'.^a

The most important conclusion was that the more influence the inhabitants of a building have on their situation, the less they complain. They should be in a position to operate the climate control and shading installations themselves, as well as to open windows.

Characteristic for study in epidemics is the large scale with which data is being assembled. For study as considered here, usually dozens of buildings are investigated. Next to the properties and characteristics of the buildings themselves, data is collected on environment, installations, furnishing, type of work done in the building and the inhabitants. Key instruments of study are a questionnaire presented to the inhabitants, a building checklist and a measurement protocol. Development of these instruments has received a lot of attention internationally; with the objective to lessen the ambiguity of the results in order to make them better mutually comparable.

A certain size of the population to be studied (buildings and people) is necessary for reaching reliable statements on possible relations. Statistical considerations determine the size through the number of relations that should be demonstrated and through the statistical distribution of properties and characteristics. These relations and distributions must be known for determining the population size, and consequently for performing the study. At the same time, the study is precisely undertaken to get to know them: a well-known methodological problem and subject of discussion; as in 'objective orientated' and 'means orientated' study.^b For meaningful study there should be an idea about possible relations, however vague it may be. Usually, ideas come into being during problem solving studies. Furthermore epidemiological study is not more than a hint that, possibly, causal relations exist. Causality and the question whether one factor influences the other, or vice versa, may be demonstrated by intervention study.

36.1.5 Intervention-study

Intervention study entails changing one factor under controlled conditions; that is to say that all others remain constant. The effect of that one change is then measured. This way a causal relation can be demonstrated. Intervention study can be conducted in normally functioning buildings as well as in laboratories. The most convincing kind is a 'double-blind' study. Then not only the persons studied, but also the people conducting the study are not aware of the fact of whether something has changed; and what has changed. The conditions prevailing when nothing has changed serve as 'control' population.

The study of an effect of a factor on people, for instance a factor of the internal environment, may be needed to get insight into the 'dose/effect relation'. Such a relation provides a basis for developing norms for an acceptable dose (and with that an acceptable effect). This study may be conducted in normally functioning buildings as well as in laboratories. In many cases the study is performed by universities or scientific institutions.

Intervention study may also relate to a factor in a process. The usefulness of the diagnostic method, described in paragraph 36.1.3, for better dealing with complaints, for instance, can be studied. For performing the study a number of buildings should be considered, let us say twenty. The buildings should be largely comparable in terms of size, usage and inhabitants composition. Before the intervention the situation should be measured by presenting a questionnaire to the inhabitants. That may be a sample, for instance one of 10% of the inhabitants.

- a Finnegan, M.J., A.C. Pickering et al. (1984) *The Sick Building Syndrome: prevalence studies*; Burge, P.S., A. Hedge et al. (1987) *Sick Building Syndrome: a study of 4373 office workers*; Kröling, P. (1988) *Health and well-being disorders in air-conditioned buildings: comparative investigations of the building illness syndrome*; Preller, L., T. Zweers et al. (1990) *Gezondheidsklachten en klachten over het binnenklimaat in kantoorgebouwen*.
- b Bergh, W.H.J. van den, A.C.J.M. Eekhout et al. (1999) *Methodologie is elkaars methoden begrijpen*; Eekhout, A.C.J.M. (2000) *Over de dialoog tussen doel- en middelen gericht ontwerpen*.

It should also be ascertained how complaints are being taken care of in the buildings concerned. Management of, say ten, buildings may be provided with the diagnostic method employed, for instance in the form of an expert system. The management of ten other buildings (the control group) just get general information. After six months, and again after a year all buildings are measured and conclusions may be drawn from the differences.

An intervention study of the effect of a particular design method may be imagined as well. A study like that could be performed in architectural education.

36.1.6 Development-orientated research

The development of equipment and systems entails more technical research. In this connection, one can think of investigations into cooling capacity of a chilled ceiling, the energy yield of an absorption-cooling process, the airflow pattern of an air supply grating, and similar issues. The purpose of this research is to attain (more) insight into how these systems work and / or how to improve their functioning. The analysis may also be related to energy use, life span and production methods. Manufacturers or large users of building installations (e.g. utilities companies) usually carry out this type of work. In a limited number of cases, study of this type is conducted at universities, like at the Faculty of Mechanical Engineering and Maritime Technology in Delft.

Developers seldom publish their study or study methods because they do not profit by that; for reasons of competition. Because of this, the study does not achieve scientific status. That does not imply that the study could not stand scrutiny of scientific criticism. Development study executed by universities is often published. In commissioned studies one is more secretive.

Research reports have to include the subject of investigation, description of the experiment set-up, methods and instruments; measurement results; analysis methodology and results (often graphs or mathematical models). Typical of this type of investigation is use of a model for the subject under investigation.

For example: in the case of the cooling capacity of a chilled ceiling it is known approximately how things work. On the basis of data from the literature it is possible to describe a theoretical model; like the heat transfer between the cooling water and the indoor space that can be described with empirical relations and 'non-dimensional' numbers like those of Nusselt, Prandtl, Grashof and Reynolds.^a A trial installation and measurements are needed in order to be able to determine the co-efficients in those relations, since they depend on characteristics of the airflow along the ceiling. The behaviour of the air current varies between a laminar stream and turbulence and also has the characteristics of a mixture of both natural and forced convection. The description of the theoretical model is one initial step in the development study.

36.1.7 Application-related investigation

Application-related studies may concern the effects of heating, ventilation and airconditioning (HVAC) installations on indoor environmental conditions, or on people. These studies can be conducted in normally functioning buildings or a laboratory. Indoor climate conditions are charted using checklists and measurements. People's reactions are measured by having them answer questions with a questionnaire. During study in a laboratory it is possible to objectify human responses by measuring physiological functions: heart beat, oxygen uptake, skin temperature.

The conclusions of the study are usually formulated quite carefully, since they are also based on statistical analyses of subjective data collected by means of questionnaires. With this type of analysis several techniques are used in order to be able to demonstrate relations.^b Although execution of the study and the manner of reporting usually obey scientific standards, the results are seldom published in refereed scientific journals; rather during interna-

a Knoll, W.H. and E.J. Wagenaar (1994) *Handboek Installatietechniek*.

b Orlebeke, J.F., P.J.D. Drenth et al. (1983) *Compendium van de psychologie. Dl. 8. Methoden van psychologisch onderzoek, het verzamelen en scoren van data, statistiek*.

tional congresses like 'Healthy Buildings', 'Indoor Air' and 'Clima 2000'. Also congresses of the American ASHRAE and the 'ASHRAE Transactions', published as a scientific journal next to the professional 'ASHRAE Journal', are highly esteemed.

36.1.8 Design-orientated studies

Design study is a form of application study. Such investigations are used to work out which technical or architectural facilities are necessary for meeting the functional requirements of a building with given characteristics and intended use. In addition to selection of the system, design study is aiming for the dimensioning of facilities. The study of the functional requirements based on the function of the building, is an essential part of this study.

Various installations are needed to make buildings fit for their function:

- climate control (heating, cooling and ventilation)
- transportation (elevators, escalators and similar)
- sanitary facilities (hot and cold water supply, sewage)
- electricity (lighting, power supply for machines and equipment)
- communication (telephone, data, security and similar)
- maintenance of building envelope.

In the paragraphs to follow, the design process of these functions and the type of research necessary will be worked out.

36.1.9 Evaluation

Design of building services and installations can be assessed beforehand (evaluation 'ex ante') and afterwards (evaluation 'ex post'). 'Ex-ante' evaluations are increasingly being carried out as part of the design process, because their use leads to better insight into the effects of the dynamic properties of the building than the usual static design methods. In such a case the aim of the evaluations is optimising the properties of the building; for instance to make mechanical cooling superfluous. The evaluation may also be needed to forecast the effect of specific installations under conditions not applied previously. See paragraph 36.2.4 on page 333 for a more detailed description of this study.

'Ex- post' evaluation is needed to judge whether the functional goals of a design have been reached. This is the final stage of the design process that makes the design into a scientific feat, if the process is regarded as an empirical cycle (see page 249). A study like that is seldom conducted in practice if an architectonic design is concerned. This does not derive from the fact that there are methods known for conducting ex post evaluations. See paragraph 36.2.5 on page 334 for a description of the study concerning climate installations.

36.2 CLIMATE CONTROL

36.2.1 Functionality

The building functions determine the requirements in terms of comfort and usage that should be honoured by the indoor climate. The study of these requirements is the first part of the design study. Climate control may be realised by installations, constructional facilities or both. The shape and thermal properties of the building determine whether mechanical systems must be used or whether architectural provisions can be made. Comfort requirements and demands of use can be met by installations, provided they have sufficient capacity and are spatially positioned so that they do not cause annoyance. This demands something of the building: a sufficient amount of built-in space at an appropriate spot.

In order to be able to meet the requirements always, the installations must be accessible for maintenance and replacement. If the building should be flexible in terms of function or use, then the installations should also be flexible or at least adaptable. Insufficient built-in space leads to the use of installations that are too small; these do not have the required capacity, so

it becomes too cold or too warm in the building, or stuffy. Or, these installations must do more than they are designed to do, without creating noise or draught problems. If terminal devices are wrongly located, it may cause draughts or unpleasant temperature gradients. These design mistakes can be prevented by ensuring that the architectural design and the design of the load-bearing, partition, and finishing constructions are in tune with each other and are being carried out synchronously.

It seems logical that the functions of the building determine which demands the indoor climate must meet, and that is indeed true. It seems less logical, that it may not be clear during the architectural design process what the function is of a particular space, and thus, that it is also unclear which demands this spatial area must meet. Often it concerns spaces that originated as a consequence of the architectural design and not because of their being mentioned in the programme of requirements. Glass spaces and atria are well-known examples. It is also possible that spatial areas are created as required by the specifications, but for which it is predictable that they will not be able to meet the normal demands related to their function, regardless of the installations or architectural measures taken. It may be attractive, for other than functional reasons, to build such spatial areas as they were designed. In that case the function of the space or the permanent character of that function should be re-examined. Often, such re-examination is not - or not openly - carried out, which leads to a lack of clarity about the possible use of these spaces. This is not a design error, but a mistake in the design process. This could be prevented by a project organisation in which all parties concerned, including client and future users, communicate openly about what is possible and what is impossible.

36.2.2 Requirements

Utility buildings usually owe their level of facilities to the requirements organisations put to them in their rôle of user. Inhabitants (people working in the building) have often different wishes. Not everything users or inhabitants expect of a building is made explicit as a requirement. For instance: a programme of requirements will never mention the quality of the water that should come out of the taps. Only if users or inhabitants have experienced an aspect as a problem, it gets attention and will there be conscious requirements formulated. It is the task of architects and advisers to establish a balanced schedule and to communicate about it with those involved. Functional requirements to be reckoned with in an installation design have been formulated largely in laws, standards and other rules. They relate to the thermal climate (temperature, velocity and humidity of the air), airpurity (ventilation), lighting (luminosity, contrasts and colouring) and acoustics (amongst others sound levels and reverberation times). Collecting this data is the first step in the design study.

36.2.3 Design process

Building and installation design

The indoor climate depends much of the time on the HVAC installations. This dependence is directly proportional to external loads (meteorological conditions, traffic and industry) and to internal loads (number of persons, artificial lighting, apparatus, production processes, building materials): the heavier the loads, the greater the dependence. The architect can influence this situation, primarily by reducing external and internal loads, and, secondarily, by reducing their effects.

A proper thermal insulation of the façade and use of sunblinds, keeping the solar heat out while allowing optimal daylighting, can reduce external heat load. An optimum is usually found by using adjustable (outside) sunshades. Tinted glazing and awnings also reduce heat at times when sun and daylight are needed. External load from emissions of annoying or harmful particles by traffic or industry can be reduced by not building in an area with traffic or industry.

If this is not possible, the façade must be constructed in such a way that it can be properly closed off, and the building must be equipped with mechanical ventilation including a proper air-filtering system (see paragraph 36.8, page 337).

Internal heat load is strongly dependent on the use of a space. The power of artificial lighting can be reduced by using high / shallow spaces and by making the façade less transparent. To clarify: in order to attain comfortable relative brightness, artificial lighting is required in proportion to the transparency of the façade. The optimum lies at about 30% light openings in the façade (as seen from the inside). Extracting air through the lighting fixtures can halve the heatload from the artificial lighting. Advising the client to use energy-efficient equipment and computers can reduce heatload from appliances. In this context one can think of computer screens turning off automatically when not in use. Further, it is possible to directly extract heat and contaminants from apparatus, for instance, by using furniture with a built-in extraction system. Thus, 70% to 80% of the heat and contaminants of apparatus can be discharged and does not enter the room.

The effect of heat load on the indoor climate can be reduced by a high capacity of heat accumulating mass. The mass absorbs heat during the day, emits it during the night. The mass of floors and partition walls is especially important. Preferably, the mass should not be shielded by false ceilings, panelling, raised floors, etc. Often, for reasons of flexibility, light movable partition walls are chosen. In practice, it turns out that many of these walls are never relocated. Here also are opportunities, if the designer can discuss this with the client. These opportunities are much reduced if the development is aimed at 'the market' and the location of partition walls is not fixed and changes per tenant.

Design process characteristics

Designing building services and installations is an iterative process, working from generic to specific and from rough to fine. There are various descriptions of the processes. They have in common that the design process is divided into phases. A well-known example comes from the Dutch 'Stichting Bouw Research' (SBR) and 'Instituut voor Studie en Stimulering van Onderzoek op het gebied van gebouwinstallaties' (ISSO).^a This description is summarised below and indicates for each phase of the design process which decisions must be taken with regard to technical and architectural aspects of building-design.

Characteristic of the design process is that decisions continually have to be made on the basis of data not yet available. For instance: in the General Layout (at the Faculty of Architecture in Delft usually referred to as Spatial Design), the overall layout and main dimensions of the air ducts have to be determined. To be able to do that, it must be known which HVAC system will be used. That, however, is not yet clear at the stage of the Spatial Design. Moreover, at a later stage it may become clear that air ducts are not required at all, for instance, because natural ventilation will be all that is required. According to the scheme (figure 337), the choice of system must be made at the Preliminary Design stage. In practice, this is only possible when form and characteristics of the façade (glazing percentage, type of sunshading, etc.) and of partition-walls and finishings (heat accumulating mass, false ceiling, and such) are known. However, these aspects are only considered at the Final Design stage, not earlier.

The scheme shows that design decisions often have to be made on the basis of assumptions and that it has to be checked afterwards whether these assumptions were correct and whether earlier decisions perhaps have to be amended. In this lies the weakness of the design process, because the further the design has gone ahead, the more difficult it is to incorporate changes. On the one hand, this has to do with the fact that practical possibilities to incorporate changes reduce with the progress of the design, while, on the other hand, partners in the design proc-

Phase	Design decision on
FEASIBILITY STUDY	objectives / functions spatial needs financing
PROJECT DEFINITION	schedule of requirements - thermal comfort - lighting and - air tightness and insulation
GENERAL LAYOUT (spatial design)	building structure outline spatial layout & basic dimensions building shape zoning & compartmentation duct layout
PRELIMINARY DESIGN	building construction (=mass) façade construction sunshade, glazing and U-values HVAC system selection HVAC build-in space
FINAL DESIGN	façade details glazing & sunshade systems roof & floor details interior & ceiling details HVAC system sizing control systems

337 Design process according to SBR/ISSO^a

a ISSO and SBR (1990) *Ontwerpen van energie-efficiënte kantoorgebouwen*.

ess are increasingly less prepared to accept changes. Further, one wants to keep to the agreements so as not to endanger progress of the design process. The assumptions must, therefore, always be as realistic as possible and, during the whole course of the design process, the focus should be on reaching coherence between the various design aspects.

This may be achieved by selecting a design method guaranteeing this coherence – and thus optimal integration. The design of HVAC installations from the perspective of installation designers is described in ‘*Concepten voor klimaatinstallaties*’.^a Figure 338 schematically renders how a well-founded system selection can be realised. That does not mean to say that each and every installation designer does it that way.

Installation designers do have their own methods; whilst rarely communicating about them among themselves. They often prefer certain systems while they have good experiences with them. An installation shows almost who designed it. The system selection process described in ‘*Concepten voor klimaatinstallaties*’ chooses the architectural sketch design for point of departure. Next to realising the programme of requirements an important objective is to conform to laws and rules, like those relating to energy conservation. Installation designers do feel themselves responsible for them and want to be held accountable.

The result of the process described is a pre-selection of viable installation concepts and variants. The final selection has just been described globally in ‘*Concepten voor klimaatinstallaties*’. It is a study orientated on requirements of comfort and creation of sufficient built-in space, possibilities of maintenance and management, aiming at flexibility, cost control (investment, energy, maintenance, exploitation), restricting environmental effects and a sufficient performance in terms of energy. It has not been indicated how various aims and costs associated with attaining them are weighed against one another. It is most remarkable that the installation design is described as a free-standing process; not as a part of the architectonic/constructional design process.

Design method

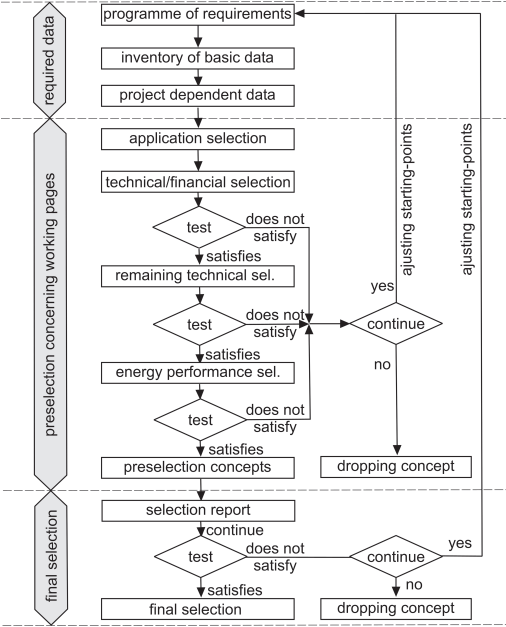
Departing from the given situation that with a design the road goes from generic to specific and from rough to fine, the installation design and the building design can be tuned increasingly better to one another during subsequent stages. The result of tuning always depends on the available data and on detailing those data. It concerns on one side constructional and physical data; on the other – as a consequence – data on the necessary installations and the built-in space needed.

The figure ‘*Integration building and climate control systems*’ indicates which data are required at each stage in order to achieve optimal integration. The use of this method leads to an efficient design process, because the chance that in a following stage the building design may have to be changed substantially in order to accommodate the installations is reduced.

It is typical of this method is that the architect directs the installation design by designing the installations in their form and function. Installation designers may provide support in the way described in the previous paragraph, but the architect remains responsible. The task and responsibilities of the installation designers are detailing and carrying out the calculations for what is chosen by the architect. The detailing concerns the choice of the installation components, dimensioning, cost control, energy consumption and other environmental effects, preparing the specifications and contract documents, quality assurance during construction, etc.

36.2.4 Evaluation ex ante

Evaluation ex ante of the design is possible by means of mock-up investigations or by using computer models. In the case of a mock-up study a space is built, life-size or on scale, with in it the HVAC and lighting installation designed; and in a stable situation measurements of temperature and air velocity are conducted on several point in that space. Summer and winter conditions are simulated by using warm and cold walls; the internal heat load from

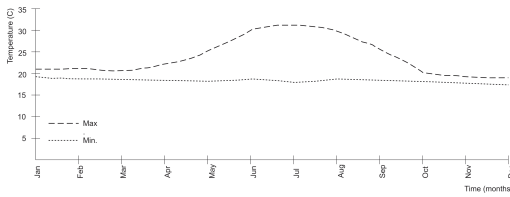


338 Design process HVAC installations

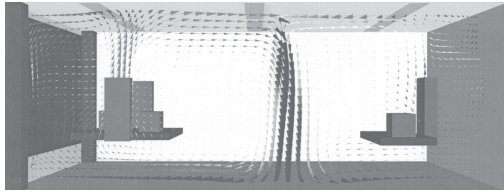
DESIGN STAGE →	GENERAL LAYOUT	PRELIMINARY DESIGN	FINAL DESIGN
DIMENSIONING →	'ROUGH'	'GLOBAL'	'FINE'
INTEGRATION STEP:	based on:	based on:	based on:
DETERMINATION REQUIREMENTS			
- indoor climate	schedule	schedule	schedule
- indoor air quality	"	"	"
- usage	"	"	"
SYSTEM SELECTION			
	room typology	global calculation heat & cooling load	specific calculation heat & cooling load
HEAT STATION			
- location			
- dimensions	building volume	load estimation	load calculation, apparatus choice and room layout
COOLING EQUIPMENT			
- location			
- dimensions			
* central station	building volume	load estimation	load calculation
* cooling towers	"	"	"
* decentral units	room volume	"	"
AIR HANDLING			
- zoning	<- room functions & building dimensions ->		
- central stations			
* locations			
* dimensions	zone volume	estimation m³/h	apparatus choice calculation m³/h and room layout
DUCTS, PIPES AND TERMINAL UNITS			
- locations			
- build-in space	system type	estimation (load & m³)	calculation and apparatus choice

339 Integration building and climate control

b ISSO (1998) *Concepten voor klimaatinstallaties*.



340 Prediction of variations in air and radiant temperature by TO program.



341 Calculation of temperature and air flows by CFD program.

people and apparatus are reproduced by heating elements. This type of evaluation study is increasingly replaced by model testing using computer programs. For evaluation by computer, there are programs available that calculate changes in temperature with time, and programs that predict variations in temperature and airflow through a room. The first type of programs (TO), perform heat load calculations to predict variations in air and radiant temperature for a whole year, including the number of hours certain temperature limits are exceeded. See Figure 340.

In order to include adaptive behaviour of people in the evaluation, there are programs simulating the influence of acclimatisation and clothing. These programs require input of room dimensions, composition and material properties of walls, windows, and sunshade systems, as well as the rate of use and the load from people, and (lighting)apparatus. Cooling and heating capacity plus the control strategy for air supply and temperature also have to be entered. In these calculations, meteorological data from various weather stations and from different years can be used. The programs can calculate energy consumption for heating, cooling and ventilation, and the energy performance of HVAC systems.

Although such programs have been intended to evaluate installation designs, they are also used to test variants in order to optimise the installation design.

With current Computational Fluid Dynamics (CFD) programs, the temperature and air flows (direction and velocity) can be calculated for a space in a two- or three-dimensional grid. By these programs, one can determine the best location for end-apparatus, for instance, in order to prevent drafts occurring in the living area. In order to limit the input it is studied presently how TO and CFD programs may be linked to a graphic CAD system.^a

Knowledge of the physics of the interior environment and of HVAC technology is needed for conducting this evaluation study aided by the computer programmes described here. In addition one should be able to use these programmes routinely. That is the reason that they are not in use – as yet – in regular architectural education. Presently it is being studied how to increase the practicability and accessibility of these programs to such a degree that they could be employed in design education and by architects as a design tool.^b

36.2.5 Evaluation ex post

To finalise the design process, an investigation can be carried out to see whether the designed building meets the design requirements; on that basis the effectiveness of the design process can be judged. In order to be able to determine whether the HVAC system has been designed effectively, it has to be determined whether the indoor climate requirements have been realised. These demands, however, are not sufficient to determine how occupants experience the indoor climate.^c That is why occupant reactions also have to be analysed. For this investigation, ‘Post-occupancy’ and ‘Post-project’ evaluation methods have been developed.

A pre-cursor of the ‘post-occupancy’ evaluation is the ‘Building in Use’ evaluation, specifically intended to find explanations for complaints of building occupants.^d

It is characteristic of these ex post evaluations that surveys have to be conducted and the occupants, or groups of them, have to be questioned with a questionnaire. The results are compared with the results of earlier building investigations. This procedure has provided extensive databases, from which increasingly reliable conclusions can be drawn.

Still larger collections come into being if the data of several researchers are linked. This has been done in the area of indoor climate study and resulted in increased insight in the human capability to adapt to the climate and in mechanisms influencing it.^e This study shows that the preferred temperature in buildings with windows that may be opened is depending on the temperature outside more strongly than in buildings where that cannot be done. This means that buildings with openable windows need less cooling than the other type. This study con-

a Hartog, J.P. den, A. Koutamanis et al. (2000) *Possibilities and limitations of CFD simulations for indoor climate analysis*.

b Hartog, J.P. den, PG. Luscure et al. (2002) *A tool for thermal analysis of conceptual design*.

c Kurvers, S.R. and J.L. Leijten (2000) *A comparison of a pre construction judgement of the design and a post occupancy evaluation in a large Dutch office building*.

d Vischer, J.C. (1989) *Environmental quality in offices*.

e Dear, N. and G. Schiller-Brager (1998) *Developing an adaptive model of thermal comfort and preference*.

firms the idea existing for a longer time that buildings of the first type need less rigorous temperature requirements.^a

International congresses have given a lot of attention to 'Building in Use' study, particularly to the development of questionnaires with minimal length. It has been shown that the original lists of more than 100 questions could be reduced to less than 20 questions. It is imaginable that 'post-occupancy' and 'post-project' evaluations, meant for ascertaining whether realised buildings reach their functional objectives reasonably, may be shortened similarly in length compared to current practice.^b

36.3 TRANSPORT INSTALLATIONS

The study of internal transport of people by means of installations (elevators, escalators e.t.q.) relates to an analysis of the demand for movement and to the performance requirements put to the transport system. This performance is determined by the impression users are getting of the ease with which the demand for movement is handled. For an objective assessment the interval time, as well as handling capacity, amongst others, are used as indicator. The interval time is the time passing between the departure of two cabins following one another from the reception lobby. For the handling capacity the percentage of the occupancy is taken that may be transported in five minutes. By 'occupancy' is meant the number of persons maximally present on the floors served by the elevator in question.

The demand for movement depends on usage and partitioning of the building and the location of the building with regard to public transport. Buildings close to a train or metro station have to cope with higher peaks in the demand for movement than buildings relying on private transportation. Horizontal distribution of the traffic flow from the entrance to the building may serve in first instance the lowering of the peaks at the elevators. Escalators are also used for this purpose. In the case of buildings for one organisation peaks are higher than in buildings housing several organisations with varying or 'gliding' shifts. In department stores, hospitals and their ilk opening times, visiting hours etc. are responsible for peaks. With varying shifts and the spreading of opening hours, peaks will be lowered and the performance of the transport systems improved.

In the case of a spatial design a global analysis of the traffic flow in the building usually suffices; location and number of elevators (and possibly escalators) is determined on the basis of tables and rules of thumb. For the preliminary design number, sizes, type of motor, steerage and elevator speed are often determined with the aid of simple calculation rules and statistics-based computer programs supplied by elevator manufacturers.^c In the case of very high buildings – where vertical transport may be of great influence on the shape of the building – this study should be conducted during the spatial design stage. For the final design simulation programmes are available enabling study of the traffic; also between floors. For the study aided by simulation programs specific knowledge of transport systems is needed as well as routine in working with them. Elevator manufacturers and a limited number of consulting companies possess this knowledge and routine. In architectural education until now only use is made of simple calculation rules and of programmes based on statistical data.

36.4 ELECTRICAL INSTALLATIONS

36.4.1 Lighting

The demand for artificial light within buildings depends on the presence of daylight. By tuning daylight and artificial light, a considerable amount of energy saving may be realised, particularly in utility buildings. As mentioned earlier, a lot of daylight does not mean that less artificial light is needed. Often it is just the other way round. More important than the amount of light (measured in the illuminance) is evenness of lighting. That is certainly applicable for spaces where work is done relying strongly on the visual function, when precise perception of small details is important, of slight differences in colour, or tiny contrasts. In the case of tuning the lighting on this limiting too large contrasts between work-surface (the task put to

a Schalkoort, T.A.J. (1994) *Normen voor een acceptabel binnenklimaat*.

b Leaman, A. (1989) *Building use studies, Post-occupancy and post-project evaluation*.

c Schalkoort, T.A.J. (2000) *Handleiding liftenprogramma*.

the eye) and surroundings is crucial, next to limiting reflections and blinding. However, it may happen that reflections and direct light are needed; for instance in order to perceive small faults in shapes or in properties of a surface. Optimal tuning is possible with regulating the amount of daylight as well as of artificial light. During the past two decades scientific study has been conducted of this combined control (also at the Technical University of Eindhoven).

Because of the development of artificial lighting, particularly fluorescent lamps ('TL'), the interest in daylight as a light source was waning for a while. Windows got much more attention in their function of visual connection between inside and outside and as architectonic elements in order to create contrasts in the appearance. Precisely these contrasts may work out unpleasantly in rooms where specific visual tasks should be executed; or may be even too stark. This may then be corrected by artificial light, shading against the sun, curtains and their ilk; at the cost of the architectonic contrast intended, of course. This implies that there exists tension between functional requirements and architectonic design. Consequently, the two should be balanced.

For the stage of the spatial design a study of the type of lighting, placing the lights and spacing cables usually suffices. During the stage of the preliminary design the placing of the light-spots and detailing of the space are tuned to one another (compartmentalisation, lowered ceilings etc.). At the final design it is studied which specific lighting fixtures are precisely needed in order to realise the requirements put to lighting in the project definition. The lighting requirements relate to strength, evenness, contrasts, colour rendering and colour temperature. Computer programs are available for studying type and positioning of the lighting fixtures that may be used; the size of the rooms and the reflection co-efficients of ceiling, walls and floors are input to these programs. They contain lighting technical data of a range of products. That is also the reason that these programs are usually made by manufacturers or providers of the equipment needed.

36.4.2 Power supply

For the design of the remaining electrical installations, like electrical power supply to equipment and machines, study is only conducted for the total needed and for the positioning and the space needed for transforming and housing electrical power and such like. For this, use is made of safety requirements – often formulated in national standards (e.g. NEN 1010) – of rules of thumb, and experiential data.^a The physical hierarchy of electrical groups and switches is determined on the basis of constructional drawings. Knowledge and experience based on the lore of the craft is used. As far as known, scientific study is exclusively conducted in the areas of producing, transporting and distributing electrical energy.

36.5 SANITARY INSTALLATIONS

Sanitary installations comprise sanitary apparatus and facilities for producing and distributing hot and cold water. Facilities for sewage and discharge of rainwater often is included. For the design of these installations as a whole, knowledge and experience based on the lore of the craft is used. The probability that this knowledge and experience is not used is large, since the importance of this 'plumber's work' is often recognised insufficiently. This importance concerns particularly the built-in part of the sanitary installations that is in the building construction. If an insufficient amount of attention is given to this, cumbersome side-effects may emerge: water hammer, noise of flowing water, stench, sewage to the outside. When the building is ready, the possibility of correcting for them is usually slight. Trouble can be prevented by dimensioning pipes for hot and cold water, sewage and rainwater generously (but not too generously) with minimal curvature and – of course – by allowing for this timely in the architectural design, so that a sufficient amount of built-in space has been reserved. For sewage the horizontal pipes should have a slope not too slight; long horizontal pipes – certainly if they are realised within concrete floors – should be avoided as much as possible.

22 An. (1998) *Elektrische installaties, ontwerp en dimensionering: hoofdlijnen*.

During the spatial design a study of the number, the most logical placing of sanitary equipment and of the horizontal and vertical built-in spaces is usually considered to suffice. The pipes are dimensioned during the preliminary design.^a At the final design stage, the selection of the material and the connecting technique is determined.

Increasingly, attention is being paid in the case of sanitary installations to environmental effects. In particular it is attempted to restrict the use of energy in the production of hot tap water, for instance by solar energy. Unfortunately water heated this way may provide 'ideal' circumstances for storage and growth of pathogenic micro-organisms like legionella pneumophila. Outbreak of legionellosis can be prevented by heating water from solar energy always to 60 degrees Celsius minimally (electrically or with a heating furnace). See also paragraph 36.8.

36.6 COMMUNICATION INSTALLATIONS

In order to be able to keep pace with the stormy developments in communication, utility building should have access to a flexible and adaptable infrastructure and built-in space to install such a structure and to expand it, if need be. Consider cabling, network servers, patch-panels and their like. The development is so highly paced that vested insight in this field may change within a very short time; sometimes months. The time needed to realise buildings runs a lot slower. This means that (optimising) study for data communication installations as they relate to design of the building is relatively senseless. A vision of the future provides a better basis for selecting and choosing. Up to now, raised floors, above a space that may be simply accessed (so-called 'computer -floors') have proven to be the most flexible option. That does not prevent buildings with such floors from demonstrating similar Gordian knots of cabling as the buildings where ducts for cables (on walls or in floors) have been applied. Obviously one does not take the time to move furniture to provide access to the space under the floor. In both cases (computer-floors or floor-ducts) ducts integrated in the furniture could provide a solution to reduce the mass of cables on the floor. Independent of this, data communication equipment and cables require less and less space; and instead of cables increasingly use is being made of infra-red transmission for communication between the pieces of equipment and between equipment and networks.

36.7 FAÇADE MAINTENANCE EQUIPMENT

Architects should indicate how maintenance of the skin of the building can be done safely. It should be accessible safely in its entirety for cleaning windows, paint-work, inspection, replacement etc. Ladders are allowed up to a height of 10 metres for washing windows. Higher than that, a 'cherry picker' may be used up to a maximum of 25 metres, if it is placed sufficiently close to the wall and safely secured on the ground. At greater heights – and in the case of walls bordering on ponds and inner gardens – they cannot be used and special facilities have to be implemented. During the spatial design the possibility of this type of maintenance should be studied, since it might cause adaptation of the shape of the building, certainly if slanting or protruding walls are considered. Large surfaces of panes under an angle, like those of conservatories and atria, should be studied for accessibility; in these cases also on the inside. At the preliminary design stage it should be checked how special facilities, like suspended access-equipment, can be implemented and what that entails for the detailing the wall and the construction of the building. During this design stage it should be studied, amongst others, how the suspended platform or chair can glide along the surface of the wall. During the final design stage the construction of the façade cleaning installation is dimensioned.

36.8 PREVENTING RISKS OF COMPLAINTS

Presently more than half of the occupants of office buildings is dis-satisfied with the internal climate. In other utility buildings as well (schools, hospitals and their likes) considerable dissatisfaction is rampant. National and international studies show that a large part of this is caused

a Schalkoort, T.A.J. and P.G. Luscure (1996) *Binnenriolering en hemelwaterafvoer, ontwerp en dimensionering*.

by other aspects of the building than the HVAC installations.^a Dis-satisfaction and complaints may be pre-empted by applying in each design stage a strategy that restricts or reduces risks of complaining. This strategy, often alluded to as 'Healthy Building'^b is best used by the designers of the building themselves. When other parties are being made responsible for reducing the risks of its study, the risk as described in paragraph 36.9.3 comes into being.

36.9 DIFFERENCE BETWEEN CLASSROOM AND PRACTICE

36.9.1 Research in learning situation

There is a difference between the study as conducted in the learning situation at the Faculty of Architecture and the study in practice. In architectural education fewer design stages are being gone through. Teaching restricts itself usually to the Project Definition, Spatial Design and Preliminary Design. In a small number of exercises a Final Design is made.

The learning situation at the Faculty is aiming at the emergence of an attitude where the building designer in the making feels him/herself responsible for the installations of the building and for the functional goals that should be realised. In order to reach this aim in the learning context, study is also conducted that does not belong typically to the task of, for instance, architects, but to the one of installation designers and advisers. These exercises should give the experience what consequences certain constructional and architectonic design decisions entail for the type of installations and for the built-in space needed to house them.

36.9.2 Research in practice

Practice comprises more stages of the design process than have been trained in the learning situation. In addition, some tasks trained for are executed in practice by advisers or installation providers. The study focusing on design and integration of the whole comprises in practice the stages of the programme, design, development, realisation and maintenance stages. As far as advisers and providers play a rôle there, the process for HVAC installations has been described in Publication 43 of ISSO.^c It describes an ideal; practice is often different. ISSO casts the installation designer for a rôle within which the architectonic design is being followed. The architect has the initiative; regularly reporting and linking back is the name of the game. This pre-supposes that in each stage of the design information is exchanged consistently. In practice this works often quite differently, since advisers or providers are getting more responsibilities and have to develop by themselves solutions for problems; even if these solutions can be found in the architectonic design.

36.9.3 Installation designers

Installation designers are aware of the fact that in the case of complaints on the indoor climate the accusing finger is readily pointed at the HVAC installations. They deem this to be understandable. Nevertheless, quite often the cause of these complaints must be allocated somewhere else. The phenomenon has been studied extensively; many congresses have been devoted to it. The solution is clear: installation designers should prevent during the design process the risks of complaints by warning commissioners and architects if they are forced to take risky design decisions. In reality most installation designers do like not to bother their clients and architects with this kind of problems. They are of the opinion – just like architects, by the way – that they have not been hired to warn for problems, but to solve them. In 'Concepten voor klimaatinstallaties' this is also shown.^d By the same token installation advisers are sensing a dilemma. They must earn an income, but also the confidence sitting on their shoulders. Usually they opt for short-term success and decide to make the best of it and hope – often against knowing better – that the final result will just work out. Client and architect can prevent this type of behaviour – risky to them – by means of a project organisation in which open communication is encouraged and realisation of a perfect result is seen as a common responsibility.

a Schalkoort, T.A.J. (1991) *Ontwikkeling en behoud van gezonde kantoorgebouwen - Studie naar het 'Sick Building Syndrome' en de mogelijkheden van het terugdringen van bewonersklachten in kantoorgebouwen*.

b SZW (1992) *Gezonde kantoorgebouwen, aandachtspunten bij ontwikkeling en beheer*; Schalkoort, T.A.J. and P. Luscuere (1997) *Gezonde gebouwen*.

c ISSO (1998) *Concepten voor klimaatinstallaties*.

d Idem.