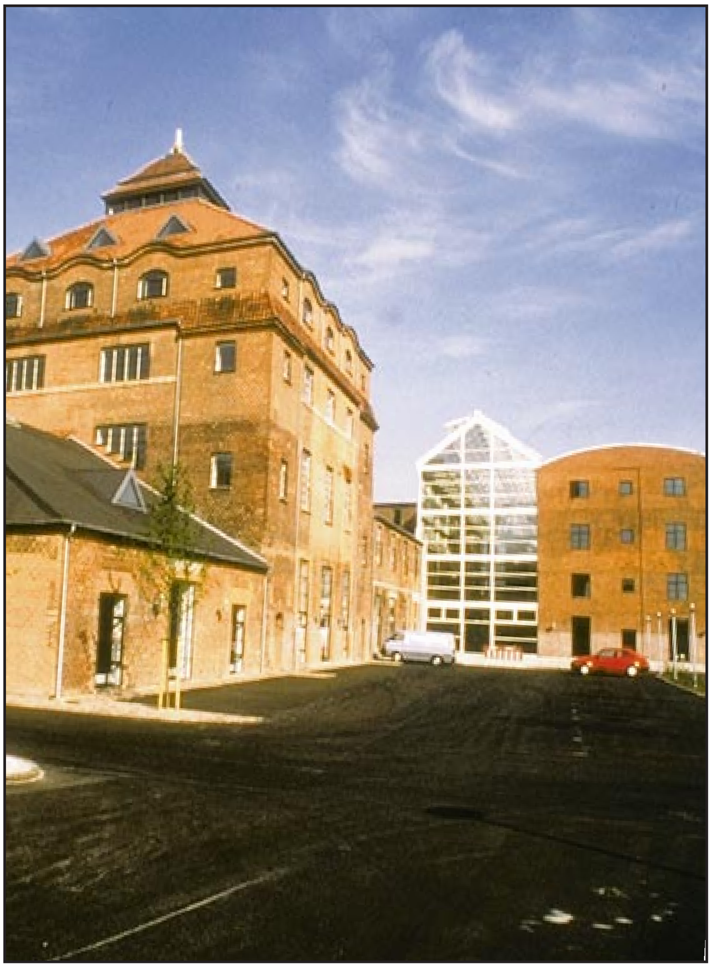
Mid-Career Education:

SOLAR ENERGY IN EUROPEAN OFFICE BUILDINGS



CASE STUDY MODULE C

SUKKERTOPPEN – COPENHAGEN, DK

Esbensen

CONTENTS

C.0 SUMMARY INFORMATION

Building name:	"Sukkertoppen"
Client:	The Employees Capital Pension Fund
Architect:	Kristian Isagers Tegnestue A/S
Main contractor:	Højgaard & Schultz A/S
Structural engineer:	Seitzberg & Neltoft A/S and KBI
Service Engineer:	Seitzberg & Neltoft A/S
Energy specialist:	Esbensen Consulting Engineers
Type of office use:	Education, publishing and multi-media
Occupants:	230 full time employees 500 trainees
Occupant period:	9 am - 5 pm, 1760 hours per year
Location:	Valby, Suburb of Copenhagen, Denmark Lattitude 55°40 N Longitude 12°30 E
Area and Volume:	Total gross floor area: 18000 m^2
Area of atrium:	600 m^2
Total volume:	Approximately 63000 m^3
Heated volume:	Approximately 63000 m^3
Cooled volume:	Nil
Cost:	Not available
Completion date:	Erected 1913 Retrofit 1991-1992

C.1 THE CLIENT

The client and owner of the building complex is The Employees Capital Pension Fund. The objectives of the client were to convert and extend the complex into a 18000 m^2 multimedia centre and subsequently rent it out in smaller individual areas to computer companies and educational organisations.

Even though the client owns and runs the building, it is the lease holders who are responsible for the utility bill. Therefore it was primarily for the purpose of renting out the building that the client was aiming at low running costs. Also the issue of getting sufficient daylight into all parts of the complex including the rooms facing the atrium had very high priority from the client and the local building authority point of view.

It should be emphasised that although energy and daylight had a quite high priority in this project, the atrium was mainly chosen for recreational and architectural reasons.

C.2 THE DESIGN TEAM

The building was retrofitted by a main-contractor (Højgaard & Schultz A/S) in association with an architect (Kristian Isagers Tegnestue A/S) and two engineering consultancies working with the structures and the services (Seitzberg & Neltoft A/S and KBI). Furthermore the main-contractor had engaged a specialist on low energy design (Esbensen Consulting Engineers). The energy specialist mainly worked with the design of the atrium and the different daylight and energy problems related to it.

The main-contractor and the architect were involved from the very start of the project, while the two engineering consultancies and the energy specialist were involved from the preliminary design phase. In fact the energy specialist was mainly involved in the preliminary design phase and very little during the later project phases.

C.3 CLIMATE

Climate type:	Northern Coastal Climate
Heating degree days (base 17):	2909
Cooling degree days:	Nil
Relative Humidity:	82% average per year
Global irradiance:	1018 kWh/m^2 per year on horizontal

Month	Daily mean temp (°C)	Mean daily range temp (°C)	Max. extreme temp (°C)	Min. extreme temp (°C)	Mean precipitation (mm)	Mean cloudiness (%)	Mean sunshine (h)	Mean wind speed (m/sec)
January	0.1	4.0	9.9	-24.2	48.8	73	35.9	2.7
Febuary	-0.1	4.6	14.0	-19.6	38.5	71	55.5	2.7
March	1.9	5.9	18.5	-17.8	32.2	59	118.3	2.5
April	6.6	7.3	22.1	-8.8	38.1	55	161.2	2.3
May	11.8	8.6	27.7	-1.5	42.4	47	244.7	2.3
June	15.6	8.6	32.7	3.0	47.0	50	245.3	2.2
July	17.8	8.2	30.7	7.5	71.0	51	239.2	2.0
August	17.3	7.8	30.5	5.6	66.1	52	204.5	2.0
September	13.9	7.0	26.7	0.9	61.9	52	156.6	2.0
October	9.3	5.4	19.9	-4.0	58.6	64	86.5	2.3
November	5.4	3.9	14.4	-6.8	47.8	75	34.0	2.3
December	2.5	3.5	12.3	-11.4	49.3	79	18.8	2.3
Annual	8.5	6.2	32.7	-24.2	601.7	61	1600.0	2.3

C.4 THE SITE

The site is part of an old area for heavy industry, which has been converted into an area with mainly light industry e.g. pharmaceutical and information technology companies.

Due to the local zoning conditions the site area was constricted. As a result the atrium became fairly narrow.

There are no problems with air-quality and noise in the area. The actual level corresponds to normal Danish conditions in suburban areas. Compared to other major European cities these conditions are good.

C.5 BUILDING DESCRIPTION

Sukkertoppen is an old sugar refinery industrial complex erected in 1913 and subsequently totally renovated in the period 1991-1992. The original and renovated building complex consists of seven individual parts of varying heights (A-G, see figure 1). The lowest part is building E which is only a single storey high, the tallest part is the sugar loaf tower which is 5-6 storeys high.

In addition to these original parts, three new buildings were added (H-K) concurrent with the retrofit project. The largest of these new buildings is the four storey wing (K1-K3) situated south of the existing complex and connected to it by an atrium.

The existing buildings had massive brick outer walls and reinforced concrete decks. The roof structure was a combination of reinforced concrete, steel and timber. Felt was the primary roof covering except for the sugar loaf tower, which was tile.

Figure C.1. The K+A building and the atrium seen from the East.

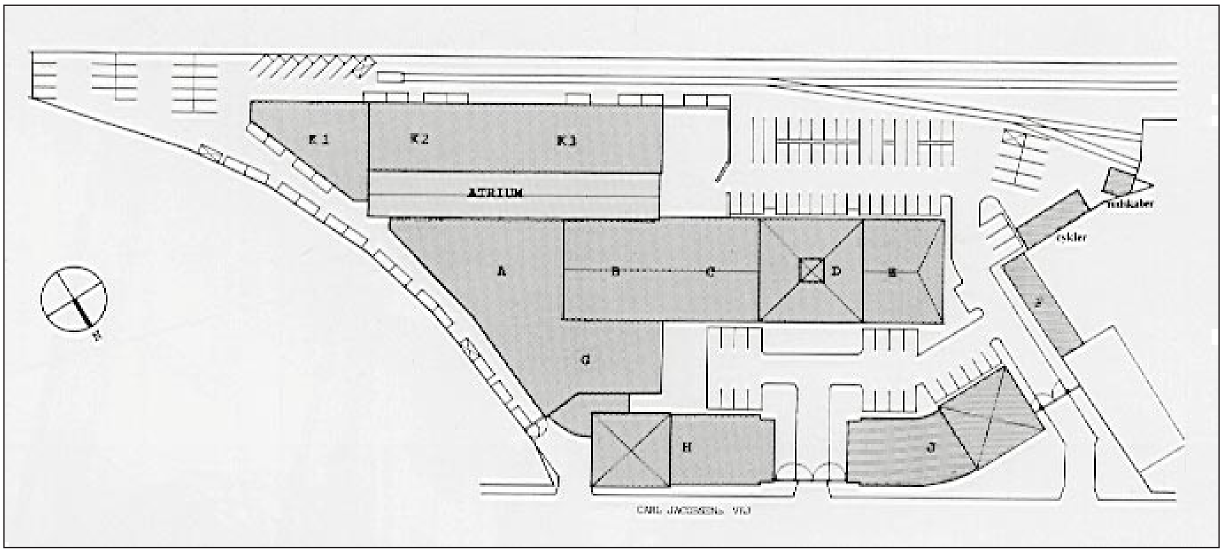


Figure C.2. Site plan of the Sukkertoppen complex, [Arkitektur DK, vol. 2-1995].

C.6 THE DESIGN AND CONSTRUCTION PROCESS

Figure C.3 The atrium west end wall seen from outside.

The design process on the Sukkertoppen project followed in many ways the traditional pattern for main contract projects in Denmark.

First the contractor developed a scheme project for the Sukkertoppen complex together with an architect (hired by the contractor). Afterwards the contractor found a client who decided to invest in the project. The clients decision was, of course, based on economic calculations concerning the future development of the particular suburban area, construction costs and subsequently the possible price level for renting out the complex. Based on discussions between the client, the contractor and the architect (still hired by the contractor), the contractor then completed a design brief for the complex. Based on this brief, the contractor hired consultants for services and structures who developed the detailed brief with drawings for the building project.

Finally the contractor used the building brief to hire the sub-contractors on the different types of building services and structures. The sub-contractors were hired after an open call for tender. Typically there are sub-contractors on the electrical, ventilation and heating systems, carpentry, floor finishes, ceilings, painting, the glazed facade (atrium) etc. The main contractor took responsibility for the heavy load-bearing construction of concrete and brick work.

In addition to these partners, the contractor hired a consultant specializing in low energy design to carry out an energy and daylight analyses of the atrium and the adjacent buildings. These analyses were completed during the preliminary design phase of the project.

In terms of energy consumption for heating, ventilation, artificial lighting and hot water services, the building complex was designed to suit modern Danish standard for office buildings in the early 1990's. Most of the buildings in the complex can therefore be characterized as examples of good practice design. One of the elements of the complex which is quite special compared to other similar Danish buildings, is the atrium.

Figure C.4 The A building seen from the South.

C.7 DESIGN STRATEGIES

C.7.1 Structure and Skin

As much as possible of the existing structures were retained and rebuilt to suit contemporary requirements. All of the roofing is new and combined with insulation. The corridors are paved with clay tile. The original single glazed windows were replaced with double glazed windows (U=2.9 W/m^{2}K) according to the Danish Building Regulation of 1982 (BR82). The windows and the roof are the only structures which were insulated to fulfil BR82. The facade towards the atrium is four storeys high in building A and two storeys high in building B and equipped with single glazed windows. Even though the size of some of the windows on the atrium facade was increased compared to the existing situation, the total glazing area is similar to the other facades on the renovated buildings.

The new buildings respect the industrial character of the existing buildings and are therefore designed with large flexible spaces. Load bearing structures are concrete wall elements, supplemented with column/beam construction and prestressed concrete decks elements that can span the entire width of the buildings. The ceiling heights are similar to the existing buildings (around 3 m, but higher on the ground floor).

The 'interior' facade on the new building facing the atrium is a light construction covered with perforated gypsum boards for acoustical purposes. The single glazed windows are larger on the ground floor than on the top floor. In addition the total glazing area on the facade is considerable larger than compared to a normal BR82 facade facing the exterior (see Section C8.2). In this way it was hoped that the daylight level on all floors in the building could be maintained at a level at least as a high as in a reference building without an atrium. The external wall is of sandwich construction with concrete elements, insulation and bricks towards the exterior. All elements except for the facade facing the atrium (walls, roofs, ground floor and windows) are insulated according to BR82.

Figure C.5. The atrium East wall and the facades of the new K building seen from inside the atrium.

Like the K and the A building, the atrium is four storeys high. The load bearing structure is made of steel tubes with supporting aluminium frames mounted on the outside. The transparent sections are clear low energy glazing with an U-value of 1.8 W/m^2K. The floor is clay tile. The atrium dimensions are L x W x H (ridge) = 60 m x 10 m x 18.5 m and the volume is around 9900 m^3. The atrium is used as circulation and exhibition area and is therefore heated to 16°C in order to avoid draughts from cold surfaces.

Description	U-value
Renovated buildings:	
Windows to exterior: Double glazing	2,9 W/m^2K
Windows to atrium: Single glazing	4,5 W/m^2K
Massive brick wall to exterior	1,4 W/m^2K
Massive brick wall to atrium	1,25 W/m^2K
New buildings:	
Windows to exterior: Double glazing	2,9 W/m^2K
Windows to atrium: Single glazing	4,5 W/m^2K
Brick-concrete wall to exterior	0,35 W/m^2K
Light facade to atrium	0,4 W/m^2K
Atrium:	
Glazed walls and roof exterior	1,8 W/m^2K

Table C.1. Primary U-values for the renovated and new buildings.

C.7.2 Services

During the heating season the complex is heated to 21°C in daytime and 18°C at night. The heat emitters are water based radiators, primarily situated below windows to avoid cold drafts. The atrium is heated to 16°C by a finned tube system located along the glazed surfaces facing the exterior.

While the atrium is natural ventilated, the rest of the complex is mechanically ventilated via different systems with separate duct systems and air handling units. Most parts of the complex are exposed to quite high internal heat gains from equipment and persons. Therefore the dominant type of ventilation is balanced displacement ventilation with an air supply temperature around three degrees below the room temperature. In this way the flow principle is maintained at the same time as drafts are avoided. In the less exposed parts of the complex, balanced mixing ventilation is used with a minimum supply air temperature of around 20°C. All air-handling units are equipped with heat recovery.

The hot water for space heating, for pre-heating of ventilation air and for domestic hot water is supplied from a common boiler heated with district heating.

The natural ventilation system in the atrium is active in the summer season and controlled by room temperature in the atrium. The temperature sensor is situated three metres above the floor on the north wall of the atrium (south wall of the A building). When the temperature exceeds 22°C, electric driven openings in the ridge will start to open in the full length of the atrium, first on the leeward side and secondly on the windward side. If the set point is still not kept, then openings in the end wall (four at each end) will be activated in sequence one by one. With this control strategy the opening area will always be much larger at the top of the atrium than at the bottom and the response time will therefore be so slow that the control is stable.

As the complex is divided into several buildings with different types of use it is difficult to make a general characterisation of the artificial lighting system. It clearly depends on the function of the specific room. In general, the installed effect for general lighting is lower than usually seen in European office buildings. This is mainly due to the widespread use of task lighting which makes it possible to design for lower lighting levels than normal. Often 200 Lux is used as design level in office-like rooms. The required lighting level of 500 Lux for reading/writing activities will then be secured by the task lighting. All artificial lighting systems in the complex, except for the system in the atrium, is manually on-off controlled via traditional wall switches. Artificial lighting in the atrium is provided by timer controlled high level metal halide street lamps. The function of this quite powerful lighting system is mainly, for aesthetic reasons, to illuminate the atrium at night.

On the West, East and South facades of the new and renovated buildings, including the internal facades facing the atrium, solar shading is provided by manually controlled internal curtains. In addition the South facade of the new K building is shaded by automatically controlled external blinds. The atrium is shaded on the South part of the roof with automatically controlled internal curtains.

C.7.3 Control systems

There is no Building Management System in the complex. All control systems are decentralized and only connected to the sections necessary for the functioning of the system. For example, the temperature sensor in the atrium is only connected to the PID (proportional Integral Differential) control unit and the actual set of actuators.

C.7.4 Building Management

Day-to-day building management of the complex is carried out by a full time caretaker. The overall building management is lead by a building manager which is responsible for several of the clients buildings in the Copenhagen area.

C.8 DESIGN EVALUATION

C.8.1. Energy analysis of the atrium

As the atrium was designed mainly for architectural and recreational purposes, it was decided by the client and the main contractor to heat the atrium during winter. This introduced a minor problem for the design team because the traditional sections concerning heat loss in BR82 put limitations on the maximum insulation value of all elements and the maximum area of transparent elements facing the exterior (assuming that the building is heated to at least 10°C). Using these requirements from BR82 it would be impossible to build an atrium with a large glazed area, even if low energy glazing was used. Instead another section in BR82 was used, which states that the requirements for U-values and the area of transparent elements can be varied if the total heat loss of the building is not higher than the heat loss of a reference building designed according to the traditional requirements in BR82.

The simple way of fulfilling the modified section in BR82, is to maintain the same average heat loss co-efficient for the whole building by increasing the insulation value of certain elements. This will compensate for the increased heat loss due to poorly insulated elements. The problem with this method is that it is a simple steady-state method which does not take some important elements into account. For example passive solar, heat accumulation in the building fabrics, internal heat gains and heat loss from the adjacent buildings to the atrium. Basically it would still be impossible to fulfil the BR82 requirements using this method.

Therefore it was decided to use a building simulation tool, capable of taking the above elements into account. The tool chosen was Tsbi3 developed by The Danish Building Research Institute. The main conclusion of the simulations were that:

- With an atrium set point temperature of 16°C, the presence of the atrium would lead to 38% savings on the energy demand for space heating compared to the reference situation without the atrium.

Based on these simulations it was decided to heat the atrium to 16°C during the heating season. The reason for not selecting a lower temperature was that calculations showed that such a situation could cause uncomfortable cold drafts in the adjacent office rooms (due to the poorly insulated single glazed windows). In addition the client wanted an atrium room with reasonably comfortable temperatures all year round.

Later field measurements and Tsbi3 simulations carried out as part of a research project [‘Indoor Climate of Large Glazed Spaces’], have shown that the early simulations from the preliminary design phase were too optimistic about the energy savings. There are a number of reasons for this, all connected to the data used in the early Tsbi3 model. The most important of these was probably an underestimation of how much solar energy the atrium would loose due to direct reflections of short wave solar radiation from the surfaces in the atrium. In Tsbi3 this heat loss should be estimated and typed into the programme as a percentage of the total solar radiation entering the atrium. Short wave heat loss is not covered by the U-value of the glazing.

Figure C.6 shows the simulated annual net heating demand for the atrium (600 m^2), the North facing A+B building (2420 m^2) and the South facing K building (3640 m^2). The heating set point in the atrium is 16°C. As in the early simulations the reference situation is without the atrium. In the reference model the adjacent buildings are designed in accordance with BR82 in terms of insulation value and area of transparent elements.

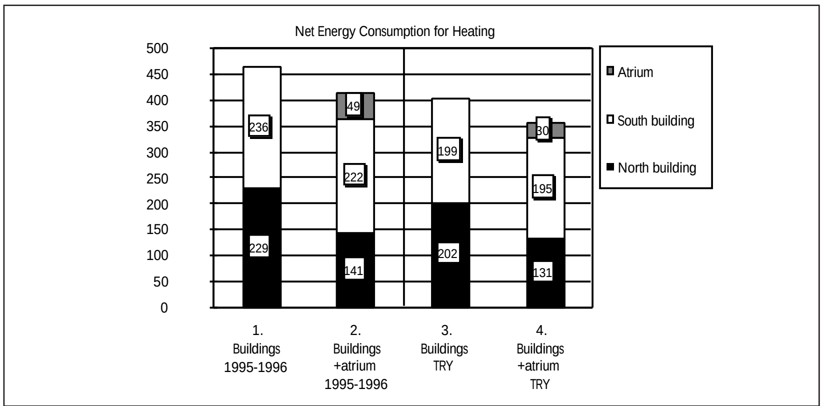


Figure C.6 Simulated net energy consumption for space heating for the North facing building (A+B) and the South facing building (K) with and without the atrium. The simulations were carried out using actual monitored weather data as well as data from the Danish Test Reference Year (CHP.TRY).

It can be seen from figure C.6 that the heating season 1995-96 was colder than the average TRY year. As a result the annual energy consumption for space heating was around 17% higher than normal. The results also show that the use of the atrium induces an annual energy saving for space heating for the North and the South buildings of around 14 kWh/m2 or 24% for both types of weather data used (note the 38% savings calculated in the early simulations). It should be noted that the atrium has the largest influence on the energy consumption of the north building. This is due to the fact that the North reference building is almost uninsulated (like the rest of the renovated buildings) while the South reference building is insulated according to BR82 (like the rest of the new buildings). The reason why the North building, in the three of the four cases in figure C.7, has a lower energy consumption for heating than the South building is that the North building faces the C+G building and therefore has a smaller exterior surface than the South building. In addition the area of the North building is smaller than the South building.

It should be emphasised that the annual simulated energy consumption for the atrium based on the real weather data from 1995-96 corresponds reasonably well with the monitored energy consumption for the same period (see Section C.9).

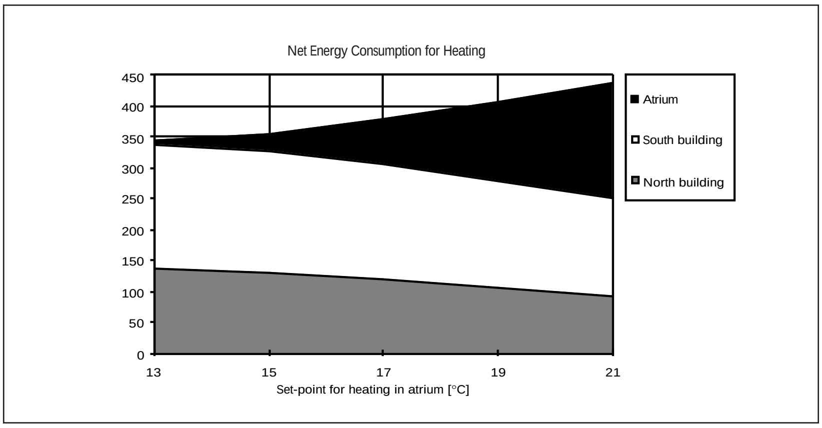


Figure C.7. The simulated annual net energy consumption for space heating for the atrium, the North building and the South building as a function of the heating set point in the atrium. The results are based on Danish TRY weather data.

From figure C.7. it can be seen that the energy consumption for the two buildings and the atrium is very sensitive to the heating set point of the atrium. If the heating set point is raised above 18.5°C there will actually be an increase in energy consumption compared to a situation without the atrium.

C.8.2 Daylight analysis of the atrium

Although atria are not unusual in Denmark, especially in connection with shopping centres and arcades, it is still quite rare for office buildings with permanent working places to face an atrium. One of the major problems with such a building layout is that the occupants in the offices facing the atrium do not get a direct view to the outside. This is actually not allowed in Denmark and therefore it will require a dispensation from the local building authorities to fulfil such a design. In the Sukkertoppen project the local authorities required some kind of documentation to prove that the daylight conditions in the offices facing the atrium would turn out to be at least as good as a reference situation without the atrium.

As a result the main contractor commissioned the energy specialist who had performed the energy analysis of the atrium to design the windows in the facade towards the atrium and complete the daylight documentation for the local authorities. The suggestion from the energy specialist was to increase the window area in the new K building south of the atrium compared to the normal area in a reference BR82 building. This was done in order to compensate for the reduced daylight admittance to the building due to the presence of the atrium. For architectural and constructional reasons it was not possible to increase the window area in the renovated A+B buildings nearly as much as in the new building. Instead rooms with little need for daylight were placed towards the atrium. In this way it was possible to design for large windows in the remaining rooms towards the atrium.

In addition to the above initiative it was suggested that the glazing area at the lower levels of the buildings should be increased compared to the top levels. This offers a solution to the problem that the daylight level is greatly reduced on the lower levels compared to the upper levels in the building.
On the basis of this solution daylight simulations were performed for the

ground floor of the renovated A building using the 'Superlite' programme. Two models were analysed, a reference model and a project model.

The window glazing area of the reference model is dictated by BR82 (min. 10% of the floor area) and naturally there is no atrium. The distance between the actual simulated room and the K building facing it is 14.3 m. This is the closest two buildings with the given heights can be placed to each other according to BR82. The colour of the ground between the two buildings is dark green like grass and the surface of the K building is red like the brick-work. The depth of the simulated room is 13 m.

The atrium is included in the project model and the window area is, as stated above, a little larger than in the reference model. The distance between the simulated room and the K building is 10 m. All surfaces in the atrium space are assumed to be light coloured. As in the reference model the depth of the simulated room is 13 m.

The results of the two daylight simulations can be found in figure C.8 where the daylight factor is shown as a function of the distance from the window. In the reference model it can be seen that the daylight factor is highest at a distance under 1.3 m from the window. Due to the quite high daylight factor in this area (greater than 5) this is actually a positive result because too much daylight can cause glare. When the distance is greater than 1.3 m the daylight factors are higher in the project model, especially between 1.5 m and 3 m from the window. This is also a very positive result because most office work will occur in this area. The high daylight level is mainly due to the increased reflection of diffuse daylight into the room because of the light coloured surfaces in the atrium space.

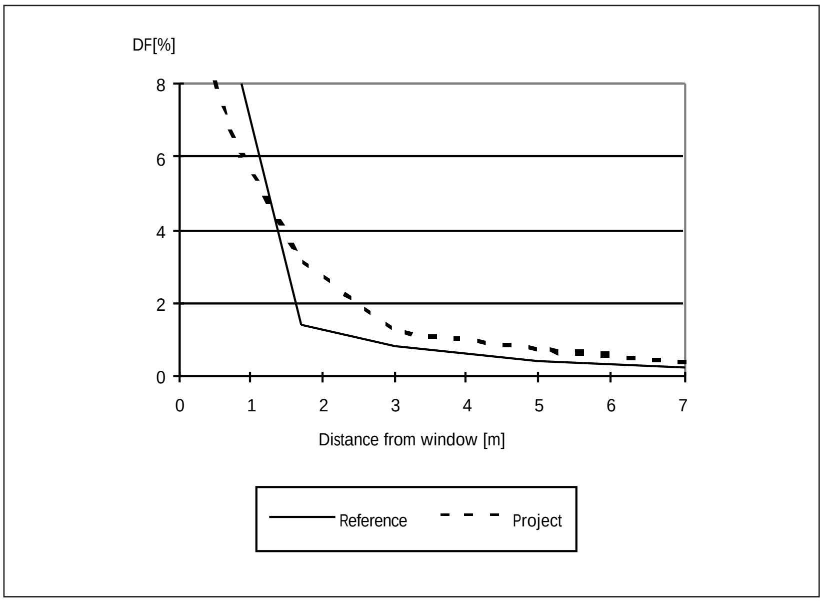


Figure C.8. Simulated daylight factors (DF) for the reference model and the project model.

C.9 BUILDING PERFORMANCE

The measured building performance regarding energy consumption is based on heating bills for an one year period in 1995-96. The energy survey is part of a VKO-report completed by the engineering consultancy Samfundsteknik A/S. The VKO-report also covers electricity and water consumption.

VKO (Varme Konsulent Ordningen) is an official arrangement administered by the State Department of Energy, where consultants, typically engineers or architects, produce a report on the consumption of energy and water for a specific building. A survey on the condition of the energy systems is also included. Such VKO reports are often ordered in connection with the sale of domestic and non-domestic buildings in Denmark. The results for the whole 18000 m^2 Sukkertoppen complex are summarized below.

In 1995-96 the actual weather resulted in 3134 heating degree days. This is, as already stated, higher than an average year which has 2909 heating degree days.

The annual energy demand for space heating was:

1995-96 (gross demand)	1754 Mwh per year	97 kWh/m^2/year
Normal year (adjusted gross demand)	1578 Mwh per year	88 kWh/m^2/year
Simulated 1995-96 (net demand)	1116 Mwh per year	62 kWh/m^2/year

To convert the simulated net energy demand to a gross demand the efficiency of the central heat exchanger and the (not usable) pipe heat loss has to be known. If the heat exchanger efficiency is assumed to be 80% and the pipe heat loss 10% the simulated gross energy demand for space heating will be:

Simulated 1995-96 (gross demand)	1468 Mwh per year	86 kWh/m^2/year

The simulated energy consumption of 86 kWh/m^2/year is lower than the measured energy consumption of 97 kWh/m^2/year. This seems reasonable, as the simulated part of the complex (the atrium and building A, B and K) is much more compact than the rest of the complex. In addition it must be considered to be a good result if simulated results are closer than 10% from the real situation.

The total annual electricity consumption for the whole complex (including lighting, small power loads, control, pumps and ventilation) are measured at around 9 kWh/m^2/year. This is very low compared to normal office buildings, but it has to be born in mind that there are large areas (e.g. various educational facilities) with corridors, toilets and other rooms which are not used on a daily basis.

C.10 COST ANALYSIS

Unfortunately it turned out to be impossible to obtain any information from the client about the construction costs of the complex. It was stated by The Employees Capital Pension Fund that it was considered to be confidential information.

C.11 CONCLUSIONS

The atrium has received favourable comments from the occupants. There have been some complaints about uncomfortable conditions in the office spaces next to the atrium. These are mainly due to overheating in the upper part of the atrium during sunny weather, which has reduced the possibility for venting via the windows towards the atrium. However the upper floor of the attached building is occupied by a multi-media computer company, so the offices contain a lot of computers which increases the room temperature due to high internal heat gains.

The atrium is experienced as favourable and uniformly well-daylit under an overcast sky. On clear days with direct sunlight the south facing slope of the roof is shaded automatically by internal curtains. This prevents glare from the atrium roof.

The south facing windows of the K building have caused several user complaints due to problems with direct sunlight. The windows are shaded with external blinds and interior curtains. However, the exterior shading system is automatically controlled for protection against wind-damage which on windy days leads to the raising of the curtains. As the internal curtains are light coloured this situation causes glare and distracting reflections in computer monitors.

The shape of the atrium roof and the roof of the nearby buildings have resulted in a valley at the junction of the two roof surfaces. During the winter snow accumulation has caused melt water penetration. As a consequense this construction detail should be completed with great care.

In general it can be concluded that the Sukkertoppen complex is an example of a well designed non-residential complex. The atrium has been shown to be a well designed space which has improved the general quality of the complex and reduced the space heating load for the adjacent buildings.