European Commission

ECO-Culture

Demonstration and dissemination of ECO-concepts for high-performing European cultural buildings

TREN/04/FP6EN/S07.30902/503079

Final Report

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Project coordinator name: Jens Ole Hansen
Project coordinator organisation: COWI A/S

European Commission

ECO-Culture - Demonstration and dissemination of ECO-concepts for high-performing European cultural buildings

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Final Report

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Checked	PEWE
Approved	JHA

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0.2 List of project partners

Company	Country	Role	Abbr.
COWI A/S Jens Ole Hansen Parallelvej 2 DK-2800 Kgs. Lyngby Denmark jha@cowi.dk	Denmark	Project co-ordinator, Consultant	COWI
The Royal Danish Theatre	Denmark	Building owner	DKT
Gemeente Amsterdam	The Netherlands	Building owner	MA
Ecofys Netherlands bv	The Netherlands	Consultant	Ecofys
Statsbygg	Norway	Building owner	
Erichsen & Horgen AS	Norway	Consultant	EH
Arup (NL)	The Netherlands	Sub-contractor to MA	
Boye Lundgaard & Lene Tranberg Architects	Denmark	Sub-consultants to DKT)	

0.3 List of work packages in the ECO-Culture project

No.	WP name	WP Leader
WP1	Project Management and coordination	COWI
WP2	Thematic workshops	EH
WP3	Eco-design	Ecofys
WP4	Construction/erection	EH
WP5	Test and commissioning	Ecofys
WP6	Monitoring	COWI
WP7	Dissemination	COWI

0.4 Disclaimer

The project partners including design consultants encourage, but take no responsibility for, use of the information presented in this report, e.g. in other design projects.

1 Executive publishable summary

Introduction
This report describes in brief the results of the EU supported project called "Demonstration and dissemination of ECO-concepts for high-performing European cultural buildings" with the project acronym ECO-Culture. The project has been supported by the European Commission DG-TREN with 1.93 million EUR.

The demonstrations are carried out in three buildings: the Royal Play House in Copenhagen, Denmark, the Opera House in Oslo, Norway, and the Amsterdam Public Library, The Netherlands.

Objectives
The objectives of the project have been to demonstrate reductions in energy consumption and CO_2-related emission related to cooling by 75-80% and to heating by 35-50%. For the specific area of ventilation, the goals are also 35-50%.

Further, to show that the use of renewable energy and intelligent control can be integrated in high-profile buildings. The technologies include energy storage, seawater cooling, heat pumps, demand-controlled hybrid ventilation, building-integrated PV systems and advanced Building Energy Management Systems as well as green concrete with less CO_2-emission than normal concrete.

A final objective has been to disseminate the ECO-concepts used in the buildings to a very wide range of people in both Europe and beyond.

Scientific achievements and results
The use of the "whole building approach" has shown that it is possible to design high-profile buildings with interesting architecture and strict user demands which at the same time has low energy consumption. It has also been shown that by using the "whole building approach", the goals have been met for all three buildings - or that they can be met based on changes in the operation.

Main deliverables
The main deliverables in the project have been the buildings themselves. The project has demonstrated the ECO-concepts and technologies in a large scale. This includes the use of the "whole building approach" to ensure low energy consumption. The aim has been to show to the public and professionals that it is

possible to build high-profile low-energy buildings with appealing architecture and a high level of functionality. Also this report is a very important deliverable, as it documents the status of the buildings and shows that the main objectives have been met.

Socio-economic relevance and policy implications

The use of seawater cooling and heat pumps for buildings near water as well as LTES has been very important ice-breakers for these technologies, which have already led the way for a number of similar projects. The use of building-integrated PV-panels as solar shading and as an architectural tool has raised the awareness of this technology.

Conclusions

The EU project and support amounting to less than a percent of the total construction cost have given significant focus on energy-conscious design. The project has highlighted the "whole building approach" as a tool for ensuring low energy consumption and appealing architecture. Moreover, the ECO-concepts have moved the state-of-the-art for cultural buildings a long way.

The buildings have become integral parts of the cultural life in the cities where they are built, and are thus working as ambassadors for Eco-buildings.

The energy consumption in the Playhouse has proven to be on par with expectations - and for heating much lower than expected. In the Opera the building also meets the expectations. In the Library, investigations are still ongoing, but already now, significant savings have been found that are ready for implementation.

Dissemination of results

The main dissemination has again been the buildings themselves. The building use has been very extensive, and the number of visitors has by far exceeded expectations. Over the past year, well over 2.4 million persons have visited the buildings as guests for shows in the Playhouse and Opera, as users in the Library, and for guided tours in all buildings. In addition to this, an estimated 1.5 million people have visited the Opera on the roof or in the building itself, together with an unknown number in the Playhouse.

The buildings have been on national television and presented on the Internet. Some important milestones have been reached, and the buildings have won several architectural and technical prices.

Keywords

Eco-building, cultural buildings, seawater cooling, ground-water cooling, building-integrated photovoltaic (BIPV), demand-controlled hybrid ventilation, thermo-active components, environmentally-friendly concrete, heat pump, Building Energy Management System (BEMS).

2 Introduction

The scientific and technological objectives of the ECO-Culture project have been to demonstrate innovative integrated energy concepts in European cultural buildings. The selected technologies are demonstrated in three European cultural buildings. The technologies and the three buildings complement one another so that maximum technological knowledge was gained from exchanging experiences during the design.

All the buildings were designed using a "whole building approach" in order to ensure the maximum energy-saving potential possible. The methodology of the "whole building design approach" is as follows:

1 Reduce the demand for heating, cooling, electricity and ventilation, and

2 Supply the necessary heating, cooling, electricity and ventilation in the most efficient way using renewables.

3 Always consider the impact on a whole-building level.

This means that within the actual design are already included consideration and concepts to reduce the demand for heating, cooling, electricity and ventilation. Use of passive solar energy and daylight is a natural design parameter for all the involved buildings.

Also the most efficient energy supply to the building is included using renewable energy sources such as PV, seawater cooling, energy storage and heat pumps.

To ensure the success of the buildings, it has been important in the design that the applied solutions make sense for the entire building. That this has been the case can be recognised from the fact that he buildings have each become integrated in the cultural life of the cities in which they are built. Each show that democratic architecture (buildings where people feel welcome) and eco-friendly design (sustainability architecture) can go together with high-performance and usability for the building owner.

2.1 Royal Playhouse, Copenhagen, Denmark

Figure 2.1 Royal Playhouse in Copenhagen seen from the harbour at night (Photo: Jens Markus Lindhe)

The Royal Playhouse was finished in February 2008 and had its grand opening on 16 February 2008, with the premiere of "Hamlet". The construction started in October 2004, giving a construction time of just over three years. The architect is Arkitektfirmaet Lundgaard og Tranberg A/S, while COWI A/S was the consulting engineer.

The building is around 20,000 m² and has three stages with capacities of 650, 200 and 100 seats. Further, the building has a foyer with a popular public restaurant, wardrobe, backstage, a rehearsal stage, offices, a library, make-up rooms, dressing rooms and other theatre-related functions. Around 180 persons work in the Playhouse.

During 2009, a total 394 of shows have been performed (or will be performed - status as of 9 November 2009) with a total audience of 109,500. The use of the building has been much more extensive than expected, and the building is already an integrated part of the Danish cultural life. 850 tours of the Playhouse have been conducted with 21,200 guests.

Generally, the building has been designed as a building with low energy consumption. The building design includes extensive use of natural ventilation in the foyer and on the third floor where offices, dressing rooms and other staff functions are located. The building is heated and cooled by thermo-active slabs that are serviced by a cooling compressor which can also function as a heat pump. When possible, however, the building uses free cooling from the seawater, which is placed adjacent to the building.

2.2 Oslo Opera House, Oslo, Norway

Figure 2.2 Oslo Opera House by night (Photo: Jiri Havran)

In July 1999, Statsbygg was commissioned to plan for a new opera house. In 2000, an international jury selected the architect Snøhette as the winner.

The Opera House is 38,500 m² in size and has close to 1000 rooms divided into three main sections: audience, rehearsal and administration and workshop. There are three stages: The Main Stage with approximately 1400 seats, Scene 2 with up to 440 seats and Rehearsal and Stage 1 with 200 seats.

On an annual basis, 200,000 persons have seen one of the shows in the Opera, while 100,000 have participated in guided tours and further 5,000 in special technical tours. In total, 1,500,000 persons have seen shows, participated in tours or simply visited the publicly available Opera roof.

The Opera House is a very complex building, and it has been demanding for everyone who has participated in the project. The building contains advanced stage technology, particularly on the Main Stage and Stage 2. The Main Stage has 16 elevators that can be moved up and down independently. It has a moveable rotating stage, two side stages and a background stage. Stage 2 will also be equipped with advanced theatre technology and a very advanced electro-acoustic system.

Energy focus was put on selecting energy-efficient end use. This means focus on energy-efficient ventilation and light by means on control systems. In addition, the duct systems have very low pressure drop and thus low energy use. The energy supply is made by district heating, which is the most environmentally-sound solution in a city. The most visible part of the energy system is the solar cells at the south facades. The cells also provide solar shading of the south facade.

2.3 Amsterdam Public Library, the Netherlands

Figure 2.3 Amsterdam Public Library seen from the front side (photo by Conijn)

The Amsterdam Public Library was opened on 7 July, 2007 (07-07-07). The building has a total area of 28,000 m². Of this area, roughly 9,000 m² are office spaces. The architect of the project is Jo Coenen.

The Library has wireless internet access for users with laptops. Further, there are nearly 500 computers throughout the library, which can be used for advanced searches of the library databases. The building also has a restaurant on the top floor with views of the city. Visitors can park their bike in one of the 2,000 parking spaces for bikes.

More than 200 persons are working at the Library.

The Library is highly appreciated in Amsterdam by the citizens and library users. The number of visitors has exceeded expectations. This means that over 2 million users have visited the building on a yearly basis over the first two years of operation. Tours of the building are offered once a week for the public.

The building is open 12 hours per day or 84 hours per week - or 24/7, if accessed through the Internet.

The energy concept in the Library consists of a Long-Term Energy Storage (LTES) in an aquifer, an advanced ventilation system, Building Energy Management System, lighting management, and PV-panels on roof and facades. The energy storage is a combined system for all buildings in the Oosterdokseiland, which makes the system more efficient than if it was only for one building.

3 Background

This chapter presents the initial problems that this project wants to solve and also addresses the initial thoughts on how to solve the challenges.

3.1 Problems to be solved

The general objectives of the ECO-Culture project are to:

- Reduce the energy consumption and CO_2 emission related to cooling by 75-80%.
- Reduce the heat consumption and related CO_2 emission by 35-50%.
- Reduce the energy for ventilation and related CO_2 emission by 35-50%.
- Use renewables; seawater, ground water and solar energy.
- Use intelligent control for maximised utilisation of the use technologies.
- Disseminate the used ECO-concepts of the high-performing cultural buildings throughout Europe and beyond.

The main elements to reach these aims are the complete integration of the following ECO-concepts:

- Energy storage (DK-"climatic belt" with thermo-active slabs, NL-double aquifer).
- Heat pump (DK-seawater, NL-ground water).
- Demand-controlled hybrid ventilation.
- Building-integrated PV systems.
- Building Energy Management Systems (BEMS) and benchmarking.
- Use of environmentally friendly concrete for thermal storage in thermo-active slabs.

State-of-the-art

All three buildings are Eco-buildings and will therefore have lower energy consumption than the current (national) building codes on energy performance.

3.2 Technology 1: Energy storage using "Climate Belt" with thermo-active slabs (Playhouse)

In the Playhouse, thermo-active slabs are used for energy storage - a so-called 'Climate Belt' (first in Denmark). Here, surplus heat from e.g. the Theatre Hall during performance at night is stored for basic heating needs at the facades during the next day. This usage is very efficient and cheap seen from an energy point of view, since the building is reusing energy that would otherwise have been lost. In summer time, the system is used for high-temperature surface cooling.

3.3 Technology 2: Heat pump using seawater as reservoir (Playhouse)

The Playhouse uses compressors for heating and cooling of the building. During the summer, compressor cooling is used as a supplement to free cooling from the seawater, when temperatures are not favourable for direct free cooling. During the heating season, the compressors function as heat pumps driven by seawater.

The utilisation of surplus heat from the auditoriums and the interaction with building-integrated energy storage will be optimised together with the overall efficiency of the systems by implementing reversible and interruptible heat pumps. This means that the systems can be used for low-temperature heating and high-temperature cooling, depending on the demand in the building. In addition, the heat pump prolongs the time of use of the seawater cooling because the heat pump can provide the required temperature in the distribution systems in periods when the seawater temperature is too hot or too cold.

The accumulation capacity of the thermo-active slabs means that the active seawater and free cooling can be stored in the slabs at night, when there is typically surplus of cheap electricity in the grid. This peak shaving is an important issue of the national electricity production.

3.4 Technology 3: Intelligent ventilation including BEMS (Playhouse)

The ventilation systems of cultural buildings are complex because of the buildings' different use patterns. In the theatres, up to six different ventilation systems are used with very strict demands on acoustics and comfort level.

The project will improve the state-of-the-art by increasing the demand-controlled part of the ventilation, using highly efficient heat recovery. The buildings will be ventilated using combinations of natural ventilation, pulse ventilation, hybrid ventilation and mechanical ventilation with different control strategies, depending on load and season.

The energy savings by an optimised BEMS will normally result in about 10% reduction in energy consumption, which will be achieved through specialist follow-up in the commissioning period.

3.5 Technology 4: Use of environmentally-friendly concrete for thermal storage in thermo-active slabs (Playhouse)

Eco-buildings should always be built of environmentally-friendly materials. Denmark is the European leader concerning the development of environmentally-friendly concrete, also known as "green concrete". Environmentally-friendly concrete will be used for the "Climate Belt" and will underline the energy savings of the Climate Belt/seawater solution. The green concrete has not been used in buildings before, but has been tested - in a slightly different format - at a highway bridge in Denmark. The environmentally-friendly concrete will reduce the embodied energy for the concrete as well as reduce the CO_2 emission from the production of the concrete.

3.6 Technology 5: Energy storage using double aquifer in external system (Library)

All the buildings at the Oosterdok location, six in total, will all be connected to a central cooling and heating system. The distribution system comprises two rings, cold and warm, and will connect to each building.

In total, 4 times two wells are constructed (4 cold and 4 warm). Via heat exchangers, the groundwater cooling respectively heating will be transferred to two circular underground pipes (two rings), the distribution system. The wells are charged during winter respectively summer.

Innovative is that all buildings have access to both the cold and the warm well at the same time. Excess cold and heat is stored in the buffer rings. As the buildings do not have the same pattern of heat and cooling demand, the buildings can use the residue heat or cold from each other.

3.7 Technology 6: Building-integrated PV system (Library)

A photovoltaic solar energy system is placed on the façade of the building. Together with the architect, an integrated façade system was designed. The use of this type of renewable energy on a highly visible location with a lot of visitors each year will enhance the awareness of RES and the ECO building concept. On top of the roof a larger PV system is installed.

3.8 Technology 7: Intelligent ventilation including BEMS and benchmarking (Library)

Ventilation and cooling are supplied via the air supply through the elevated floor. The open space in the library functions as air duct for the exhaust air. At the upper parts, the air is extracted. The ventilation is demand-controlled based on the measured CO_2 levels in the exhaust air. The heat is recovered from the exhaust air.

Compared to a standard building, more energy meters have been installed for the monitoring of the ECO-Culture project. All mechanical and electrical systems will be controlled via the BEMS. The system is functioning to minimize the energy use, meanwhile also maintaining a healthy and comfortable indoor climate.

3.9 Technology 8: Demand-controlled ventilation (Opera House)

The energy use for the distribution of ventilation air is most critical. The first step is to reduce this is the demand-controlled ventilation. The next step is design a ventilation system with a low Specific Fan Power (SFP).

The properties of the demand-controlled ventilation system are the following: Energy-efficient distribution of ventilation, including humidity control, a high maximum ventilation rate and a long running time for the plants. The need for demand-controlled ventilation is caused by the users being highly sensitive to poor indoor climate and at the same time requires humidity control of the air. Since a constant air volume ventilation system would result in very high energy consumption, it was chosen to use demand controlled ventilation.

3.10 Technology 9: Control strategies, BEMS and benchmarking (Opera House)

Control strategies for glass façade, light, ventilation, heating and cooling to improve use of daylight and passive heating and cooling. An integrated bus system will be developed, which works on the shading, light, heating, cooling and ventilation system. The design has been developed to maximise the use of daylight, and reduce the cooling, heating and ventilation demand.

The BEMS is developed to measure the use for all functions according to the national standard NS3031 and for each of the three areas:

- the audience section
- the rehearsal and administration section
- the workshop section.

In addition, external and produced energy use is measured. The energy use is displayed at several levels and for selected periods.

3.11 Technology 10: Building-integrated PV system (Opera House)

The lower part of the south façade in the foyer is partly covered with solar cells. The cells are integrated in the façade as a part of the solar protection. In the west part of the façade, the solar cells act as outside shading in front of a terrace, in the eastern part it is integrated in the double glazing.

4 Scientific/technological and socio-economic objectives

The ECO solutions in this project have been demonstrated in three cultural buildings centrally placed in three different Northern European capitals. The aim has been to demonstrate integrated design solutions with emphasis on certain technologies and solutions. The goal has been to show that cultural buildings used by many persons on a daily basis can have low energy consumption without sacrificing functionality or architecture.

All buildings are visually appealing, and both users and staff are happy with the buildings. The large number of visitors shows that the buildings have become an integrated part of the cities cultural life.

Scientific objectives and approach

Building Energy Management System (BEMS)

Seen from a scientific/technological point of view, all three buildings generally have advanced Building Energy Management Systems, which;

1 Control the systems in the complex buildings.
2 Measure and document the energy consumption and energy production.

Control systems

The complexity of the buildings requires an overall system for combining the systems and ensuring that they do not interfere with one another and that the buildings are operated as optimally as possible.

A natural focus has been on the ventilation system, which accounts for a large part of the energy consumption. The approach has been different in each building, but the main objective has been to integrate ventilation systems and BEMS.

Measurements and documentation

The inclusion of advanced BEMS does not mean that the buildings are self-controlling. There is a need for continuously ensuring that the ambitious energy goals are met - together with the comfort and usage requirements. The BEMS makes it possible to monitor the energy consumption in great detail due to the large number of measurement positions.

In the frame of the ECO-Culture project, the energy monitoring for the first 1-2 years of operation has been analysed and reported. The results show that the buildings have come a long way towards the initial targets. The buildings have now been handed over to the facilities management, and their efforts will be based on the knowledge that has been reported here. The BEMS is a vital part in the ongoing effort of ensuring low energy consumption.

Other technologies used in the buildings

Besides the BEMS, the three buildings have integrated a number of technologies, the objectives of which are mentioned in the following:

1 The use of a Climate Belt in the form of thermo-active slabs.
2 Use of seawater reservoir for heating and cooling.
3 Use of long term energy storage in the aquifer.
4 Building-integrated PV-system.

Climate Belt

The Climate Belt used in the Royal Playhouse reuses surplus heating energy from shows in the main auditorium, by storing it in thermo-active slabs. The thermal mass ensures that the heat is not emitted from the slabs until the next day. This is an innovative approach to save energy at a low temperature that would otherwise be useless and therefore simply removed through the ventilation system.

Also, the use of thermally heavy thermo-active slabs can help shave the heating peak load and level demands over the entire day. This gives lower peak loads for the district heating and consequently a more environmentally-friendly operation.

Seawater for heating and cooling

The position of the Royal Playhouse adjacent to the waterfront makes it obvious to use seawater for cooling, either directly when temperature allows, or as a reservoir through the compressor. This saves almost all of the electric energy needed for cooling.

Long-Term Energy Storage (LTES)

The Library is connected with five other buildings at the Oosterdok Island to a central heating and cooling system using a LTES. The distribution system comprises two rings, cold and warm. The wells in the LTES are charged during the winter time with cooling and during the summer time with heating. Heat pumps are used for peak loads.

It is an innovation that all buildings have access to the cold and warm well at the same time. Since the buildings do not have the same pattern of heating and cooling demand, they can use the residue heat or cold from each other.

Building-Integrated Photo Voltaics (BIPV)

A photovoltaic solar energy system is placed on the façade of the Opera and Library, using an integrated façade system. The use of renewable solar energy on a highly visible location with a lot of visitors each year will enhance the awareness of RES and the Eco-building concept.

In both buildings, the PV systems are integrated in a large glazed south-facing façade. The shading effect of the panels prevents over-heating. In addition, the visible location of the PV systems is a demonstration of the technology to a large audience. In the Library, there is also a more traditional roof-mounted PV system.

5 Applied methodology, scientific achievements and main deliverables

5.1 Overall objectives

Table 5.1 states the main project objectives presented in section 3.1 together with an overview of the status at the end of the project.

Table 5.1 Overall status of the main project objectives

Objective	Target	Status
Reduce the energy consumption related to cooling (only DK and NL)	75-80% reduction	71 % achieved in DK 41 % achieved in NO 60 % achieved in NL
Reduce CO_2 emission related to cooling (only DK and NL)	75-80% reduction	71 % achieved in DK 60 % achieved in NL
Reduce the heat consumption	35-50% reduction	41% achieved in DK 31 % achieved in NO 41 % achieved in NL
Reduce CO_2 emission related to heating	35-50% reduction	67 % achieved in DK 15 % achieved in NL
Use renewable heat sources	Used in all buildings	Use sea water for cooling in DK Use of PV in NO and NL
Use intelligent control for maximised utilisation of the used technologies	Used in all buildings	Included in all buildings
Number of visitors	2.4 million visitors per year	Over 4 million visitors per year

The monitoring results from the project are positive and have shown that the overall objectives from the ECO-Culture project are met. In the Royal Playhouse the main targets for heating, electricity and cooling was met already from the first 18 months of operation. But continuous work to further improve energy efficiency especially for lighting is ongoing. A reduction of 10-15% of the total electricity consumption in the building is expected to be within reach. In the Opera House, monitoring data has shown a very large improvement in the heating and total energy consumption from the first to the second year of operation and also here continuous work is ongoing for improvement of energy efficiency of the operation. The building is now well under the main targets set up for the Opera House at the project initiation. For the Library we can expect the same development but the progress at the end of the EU project, is not as advanced as for the 2 of the buildings. However, given the results and trends from the first two buildings, there is no reason to believe that the targets will not be met for the Library as well. In general it is seen that in the light of the complexity of these buildings, the first 1-2 years of operation will be influenced by the running in and learning process and thus will only give first indications. Hereafter the results of fine trimming are seen. It will therefore be interesting to analyse the energy consumption again after five years of operation.

5.2 Energy balance for the buildings

5.2.1 Playhouse

The ten design target values for the Royal Playhouse are shown in Table 5.2. The expected values are shown together with the actually achieved values. A comment indicates the status of the design target.

Table 5.2 Status of design target values

Target	Expected	Actual	Comment
Overall			
Total heating consumption	1530 MWh/year	1244 MWh/year	Achieved.
Total electricity consumption	1131 MWh/year	1366 MWh/year	The utilisation time is much larger than expected. Achieved if utilisation was as originally presumed.
Total energy consumption	2661 MWh/year	2610 MWh/year	Achieved in spite of larger time of use.
Integrated climate belt energy storage			
Utilisation of stored heat from heat pump	250 MWh/year		Compressor has been activated June 2009 as heat pump. Measurements are continued.
Heat pump and seawater cooling			
Max. heat demand	1-1.5 MW	1.1 MW	Achieved. Based on heating degree days.
Electricity consumption, heat pump	56 MWh/year	Potential shown	Basis for consumption has been shown.
Annual savings in CO_2	76 %	71 % (potential)	Potential has been proven based on measurement of sea water.
Optimised and intelligent controlled ventilation systems incl. BEMS			
Heating consumption, ventilation	367 MWh/year	324 - 487 MWh/year	Achieved when time of operation is over 4.5 hours a day for 150 days a year. This has been the case, so far.
Annual savings in CO_2	49%	67%	Achieved.
Environmentally friendly concrete			
Savings in CO_2	26%		Achieved.

The overall result is that the targets have all been fulfilled or - in a few cases - the potential for fulfilling the target has been shown.

This is the case even in spite of a building that has turned out to be hugely successful in the first 1.5 year of operation, meaning that the time of operation has been much longer than expected. Thus, the electricity consumption related to especially ventilation, lighting and technical stage equipment has been larger.

Because of the complexity of the building, some of the systems have not functioned as designed during the initial phase of the life span of the building. This is the case for the cooling central, which has not yet been pressed to its full potential, as the compressor units have only functioned as cooling machines and not as heat pumps. A flaw in the initial design of the cooling central has been changed, and the cooling central is now functioning to supply both heating and cooling to the thermo-active slabs. However, since only limited data exist, it has not been possible to show that the targets related to the cooling central have been met, but the potential has been documented by the available data. Once the system has operated using the full potential in the cooling central, the energy consumption will drop to an even lower value than today.

Concerning *heating energy*, the building is using 19% less than expected. This is a big success and shows that the overall building design has a low requirement for heating.

Concerning *electricity consumption*, the building uses 23% more than originally expected, but this is due to the fact that the time of use is over 40% longer than originally expected. When data are corrected to the expected time of use, the building meets the design target value.

Finally, it should be mentioned that the investigations made will lead to further energy savings, as several systems can be optimized to achieve even lower energy consumption. This is especially the case for ventilation and lighting.

Further improvements to lighting system

An example to the continued effort of lowering the electricity consumption for lighting is shown here. Due to the appearance and rapid development of new LED and compact fluorescent lighting, tests are on-going for replacement of the mainly incandescent light bulbs that are currently used. A preliminary estimate suggests that 10-15 % of the total electricity consumption in the building - corresponding to 200.000 - 250.000 kWh per year can be saved by changing light sources to next generation compact fluorescent and LED bulbs. An example of this testing is shown in Figure 5.1.

Figure 5.1 Test of new light bulbs in two neighbouring toilets. To the left 2W LED light bulbs (16 W total), to the right 5 W compact fluorescent light bulbs light bulbs (40 W total). Original lighting was 25 W incandescent light bulbs (200 W total).

5.2.2 Library

Table 5.3 shows the overall status of the design target values.

Table 5.3 Status of design target values

Target	Expected	Actual	Comment
Overall			
Total heating consumption (HP)	1001 MWh/year	1044 MWh/yr	Achieved
Annual savings in CO_2	23%	15%	Achieved
Total electricity consumption cooling	54 MWh/year	64 MWh/year	Achieved
Annual savings in CO_2	67%	60%	Achieved
BEMS advanced ventilation system incl. lighting			
Total electricity consumption (prim.)	3714 MWh/year	9026 MWh/year	Much larger time of use than expected
Annual savings in CO_2	13%	-	Not yet achieved
Solar PV systems			
Total electricity production	55.5 MWh/year	57.6 MWh/year	Achieved
Savings in CO_2	33 ton	34 ton	Achieved

The principal flows of energy are the heat, cold and electricity flows. In Table 5.4, the overall results for 2008 are presented.

Table 5.4 Monthly results energy use Library 2008

Month	Heat		Cold		Electr.
	GJ	MWh	GJ	MWh	MWh
Jan	901	250.3	206	57.2	311,129
Feb	700	194.5	159	44.1	288,161
Mar	805	223.6	186	51.7	275,200
Apr	456	126.7	181	50.3	292,182
May	282	78.3	748	207.8	295,449
Jun	135	37.5	376	104.4	329,348
Jul	133	36.9	698	193.9	314,407
Aug	101	28.1	771	214.2	332,116
Sep	259	71.9	435	120.8	372,835
Oct	475	131.9	274	76.1	359,303
Nov	803	223.1	263	73.1	377,073
Dec	1299	360.8	295	81.9	336,956
Total	**6349**	**1764**	**4592**	**1275**	**3884.2**

The data have not been corrected for degree days. These are data on meter level, or so to say the level of the building. These data have to be calculated back to primary energy use.

For the heat and cold, the Coefficient Of Performance (COP) has to be used to determine the primary energy use. For the electricity, the efficiency of the power generation in the Netherlands has to be taken into account. At this moment, a factor of 0.39 has been used. The COP and efficiency factors are in line with the factors used in the obligatory energy performance calculation. This calculation was made in order to get a building permit.

Table 5.5 Primary energy use in the Library 2008

	Meters		Primary energy		Design
	GJ	n_{gen}	GJ	MJ/m^2	MJ/^{m2}
Heat	6349	4.2 x 0.39	3876	139	118
Cold	4592	12	383	14	7
Electr.	12673	0.39	32494	1169	481
Total				**1322**	**606**

The electricity use of the in-house restaurant is estimated to be 364 MWh/yr and is subtracted because this was outside the original design.

The objectives for the heat and cold usage for this Eco-building are met, however further improvements are possible. The monitoring is only done for a relatively small period and need to be followed the coming years.

The Long Term Energy Storage system (LTES) is, taking into account that the Oosterdokisland is not yet fully completed (other building are now being constructed), working good.

Concerning the electricity use a further analysis is necessary.

The solar PV systems are functioning. The production needs to be monitored longer to determine the performance ratio, PR.

5.2.3 Opera House

The Opera House is one of Oslo's most famous tourist attractions and is therefore a perfect arena for demonstrating energy-effective technologies.

Results from energy measurements of different running strategies on ventilation system 360.022, which is supplying rehearsal room D, showed that the set-points for CO_2 and temperature are important user-related functions concerning energy consumption for ventilation. Small adjustments of the set-point lead to significant reduce in the daily energy consumption. This documented that the designed system works as long as it is operated correctly. The reduction of supplied air to rehearsal room D, due to the adjusted set-points, did not have any negative effect on the indoor environment. Simulations based on the different running strategies, showed that the energy consumption for rehearsal room D can be reduced by 93,000 kWh/year by changing the operation strategy. It is important to notice that the simulated saving potential only considers one single room in the Opera House, rehearsal room D, with an area of 225 m^2. The saving for the whole building is 2 213 000 kWh.

The Opera House is extensively equipped with energy meters for heating, cooling, ventilation and electricity. The energy meters are connected to the BEMS, and the users have the possibility to survey the energy consumption down to a detailed level through the BEMS. The BEMS has shown to be an important tool to reduce the energy consumption to a minimum.

A budget for 2010 is set up based on the monitored results of 2. Part of 2009

Table 5.6 Energy budget for 2010 based on monitoring results from second half of 2009 (Area 47 000 m^2)

	ECO Budget	Budget 2010
	kWh	kWh
District heating	3 930 164	3 491 680
Electricity cooling	916 500	544 255
Electricity rest	5 364 435	7 842 425
Sum	**10 211 099**	**11 878 360**

The results show that we are now within ECO culture target for 2010 for heating and cooling. We still do not have enough monitoring on all the electrical elements, but the tests on the HVAC systems and the reduction on the electrical part is positive. The electricity use has large user related connection and as mentioned the restaurants make influence. This was not a part of the EC project, and must therefore be subtracted when comparing with the budget.

The solar cells on south façade of the Opera House have been running since 12 February 2009. In addition to have a utilitarian value, the solar cells demonstrate to the public that the Opera House is focusing on renewable energy and has concerns for the environment.

Table 5.7 Production of electricity from PV-panels - monitoring results 2009 and budget for 2010

	ECO Budget	Monitored 2009 After 12/2-09	Budget 2010
Solar cells	20 618 kWh	18000 kWh	24000 kWh

5.3 Energy storage using "Climate Belt" with thermo-active slabs (Playhouse)

5.3.1 General description

The 'Climate Belt' is the use of thermo-active slabs in the building. The slabs are used for high-temperature cooling and low-temperature heating. The term 'Climate Belt' refers to the fact that the thermo-active slabs are mainly located near the facades of the building, where the need for heating and cooling is largest.

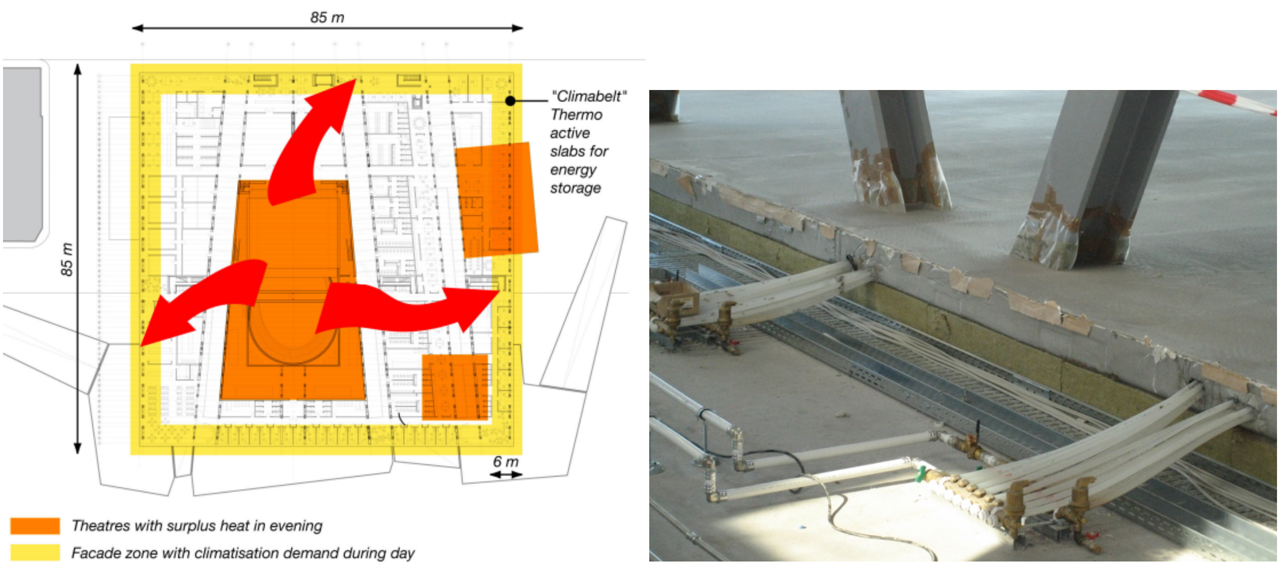

Figure 5.2 Surplus heat in the Theatre Hall is distributed to the energy storage - the Climate Belt

Further, the Climate Belt is used as a thermal storage of heating and cooling, which, due to the thermal mass of the concrete, can store heating and cooling for a period of time, about a few hours. That is, surplus heat from e.g. the Theatre Hall during performance at night is stored for basic heating needs at the facades during the next day. The principle is shown in Figure 5.2. Also, the figure shows the pipes installed in the decks for the construction of the TABS.

In summer time, the system is used for high-temperature surface cooling, where cooling is either taken directly from the seawater, or the seawater is used as reservoir for the compressor.

5.3.2 Results

One of the goals of the thermo-active slabs is to reuse 57MWh/year of recovered energy from the stage tower ventilation. Due to the fact that data are not conclusive, it has not been possible to show this based on direct measurements. However, it can be shown indirectly that the surplus recoverable energy from the ventilation of the stage is at least 57 MWh, and that the thermo-active slabs can accept this energy.

The outlet temperature from the stage is shown in Figure 5.3 along with the outdoor temperature and the temperature after the heat exchanger, assuming that an inlet temperature of at least 18°C is needed for the stage for a period of one week in April/May 2009. The temperature after the heat exchanger can be used for the cooling compressor when operating as a heat pump to supply heat to the thermo-active slabs.

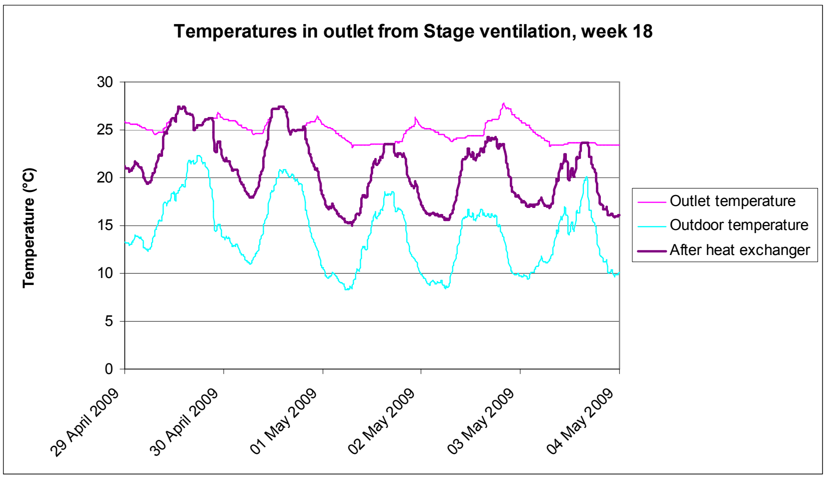

Figure 5.3 Outlet temperature from stage during week 18 in 2009

Similar investigations can be made when the outdoor temperature is colder than shown here, which is the case for most of the heating season. Assuming that the stage temperature from the shows is independent of the outdoor temperature, as the conditions are very much dominated by persons and lighting on the stage and in the auditorium, it is found that the average temperature after the heat exchanger is 14°C during the heating season.

Further, the heat supply to the thermo-active slabs must be investigated. It is found that during the period from November 2008 to March 2009, around 51 MWh were supplied to the thermo-active slabs. However, the slabs were not extensively used, since at that time it was not possible to get sufficient water flow. This problem has been solved, so the capacity is now much larger.

5.3.3 Comparison with energy objectives

Table 5.8 shows the extractible heat from the stage to the TABS for three different average temperatures of the exhaust air after the heat exchanger.

Table 5.8 Correlation between average temperature in the outlet air after the heat exchanger and the expected extractible heat supply to the TABS

Average temperature	14°C	20°C	23°C
Expected heat supply from stage to thermo-active slabs	26 MWh	65 MWh	85 MWh

A very important aspect of the expected heat supply from the stage to the thermo-active slabs is that it is basically a choice between using the energy in the exhaust air for reheating the inlet air or supplying energy to the TABS. If for instance the heat exchanger is bypassed, there will be a much larger potential for using the energy in the thermo-active slabs. This is a choice to be made by the operational staff. Based on the data from the exhaust air there is sufficient energy supply available for the thermo-active slabs.

5.3.4 Feasibility

Table 5.9 shows the main input and result of the feasibility calculations for the "Climate Belt". The result is a payback time of 15.8 years. This value was initially estimated at 14.1 years. However, the changes in mainly the prices of district heating and electricity have increased the payback time by about 1.5 year.

Table 5.9 Feasibility calculation for energy storage in the "Climate Belt" using TABS. All construction prices are based on 2004 price levels while energy prices are based on 2009 levels.

Construction cost (2004 prices)	1 114 000	€
Extra cost compared to conventional heating system (2004 prices)	128 000	€
Heat recovery from stage and auditorium	57	MWh/year
COP of compressors, yearly (assumed)	4.5	-
Heat supply from compressors	250	MWh/year
Electricity consumption	56	MWh/year
Energy supply to TABS (recovery from stage and heating from compressor)	57+250	MWh/year
Cost of electricity (2009 prices)	0.271	€/kWh
Cost of district heating (2009 prices)	75.43	€/MWh
Cost saving	60 312	€/year
Payback time, expected in 2004	14.1	Years
Payback time, actual	15.8	Years

5.4 Heat pump using seawater as reservoir (Playhouse)

5.4.1 Description

The thermo-active slabs are linked to the overall energy concept. In the concept, the use of the heat pumps and seawater is the central element. Here, the required temperatures in the thermo-active slabs match perfectly with the temperature levels offered by the seawater directly and/or assisted by the compressor. Figure 5.4 shows the different operation modes during winter, spring/autumn and summer. In the winter time, the heat pump is used for heating. Surplus heat from the stage is supplied to the Climate Belt through the heat pump, where the seawater is also used as reservoir. When more heating is needed, the system is complemented by district heating. During spring/autumn there is no need for heating, and the required cooling can typically be taken directly from the seawater. During summer, the seawater is too warm for direct cooling, and therefore the compressors are used for cooling of the Climate Belt. The surplus heat is sent back to the seawater.

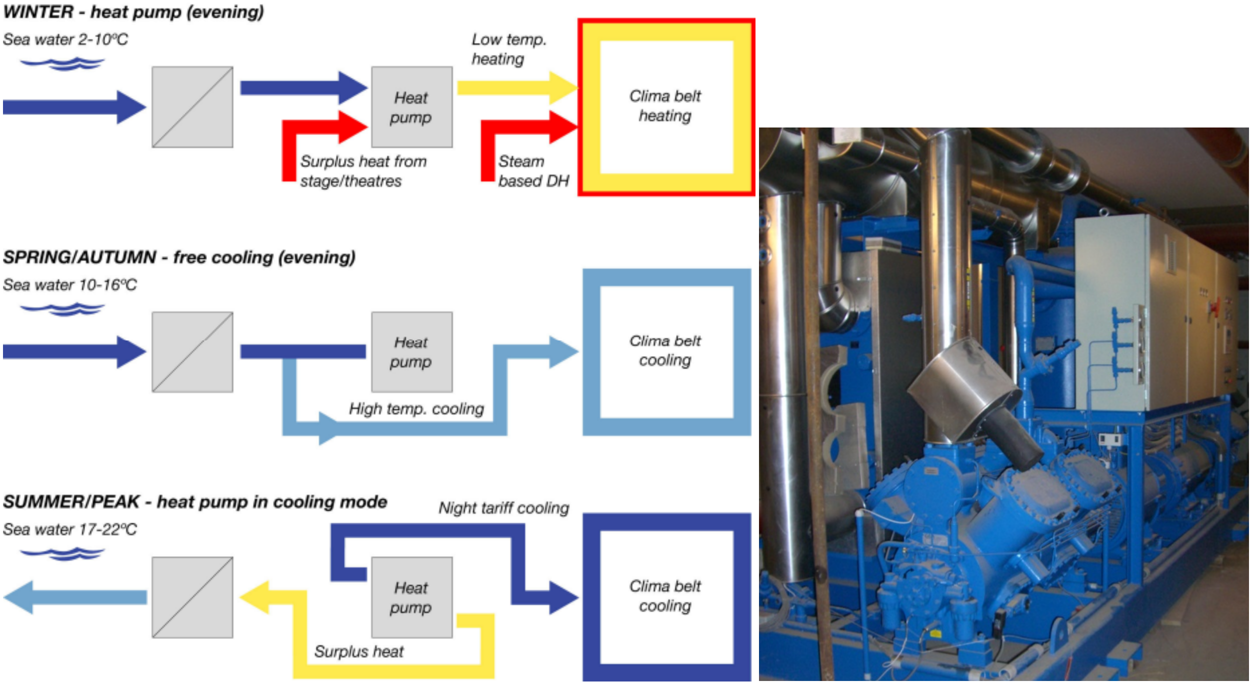

Figure 5.4 The operation principles of the seawater /heat pump systems at different times of the year. Also shown is the compressor

This use of renewable energy sources and surplus energy is controlled by the intelligent BEMS to utilise the surplus heat and the interaction with building-integrated energy storage. Further, the system optimises the overall efficiency of the systems by reversible and interruptible heat pumps. This means that the system can use low-temperature heating and high-temperature cooling, depending on the demands.

The accumulation capacity of the thermo-active slabs means that the active seawater, ground water and free cooling can be stored in the slabs at night, when the cost of electricity for pumps is low. This peak shaving is an important issue of the national electricity production.

5.4.2 Results

Four objectives will be shown:

1	Heat pump, heating:	Saving = 250 MWh/year
2	Heat pump, extra electricity :	Increased consumption = 56 MWh/year
3	Seawater cooling, electricity:	Savings = 300 MWh/year
4	Annual saving of CO_2:	76%

Heat pump, heating and extra electricity

The first two savings objectives are linked, as the saving in heating is linked with an extra electricity consumption in the heat pump. The COP for heating in the heat pumps is expected to be 4.5.

Tthe measurement data from the heat pump are not conclusive to document this at the present time, mainly due to the fact that the cooling machine has not yet been in operation as a heat pump. This has been changed April 2009, and the cooling machine is expected to operate as a heat pump starting in the next heating season.

It is not expected that there will be any problems in delivering the necessary heating from the heat pumps.

Seawater cooling and CO_2-savings

The purpose of the seawater cooling is to show an energy saving for cooling of 300 MWh due to free cooling and efficient operation of the cooling machine with a high COP.

The layout of the system means that as long as the water temperature is below 12°C it is possible to have 100% free cooling. Above 18°C, it is not possible to use free cooling, and between 12°C and 18°C a combination of free cooling and compressor cooling is possible.

Since data for the cooling are inconclusive, the expected values from the building design will be used. These are assumed to be 20 kWh/m², or approximately 400 MWh during the year, except June and July, when no shows were expected. The cooling requirement is set at 1.8 kWh/m² per month, which including the summer cooling equals to 400 MWh of cooling.

In Figure 5.5, the seawater temperature from August 2008 to May 2009 is shown.

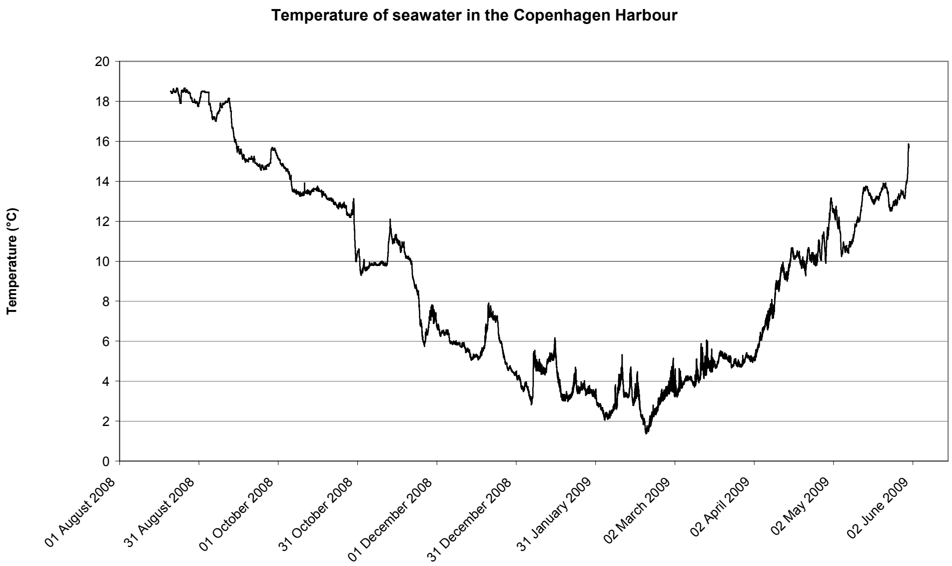

Figure 5.5 Measured seawater temperature from August 2008 to May 2009

Combining the cooling need and the availability of free cooling, the part of the cooling from free cooling can be found using the month-by-month values taking the actually measured seawater temperatures into account. In total, the share of the free cooling as part of the total cooling is found to be 297,000 kWh out of the expected total cooling load of 400,000 kWh. The 297,000 kWh of free cooling should be compared to an expected value of 300,000 kWh. This equals 71% versus an expected value of 76%.

Table 5.10 Share of free cooling

Free cooling	Expected	Actual based on seawater temperature
Free cooling	300,000 kWh	297,000 kWh
Share of free cooling	75%	71%
CO_2 emission, savings	76%	71%

At the same time, since the part of the cooling that is not free cooling is coming from the electrically driven compressor, a linear relationship between the savings in free cooling and the savings in CO_2 emissions from the cooling will also be 71%, which is slightly lower than expected. This calculation is using a conservative estimate of the COP of the compressor and does not take other optimisations of the operation into account.

5.4.3 Comparison to energy objectives

See Section 5.4.2.

5.4.4 Feasibility

Table 5.11 shows the main input and result of the feasibility calculations for the seawater cooling central. The result is a payback time of 12.2 years. This value was initially estimated at 13.5 years. The reason for the differences is mainly based on different energy prices than in 2004.

Table 5.11 Feasibility calculation for energy storage in the "Climate Belt" using TABS

Construction cost (2004 prices)	1 850 000	€
Extra cost compared to conventional cooling system (2004 prices)	770 000	€
Cooling need in building	400 000	kWh/year
Free cooling from seawater cooling	297 000	kWh/year
Resulting cooling need	103 000	kWh/year
Saving in energy compared to conventional system	71	%
Electricity consumption for heating	56	MWh/year
Energy savings for heating	250	MWh
Cost of electricity (2009 prices)	0.271	€/kWh
Cost of district heating (2009 prices)	75.43	€/MWh
Yearly operation cost of cooling system	20 000	€/year
Cost saving	83 741	€/year
Payback time, expected in 2004	13.5	Years
Payback time, actual	12.2	Years

5.5 Intelligent ventilation including BEMS (Playhouse)

5.5.1 Description

The ventilation system is complex, combining natural, hybrid and demand-controlled mechanical ventilation. On top of this, the systems also have to be able to deal with varied usage patterns. In total, up to six different ventilation systems are used with very strict demands on acoustics and comfort level. The distribution of the different ventilation systems is shown in Figure 5.6 and Figure 5.7 below.

The project has improved the state-of-the-art in terms of ventilation of cultural buildings by increasing the demand-controlled part of the ventilation, by highly efficient heat recovery rate using regenerative heat recovery systems, by heat pumps with storage of surplus heat/cooling in the thermo-active slabs, and finally by using natural ventilation. The buildings are ventilated using combinations of natural ventilation, pulse ventilation, hybrid ventilation and mechanical ventilation with different control strategies depending on load and season of the year.

As cultural buildings are complex by nature, not least with the systems described above, an intelligent BEMS is needed. The energy savings by an optimised BEMS will normally result in about 10% reduction in energy consumption, which will be achieved through specialist follow-up.

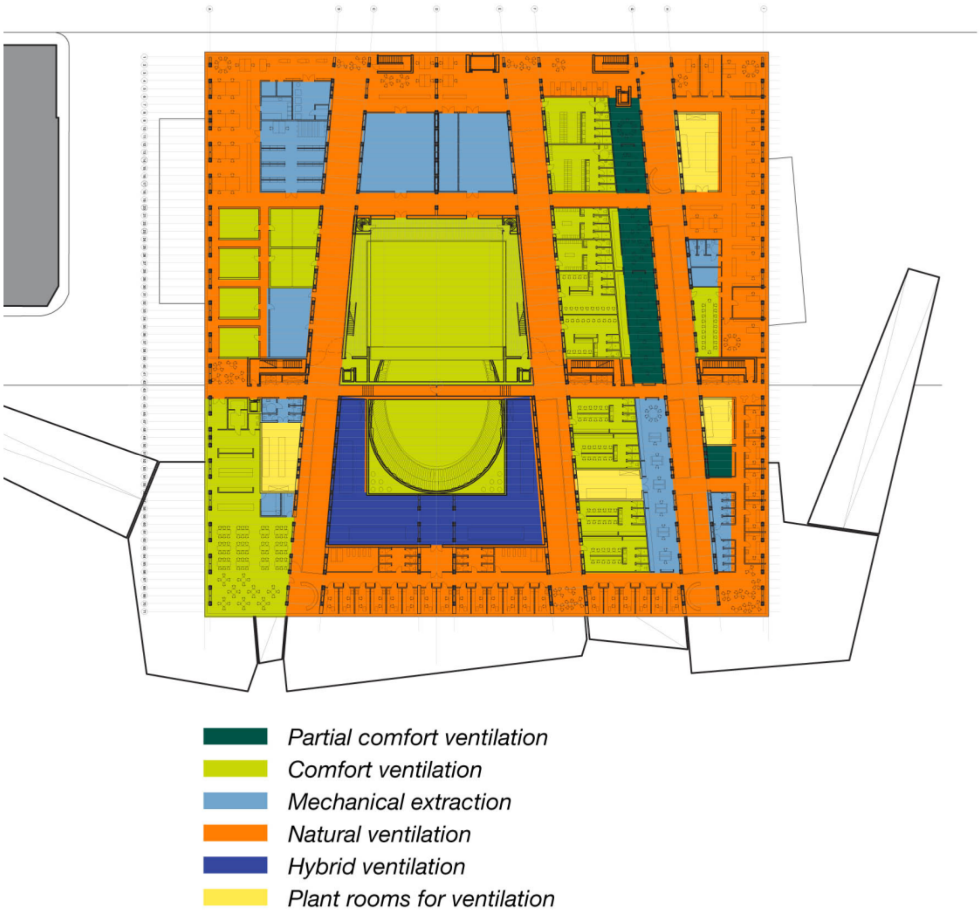

Figure 5.6 The use of different ventilation principles in different parts of the building

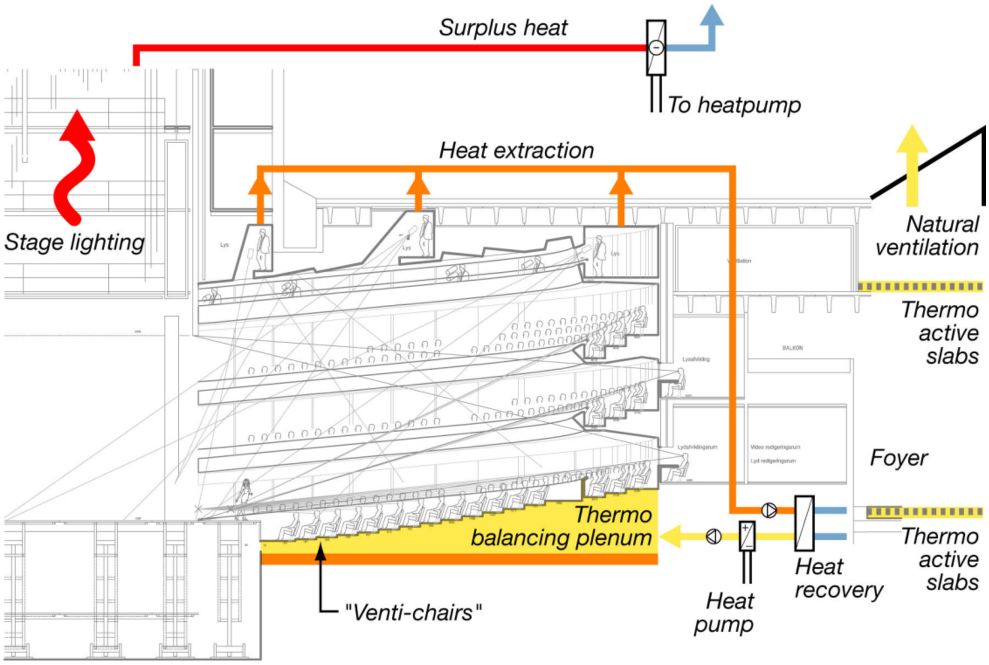

Figure 5.7 The interaction of the seawater/heat pump system and the ventilation system

5.5.2 Results

In this section, the savings in heating and the consumption of electricity in the ventilation system will be documented along with a total saving of CO_2.

Heating of the ventilation air

A saving in heating of 367 MWh/year was expected due to the ventilation system.

During shows, the mechanical ventilation systems supplies 130,000 m³/h air. A weighed average of the thermal efficiency of the heat exchangers supplying this air is 68%. Both rotary heat recovery coils and cross flow heat exchangers are used. In Figure 5.8, the measured temperature in the Auditorium is shown for three days in March 2009, measured in 22 different positions.

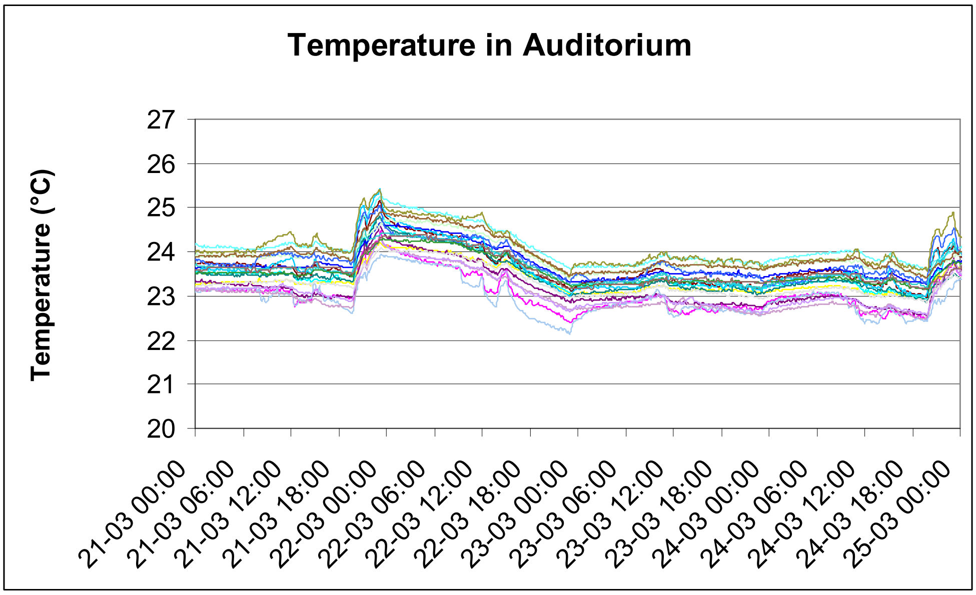

Figure 5.8 Typical temperatures in Auditorium during three days in March 2009

As can be seen, the temperature is normally in a very narrow band. During the daytime, the temperature is normally between 23°C and 24°C, whereas it increases to 25°C during shows. A similar picture can be seen for the remaining stages. The average temperature during the time of operation is assumed to be 24°C. During the heating season, the average outdoor temperature is found to be 5.3°C.

Using measured average indoor and outdoor temperatures, Table 5.12 shows the savings due to heat recovery for four, five and six hours of operation daily for 150 days during the heating season.

Table 5.12 Energy savings due to energy savings in the intelligent ventilation system. 150 days of operation during the heating season are assumed

	Expected	4 hours/day	5 hours/day	6 hours/day
Heat savings due to heat recovery	367 MWh	324 MWh	406 MWh	487 MWh

As can be seen, even with the minimum expected hours of daily operation when there are people in the Auditorium, the target of 367 MWh is nearly fulfilled.

Electricity consumption for ventilation

The electricity consumption in the ventilation system has been found to be between 10,000 kWh and 14,000 kWh per month or an average of around 12,000 kWh per month. As the building is in operation for 10 months of the year, this equals 120 MWh/year, which is close to the expected value.

Table 5.13 Electricity consumption for ventilation

	Expected	Actual
Electricity use for ventilation	125 MWh	120 MWh

However, notice that the expected value of the electricity consumption for the ventilation is based on a much shorter time of use than the actual value. If instead the expected period of operation had been the case, the electricity consumption for the ventilation would have been only 85 MWh, which is over 30% less than expected.

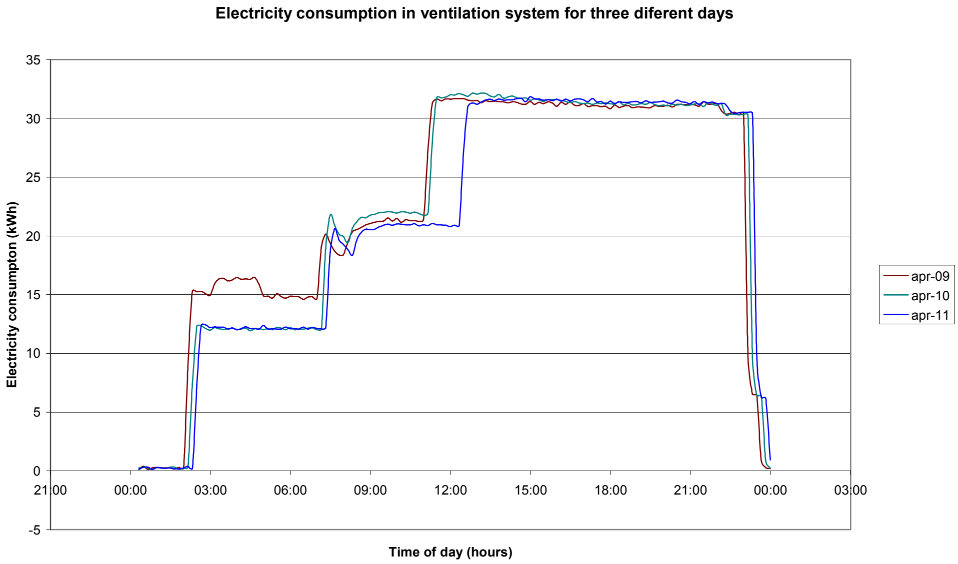

Figure 5.9 Electricity consumption for ventilation systems in the building for three days in April 2009

A typical picture of the electricity consumption during a daily operation of the ventilation system is found in Figure 5.9. The figure shows the electricity consumption in the 8 different ventilation units that are used for the main stage, auditorium and the test stages. In the figure, three consecutive days are shown with data from midnight to midnight.

Here it can be seen that the consumption is more or less identical on the three days. Since it is highly unlikely that the need for fresh air is the same during the day as when there is a show with 650 persons in the Auditorium as well as actors and heat loads from lighting, it seems that there would be a large potential for further savings in the electricity, if the set-points in the system are changed. But still, the energy consumption is not higher than expected.

Total CO_2-savings from ventilation

In total, the annual savings of CO_2 from the ventilation system are expected to be 49%.

The electricity for ventilation has been found to be on average 12,000 kWh/month or 7 kWh/m² year. The heat used in the ventilation units has been found to be 8 kWh/m². As seen below the target is fulfilled.

Table 5.14 Comparison of actual and reference values for the calculation of savings of CO_2

	Reference	Actual
Heating	35 kWh/m²	8 kWh/m²
Electricity	12 kWh/m²	7 kWh/m²
CO_2	256 tons CO_2/year (1)	84 tons CO_2/year (2)
Savings		67% (49% target)

(1) For heating the CO_2-emission in 2004 was 143 g CO_2/kWh, and for electricity 617 g CO_2/kWh.
(2) For heating the CO_2-emission in 2008 was 113 g CO_2/kWh, and for electricity 459 g CO_2/kWh

5.5.3 Feasibility

Table 5.15 shows the main input and result of the feasibility calculations for the intelligent ventilation system including BEMS. The result is a payback time of 12.2 years. This value was initially estimated at 13.5 years. The reason for the differences is mainly based on different energy prices than in 2004.

Table 5.15 Feasibility calculation for intelligent ventilation system including BEMS. All construction prices are based on 2004 price levels while energy prices are based on 2009 levels.

Construction cost (2004 prices)	3 192 000	€
Extra cost compared to conventional heating system (2004 prices)	404 000	€
Savings in heat consumption (based on Table 5.14)	559	MWh/year
Savings in electricity (based on Table 5.14)	104	MWh/year
Cost of electricity (2009 prices)	0.271	€/kWh
Cost of district heating (2009 prices)	75.43	€/MWh
Cost saving in energy	76 250	€/year
Operation cost (assumed)	14 100	€/year
Payback time, expected in 2004	14.1	Years
Payback time, actual	6.5	Years

The simple payback time is found to be 6.5 years. This should be compared to an expected value of 14 years. This difference mainly comes from the fact that the savings in heating have been much larger than expected and that the energy prices are higher than the initially used values.

5.6 Use of environmentally-friendly concrete for thermal storage in thermo-active slabs (Playhouse)

5.6.1 Description

Eco-buildings should always be built of environmentally-friendly materials. Denmark is the European leader concerning the development of environmentally friendly concrete, also known as "green concrete". Environmentally-friendly concrete will be used for the "Climate Belt" and will underline the energy savings of the Climate Belt/seawater solution. The environmental concrete has not been used in buildings before, but has been tested - in a slightly different format - at a highway bridge in Denmark. The Environmentally-friendly concrete will reduce the embodied energy for the concrete as well as reduce the CO_2 emission from the production of the concrete.

5.6.2 Results

Two types of green concrete have been used:

1 Green concrete where the cement is replaced by large amounts of fly ash (between 28 and 30% of the total binder). A reduction in CO_2 emission of about 50% in case of a cement replacement of 40% has been documented. This extremely high amount of fly ash is not very workable on site, and therefore, the cement replaced by fly ash has been limited to 30%.

2 Green concrete with a new type of cement (Rapid ® cement) leaving less impact on the environment already during the cement production. This is achieved by using among others 18% renewable fuels instead of coal. The reduction in CO_2 and NO_x emissions by using this new type of cement instead of the cement commonly used in Denmark (sulphate-resistant Portland cement) is presented in the following table (guiding values)[1]:

Table 5.16 Comparison of normal cement to green cement

Type of cement	CO_2 (kg CO_2/ton cement)	NO_x (kg NO_x/ton cement)
Sulphate resistant Portland cement (commonly used)	1158	8.9
Rapid ® cement (green concrete)	834	3.4

[1] Source: Aalborg Portland

In the Playhouse, where either a green cement (Rapid ® cement) alone or a combination of fly ash and Rapid ® cement has been selected, a reduction in CO_2 emission of at least 30% can be assumed.

5.6.3 Feasibility

The cost of the environmentally-friendly concrete is 14.8 million DKK or 2.0 million EUR, the extra cost being 1.5 million DKK or 200,000 EUR.

It is not possible to estimate a payback time for this technology, as there are no direct savings connected to the use of green concrete.

5.7 Energy storage using double aquifer in external system (Library)

5.7.1 Description

The built and planned buildings at the Oosterdok location are or will all be connected to a central cooling and heating system. This central energy supply system comprises a Long Term Energy Storage (LTES) system, heat pumps, a boiler and a distribution system. The latter comprises two rings, cold and warm. Each building is connected to this distribution system via heat exchangers.

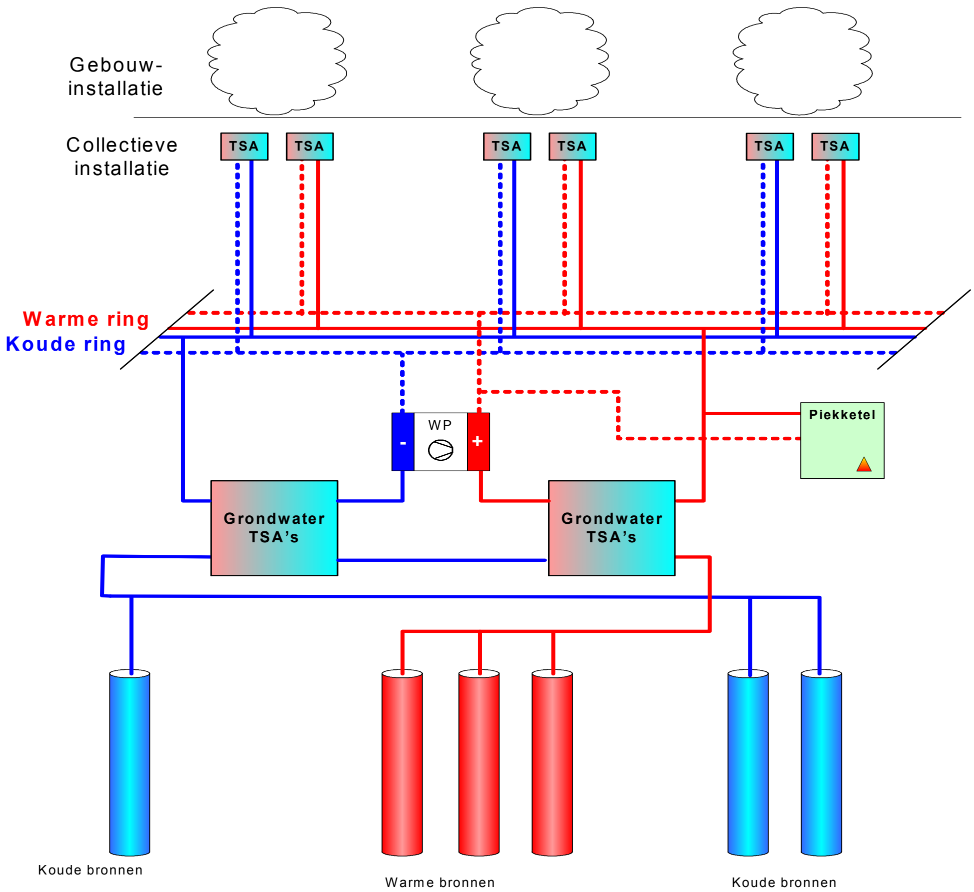

Figure 5.10 Schematic overview of the heat/cold storage in water layers

Overall system design

The system is shown in Figure 5.10. In total, there are six wells (and two extra wells). The cooling and heating is transferred from the groundwater pipes to the distribution system via heat exchangers. The wells are charged during winter respectively summer with surplus cooling and heating. The condensers, which are used to charge the cold wells are placed on top of the office buildings next to the library.

An innovation is that all buildings have access at the same time to both the cold and warm well, where surplus cooling and heating are stored in buffer rings. Since the buildings do not have the same pattern of heat and cooling demand, they can use the residue heat or cold from each other.

Heat pumps are used to reach the desired temperature levels. A boiler fired with bio-oil, is used for heating peak loads. When extra cooling is needed, this will be produced by the heat pump. The excess heat will be stored in the buffer ring.

Production of heating

In the winter period, heating from the warm wells is delivered to the heat pumps. It is cooled to 6°C and stored in the cold wells. This process occurs on the evaporator side of the heat pump. During the process, heat is produced on the condenser side at a level of 50°C. This heat is delivered to the buildings via the distribution system. In case of a higher heat demand, additional heat is provided by the boiler. A water temperature of 65°C can be reached.

The total installed power is approximately 10,680 kW, which is 70% of the maximum heat demand of all buildings (heat pumps 5280 kW, boiler 5400 kW).

Production of cooling

In the summer period, cold from the cold wells is supplied to the buildings. During this process, the cold is heated to 17°C and stored in the warm wells of the aquifer. When additional cooling is needed, the heat pumps are activated as refrigerating apparatuses (cooling machines).

When the heat pumps are in cooling mode, the condenser side produces hot water at a temperature of 40 or 50°C. The exhaust heat is stored in the warm wells via the heat exchangers. There are in total 3 heat exchangers.

The total installed cooling capacity is approximately 12,000 kW, which is 90% of the maximum cooling demand of all buildings combined.

Distribution system

Heat and cold have a separate transport system, the warm and cold ring. Each building is connected to the distribution system via a separate heat exchanger. Consumed heat and cold are measured via GJ meters. Both distribution systems have frequency-controlled pumps.

Dry coolers

The energy supply has a dry cooler installation with two functions: firstly to residual heat and secondly to regenerate the wells ('recharging cold').

5.7.1 Results

The results from the first year of operation are shown in the table below. As can be seen

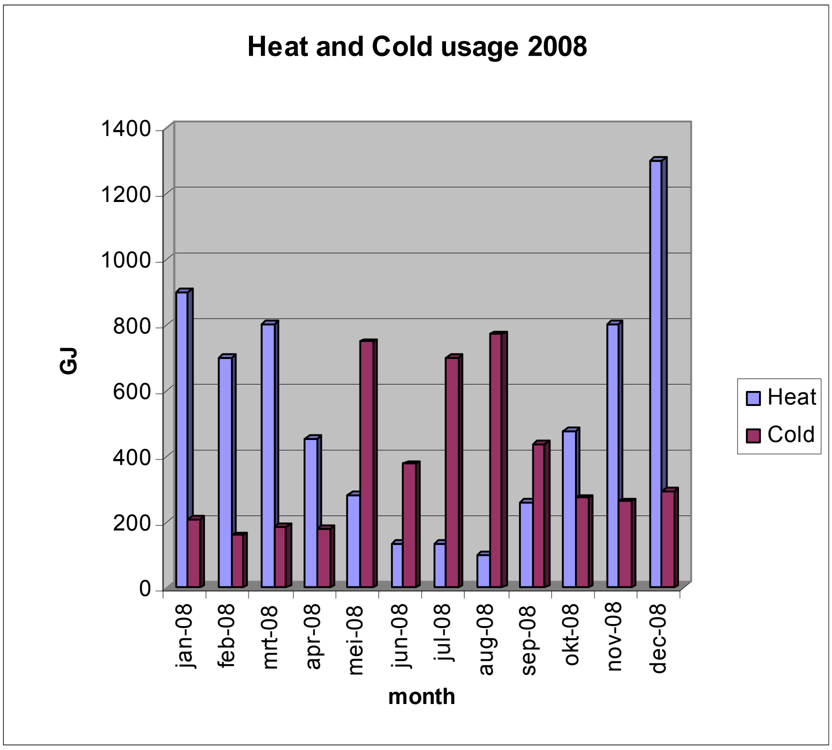

Figure 5.11 Monthly overview of heat and cold from the LTES

The monthly values are not corrected for degree days. However, in the autumn and winter months, a substantial use of cold is still visible. This indicates that heating and cooling are supplied at the same time.

5.7.2 Feasibility

In the case of the Library the municipality of Amsterdam has chosen to outsource the exploitation of the LTES system. Exploitation of the LTES is now done by the company GTI. For a period of 15 years they will maintain the LTES an deliver the heat and cold to the buildings. They have the right to give the LTES back to the municipality after 15 years. In this period of 15 years the system is ay back. The additional costs for the LTES including the heat pumps are estimated to be €960.000. These are the costs after subtraction of the fee paid by GTI to exploit the system for 15 years.

Table 5.17 Comparison of actual and reference values for heating and cooling

	Reference	Actual	Savings	Savings CO_2	% achieved
Heating	1815 MWh	1077 MWh	738 MWh	53 ton	15%
Cooling	159 MWh	64 MWh	95 MWh	56 ton	60%

5.8 Building-integrated PV system (Library)

5.8.1 Description

Façade PV system

A photovoltaic solar energy system is placed in the façade. The system consists of PV laminates. The laminates are placed in the wooden window frame. The laminates are made up of two glass layers laminated with the cell in between. A total of 43 modules are installed in three different sizes, with a total area of 169 m² and a total installed kWp of 14 kW.

The modules will are placed in the south-façade windows following a certain random-looking pattern. The eastern façade also has three columns of windows with PV modules.

Table 5.18 Power and surface of the PV façade system

Location	Number of panels	W_p	Area (m²)
Façade (south)	29	9484	113.7
Façade (east)	14	4573	54.9
Total	43	14057	168.6

The installation of the PV panels can be seen in Figure 5.12

Figure 5.12 The PV modules placed in the front window during construction and the inverters for the façade system

Roof PV system

The rooftop PV system consists of two large areas with a total of 455 PV modules. In total, 82 kWp are installed. 208 modules are placed on the lower roof, while 247 modules are placed on the higher roof.

Table 5.19 Total installed PV power on rooftop

Location	Number of modules	W_p	Area (m²)
Lower roof	247	44460	381
Upper roof	208	37440	456
Total	455	81900	837

The inverters are placed inside the technical room.

5.8.2 Results

The production of the solar roof PV system is measured and stored in the BEMS. The production of 2008 and 2009 is presented in the table below.

Table 5.20 Production PV roof

Year	Production (kWh/year)	Irradiation (kWh/m2)	Savings CO2 (ton/year)
2008	57634	1032	34
2009	52544	1044	31

The renewable electricity production is as expected

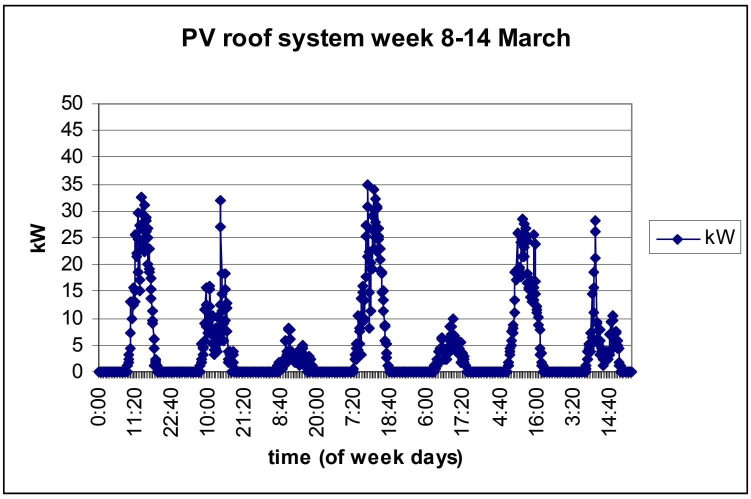

Figure 5.13 Solar electricity production of the PV roof system

5.8.3 Feasibility

The total additional cost for the PV roof and faced system are estimated be €450.000 and €250.000. The average production of the systems is 65 MWh per year. Because of the low electricity price this results in a simple payback time of 175 years.

5.9 Intelligent ventilation including BEMS and benchmarking (Library)

5.9.1 Description

The ventilation system is controlled by CO_2 levels to ensure efficient use of energy for ventilation. A high-temperature air inlet of 17 to 18°C is used. This means that during a long period over the year, outside air can be used without heating.

A cultural building like the library is large and complex with several users and different temperature and humidity levels. The building is therefore equipped with an automated climate control or BEMS.

The system will control the climate in the building (heating and cooling), the lighting and energy use. It comprises the following:

- CO_2-controlled ventilation system.
- Temperature control of inlet air.
- HF lighting with daylight control and signal to shut down all the lighting tubes.

The BEMS can be followed and operated from outside the building; an interface will be part of the system. Thus, the building can be on-line monitored.

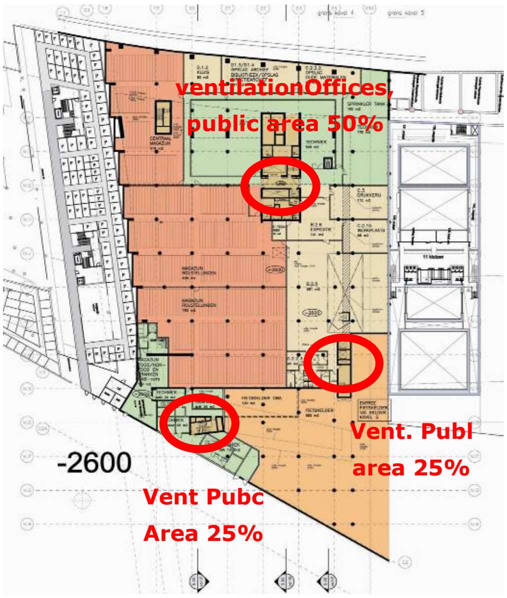

Figure 5.14 Schematic overview of the library, ventilation

BEMS

More energy meters have been installed compared to a standard building. All mechanical and electrical systems will be controlled via the BEMS. Analogous and digital readings will be stored. Storage capacity of data is 100 Mb, which will be enough for precise monitoring. Measurements can be taken each minute.

The system functions to minimize the energy use and meanwhile also maintaining a healthy and comfortable indoor climate. The implementation of proper control strategies will be based on the monitoring of the energy use.

Monitoring

The BEMS will be used to monitor the energy use of the library. There are three levels of energy use and monitoring:

- The island level:
  Efficiency and primary energy use of the long-term energy storage.
- Building level:
  Energy use of the installations.

- Building/user level:
  Heat production visitors.

For the installations, the following main energy flows are identified: Heating, ventilation, lighting, computers/appliances, transport, cooling, PV.

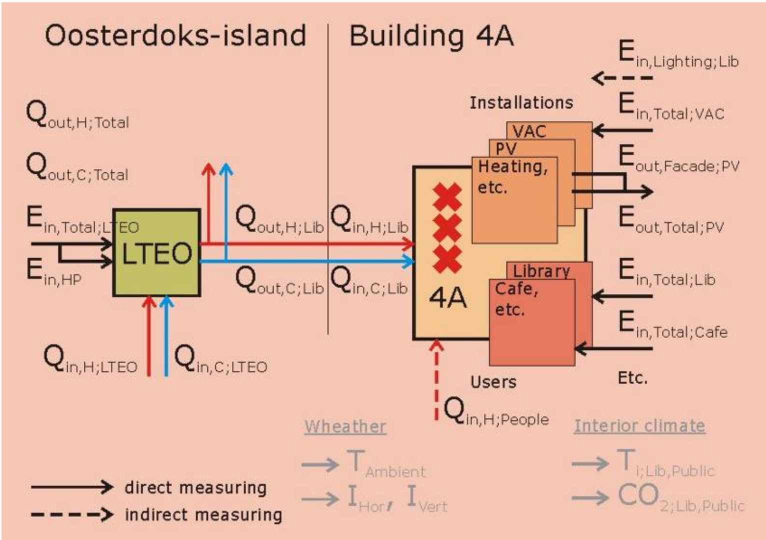

Figure 5.15 Principles of the energy-use monitoring

The total energy use is calculated on the basis of direct and indirect measurements. Direct measurements are e.g. total electricity use, total heat, etc.

Indirect measurement are based on assessments. These assessments are e.g. heat load due to visitors (based on number of visitors), electricity use and lighting based on installed capacity and opening hours.

Lighting

The lighting system has a maximum installed power of 12W/m^2. To get here, HF fluorescent tubes are used wherever possible. This is more or less restricted to offices, meeting rooms and corridors. Special attention is given to the lighting of the bookshelves. TL tubes and LED lights are used.

In several rooms and offices, a sweep-pulse system is installed as well as a person-detection system. Further, a daylight control system is installed.

5.9.2 Results

It is believed that the energy savings for lighting and ventilation can be reached. However currently, no sufficient data is yet available to make an analysis of the electricity use of the library.

5.9.3 Feasibility

Based on the results currently available, it has not been possible to do any feasibility calculations or find the payback time. The additional cost for the BEMS, metering, CO_2 detection and intelligent controlled ventilation are estimated to be €60 000 and €80 000.

5.10 Demand-controlled hybrid ventilation (Opera)

5.10.1 Description

The Opera House has a high maximum ventilation rate due to extreme variation in loads. Further, it is used from early morning to late night, which causes a long operation time for the plants. The users are highly sensitive to poor indoor climate and require humidity control of the air. The facility management personnel of the building require robust plants that are easy to run and maintain.

The Opera project provides solutions to control the ventilation with respect to indoor air quality, temperature and humidity when the users are in the building. Focus is put on making the systems robust. Since the building has a humidifying system, the ventilation system also controls the humidity when the building is not in use to avoid condensation and risk of fungi.

Energy-efficient in-house energy distribution systems

Modern buildings use a lot of energy to transport ventilation air and circulate water. In the Opera House, the energy consumption for the distribution of ventilation air is most critical. The first step to reduce this is the demand-controlled ventilation. The next step is design of a ventilation system with a low SFP (Specific Fan Power). The focus regarding SFP will be put on good aerodynamics in the ducting system, the plant and its components. Proper design of each component in the plant room is essential for a good result. This focus goes very well in hand with the extreme focus on sound and noise in the Opera House.

Humidity control through active use of building material and technical systems

The singers and the wooden instruments require high humidity all the year in all rooms. With the cold and dry winter climate in Norway, this leads to extremely high energy consumption.

The design of the energy-efficient humidity-control system has been made to support the humidity buffering capacity of the wooden material in the large audiences, in order to reduce the demand for humidification of ventilation air and local humidification.

5.10.2 Results

Results of simplified calculations for ventilation heating are presented in Figure 5.16. The calculations are based on the conditions described in Table 5.21. For the calculations 19°C was used as the temperature of the supplied air.

Table 5.21 Conditions for the calculated energy consumption for ventilation heating

High budget:	All ventilation systems run continuously on maximal capacity all year through.
Low budget:	All ventilation systems run 10 hours a day, 5 days a week. The VAV systems run with an average capacity at 50% during operation.

There is a significant potential for energy savings for different running times. The energy consumption can almost be reduced to 1/5 by operating the ventilation systems in accordance with the conditions for the low budget compared to the conditions described for the high budget.

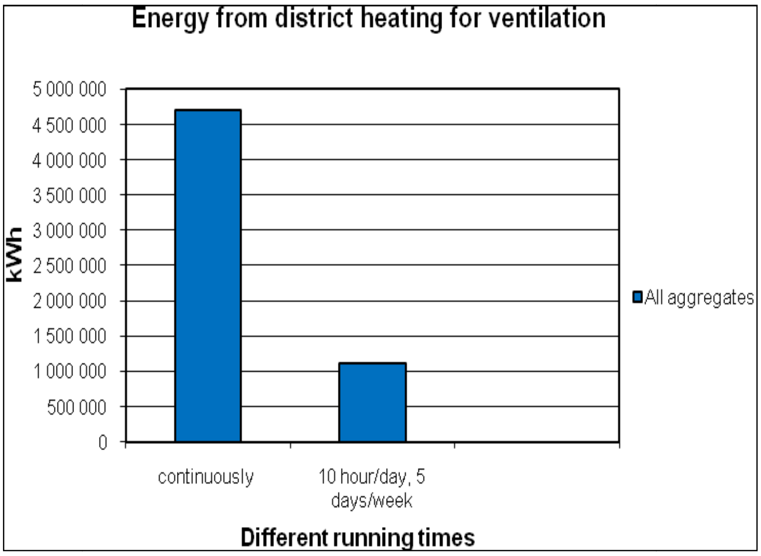

Figure 5.16 Total energy consumption for ventilation heating - different running times

Different running strategies have been tested on ventilation system 360.022 to document the energy saving that can be achieved through correct operation.

Table 5.22 Description of the different ventilation strategies tested on system 360.022

Test	Set-point tempera-ture [°C]	Min. air volume [%]	Set-point CO_2 [ppm]	Set-point RH [%]	Run-ning time	Remarks
1	21,5	50	400	30	7am-10pm	Original operation strategy
2	26	50	800	30	7am-10pm	Eliminate control con-flict between ventila-tion and heating
3	26	30	800	30	7am-10pm	Reduce minimum air volume

The different strategies are described in Table 5.22. The daily energy consumption for ventilation during the tests is shown in Figure 5.17.

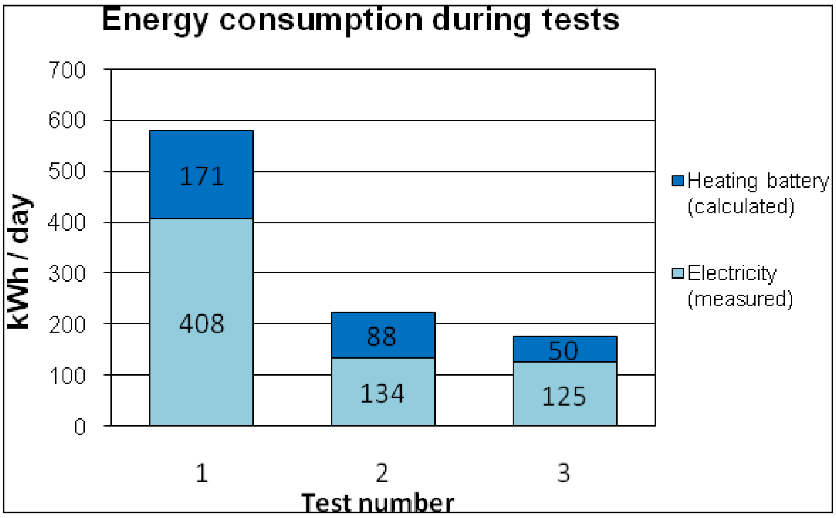

Figure 5.17 Energy consumption during tests

The operation strategy has great influence on the energy consumption for ventilation. During test 1, the ventilation operated on maximum capacity the whole day, 8000 m^3/h, due to the set-point for CO_2 and temperature. The original set-point for CO_2 in ventilation system 360.022 was 400 ppm, the Oslo outdoor concentration being around 400 to 450 ppm. This conflict leads to a constant maximum air flow. Also, the set-point for temperature was 21.5°C for the ventilation system, while the set-point for the heating system was 23°C, which also indicates a conflict.

Changing the set-points dramatically reduced the energy consumption, as seen in the results of test 2. For test 3, the minimum air volume was adjusted to 30% (2400 m^3/h). It was observed that the air volume was reduced to 30% for the main part of the time during test 3, indicating that the load of the room is less than predicted. The reduction of electrical energy consumption between test 2 and test 3 is negligible even if it was observed that the air volume was reduced from 50% to 30%. This indicates that the fan efficiency drops a lot when the capacity is below 50%. Nevertheless, it is recommended to operate the ventilation system according to test 3 since the total energy saving is considerable.

The results of the tested running strategies show that the design of the ventilation system in the Opera House works when it is operated and controlled correctly.

The indoor air quality and temperature were measured during all three tests to make sure that the reduction of supplied air did not have any negative effect on the indoor environment. The results showed that the indoor environment was satisfactory for each and all of the operation strategies.

The energy saving due to the design of the ventilation system has been documented by determining the SFP on the fan in ventilation system 360.022. The results are shown in Table 5.23

Table 5.23 SFP for ventilation system 360.022

Air volume [m^3/h]	Air volume [% of max]	Power, supply air [kW]	Power, return air [kW]	Total power [kW]	SFP [kW/(m^3·s)]
8000	100	2,02	2,07	4,09	1,84
2400	30	0,19	0,21	0,4	0,65

The predicted SFP ≤ 2 is achieved for ventilation system 360.022. The reduced air volume as a result of adjusted operation of the ventilation system had a positive effect on the SFP, since the pressure drop was reduced resulting in less electricity consumption. In average the SPF will be below 1.

The results of these tests made a basis for simulations of annual energy consumption of rehearsal room D. The different tested ventilation strategies was modelled. Simulations in SIMIEN did not consider energy consumption for humidifiers. Manual calculations have therefore been done to determine the energy consumption for the humidifier.

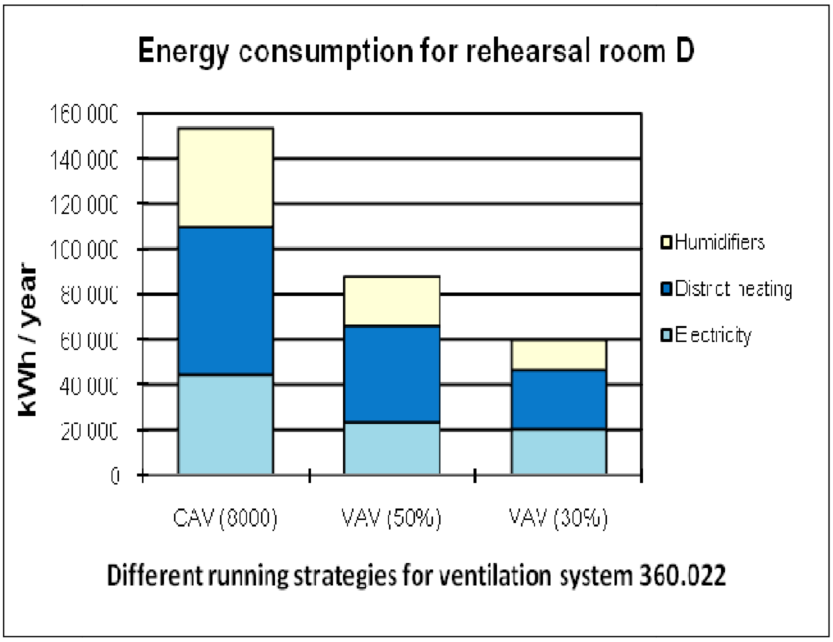

Figure 5.18 Energy simulations for rehearsal room D

Figure 5.18 shows that there is a significant potential for energy savings related to the operation of the ventilation system. The difference between CAV (8000) and VAV (30%), based on test 1 and test 3, respectively, is 93 000 kWh/year. This indicates how important running strategies are for the energy consumption. It is important to notice that Figure 5.18 illustrates the saving potential for only one single room in the Opera House with an area of 225 m^2.

Experience shows that the ventilation system most of the time runs on 30% of maximum in the rehearsal areas. The energy saving potential for rehearsal room D is 90,000 kWh.

The total treated air volume in the Opera House is 453,350 m^3/h. 245,920 m^3/h or 45% are split into plants like 360.022.

5.10.3 Feasibility

If the savings for all VAV plants are considered to be the same as for 360.022, a decrease of 2 767 000 kWh in energy consumption would be expected. However, a more realistic approach would be to assume that 80 % of the savings found in 360.022 can be achieved in all ventilation plants. This will lead to a total reduction of 2 213 000 kWh.

The extra investment costs were 5,250,000 NOK. With maintenance costs of 300,000 NOK per year and an energy price of 0.7 NOK/kWh, this gives a simple payback time of 4.2 years.

5.11 Control strategies, BEMS and benchmarking (Opera House)

5.11.1 Description

Ventilation

There are 30 ventilation units in the Opera House.

Lighting

The light system in the Opera House is designed to use as little energy as possible. Most of the lights are efficient thin-type fluorescent tube light, metal vapour halogen and some LED; there is no use of 12 V halogen spots in the building. There is a double set of light in the orchestra rehearsal room due to strict sound criteria. For normal everyday use, energy-efficient fluorescent tube light will be used, and for occasions when recording is taking place, incandescent lamps will be used.

Lighting control

Time regulation or presence detectors are used to switch on and off the light in almost all rooms. This is common in Europe, except for Norway. In addition, daylight control is used in several relevant areas, e.g. in the foyer. Daylight control switches off a part of the light, depending on the daylight level. The daylight level is controlled by a daylight sensor. This is - in addition to saving electricity for lighting - an important strategy to avoid cooling. Saving electricity for lighting therefore has a double effect on the total energy savings.

Snow melting

The outdoor area of the Opera House is equipped with a snow-melting system in the ground. The original plan was to install a thermal system connected to district heating. Later, the thermal system has been supplemented with several areas with electrical snow-melting systems. Since the electrical snow-melting systems were attached after the planning of the building, their energy consumption was not considered in the original energy budget.

Figure 5.19 The snow-melting system in the outdoor area of the Opera House

Snow-melting control

The snow-melting system has a sensor that detects the snowfall ahead. The pumps start on signal from the sensor, and the shunt valve opens before the snow falls. This control strategy reduces the heating time and starts the melting process earlier than common snow-melting systems. The system is turned off between snowfalls. The suppliers of the control system claim that correct operation of the snow-melting system may lead to an energy consumption of approximately 100 kWh /m^2, while a construction without any control system may have energy consumption above 400 kWh /m^2.

All the control strategies are directed via the common bus. The bus system collects data from all sensors, actuators, controllers and system components. The data are useful information to follow the strategies for energy-efficient management and all the technical equipment.

Ventilation

The control strategies for ventilation, cooling and heating are described in Section 5.10.1

5.11.2 Results

The first year of operation, april 2008-2009, had a high energy consumption, which is quite normal to the first year of operation. The HVAC systems in the Opera House were running differently than predicted, which led to higher electrical energy consumption for fans, pumps and humidifiers.

The system managing the light control was not in function. The light was therefore on continually in large parts of the building. The system has now been programmed.

In addition, the original budget for electricity did not include the restaurant, workshops or electrical snow-melting system. These are all major posts. The restaurant has reached another dimension compared to the original thoughts, and the number of visitors has been much higher than assumed.

In the second half of 2009 a broad improvement process was performed. It shows how the BEMS is used to tune all systems and reduce the energy consumption in steps. It shows the power and potential of the use of such system.

During the first half of the second year the energy consumption fall dramatically, and the budget for 2010 is below EU target for heating and cooling.

The following figures show the monitored monthly total energy use and energy use for district heating in the opera house in 2008 and 2009.

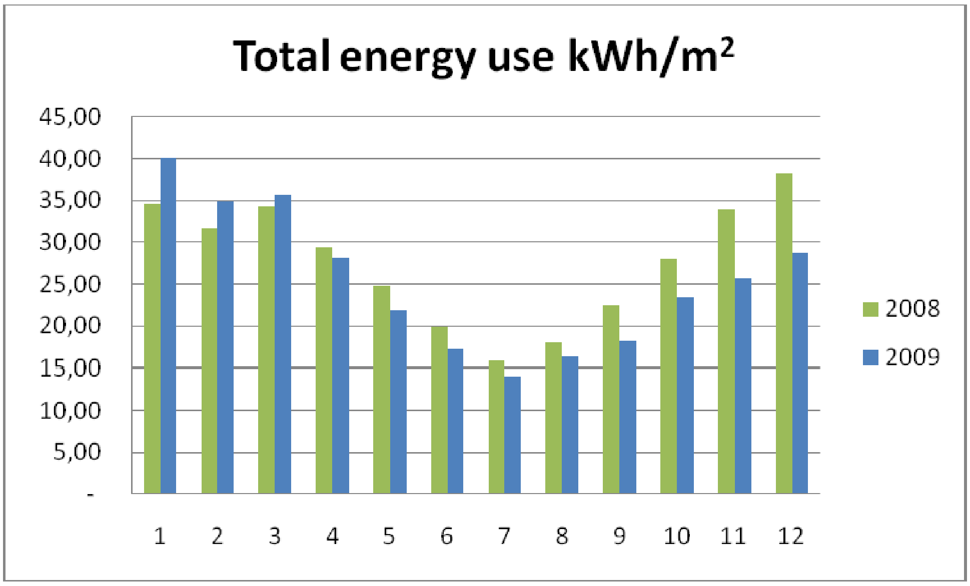

Figure 5.20 Total energy consumption in 2008 and 2009

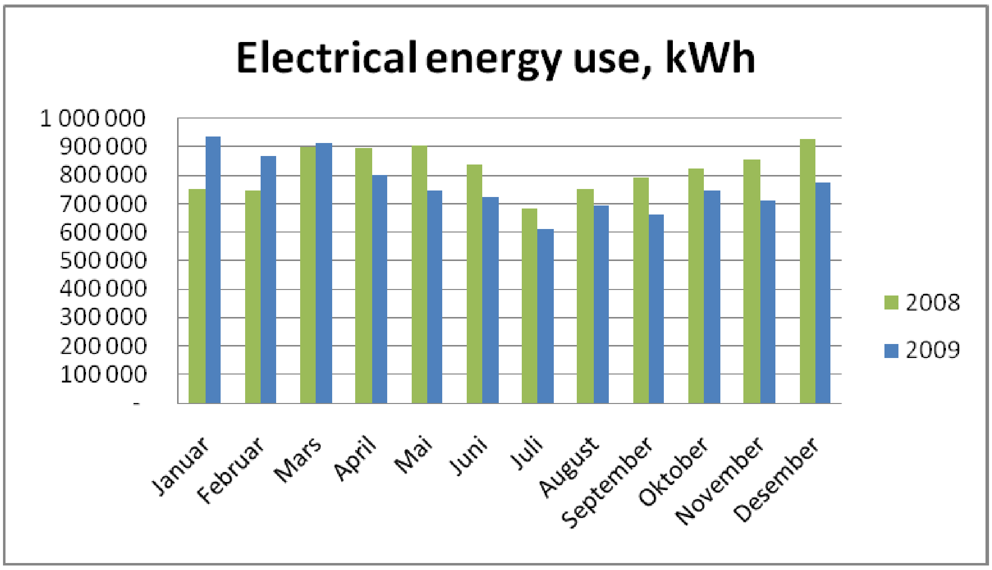

Figure 5.21 Electric energy consumption in 2008 and 2009

Table 5.24 Electrical energy consumption in kWh for 2008 and 2009.

Energy meter:	2008	2009
Transformer 1. Lightning and electrical points	3 439 014	3 557 225
Transformer 2. HVAC, kitchen, theatre lightning, elevators	5 833 245	5 086 640
Transformer 3. Cooling machine, Scene elevator	590 445	544 255
Total	9 862 704	9 188 120

The electrical energy consumption for 2008 was characterized by testing of systems and some unfinished work on the technical equipment and installations, especially before the opening in April. 2008 and first half of 2009 was dedicated to finishing, adjusting and testing the systems. The result is proven in the second half of 2009.

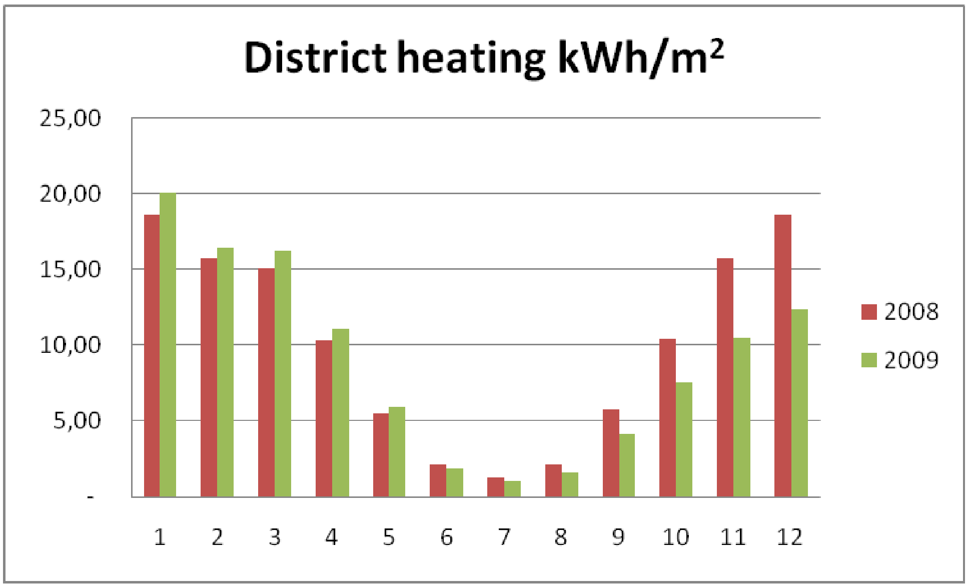

Figure 5.10 District heating consumption in 2008 and 2009

Both figures on electricity and district heating show a remarkable change in energy use the second part of 2009, the most remarkable on district heating. This change is a direct result of the on-going improvement process. This process will continue. There is still a potential for improvements and further reductions are expected. Normally it takes at least 3 years to optimize such complex buildings.

A budget for 2010 is set up based on the monitored results of 2. Part of 2009

Table 5.25 Energy budget for 2010 based on monitoring results from second half of 2009 (Area 47 000 m²)

	ECO Budget	Budget 2010
	kWh	kWh
District heating	3 930 164	3 491 680
Electricity cooling	916 500	544 255
Electricity rest	5 364 435	7 842 425
Sum	**10 211 099**	**11 878 360**

The results show that we are now within ECO culture target for 2010 for heating and cooling. We still do not have enough monitoring on all the electrical elements, but the tests on the HVAC systems and the reduction on the electrical part is very positive and promising to also this target. The electricity use has large user related connection and as mentioned the restaurants make influence. This was not a part of the EC project, and must therefore be subtracted when comparing with the budget.

Figure 5.11 The snow is not melting on the windows in the foyer. A sign of energy efficiency.

5.11.3 Feasibility

As mentioned, the energy consumption of the building was higher than expected the first year. The second year we are very close to the target. The features of the BEMS made it possible to detect errors in the principle of running the heating, cooling, light and ventilation systems and further optimize the performance. It would have been hard to find a strategy on how to reduce this without the BEMS. A conservative expectation gives a minimum 5% energy reduction when the system is running properly, exclusive the effects of the Demand controlled ventilation. This means a reduction in energy consumption of 1 187 836 kWh. This might seem low, but 2 213 000 kWh is already calculated within Demand Controlled Ventilation.

The costs of the BEMS are 2,950,000 NOK. This gives a simple payback of 2.5 years when maintenance is not considered.

5.12 Building-integrated PV system (Opera House)

5.12.1 Description

A 450 m^2 solar cell grid has been integrated in the south façade. This can provide both shading and electricity. Since the Opera House has a large glazed south facing façade in the foyer, it is necessary to use shading, to avoid overheating. With the exposed location, it will also be a demonstration of the technology to a large audience.

The south façade with solar cells is shown in Figure 5.22

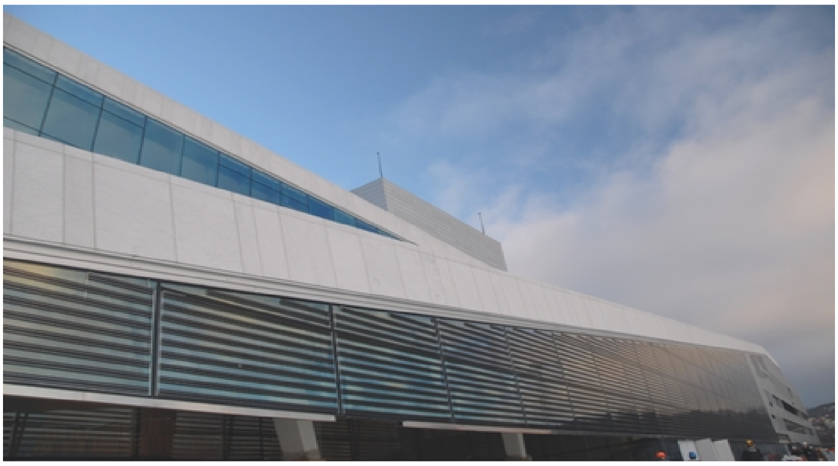

Figure 5.22 South glass facade with solar cells

Figure 5.23 The south facade of the Opera House

The pictures above show the south façade of the Opera House with the integrated solar cells. As seen, the solar cells are well exposed for the tourists. From floor level and up to 3 m, there are no solar cells to keep an open view to the sea. The foyer area is shaded by an overhang and outside solar cells.

With a size of 3.4 x1.8 m, the solar panels are presumed to be the largest in the world at the time of construction. Saint Gobain indicates that the energy output will be 20,618 kWh per year.

5.12.2 Results

The solar cells on south façade of the Opera House have been running since 12 February 2009 and had produced 6112 kWh per 29 May. The solar panels had some reduced capacity due to problems with some inverters, only 22 kW was working properly a part of the year. This is now corrected. The expected production in 2010 is 16 % higher than the original budget. In addition to having a utilitarian value, the solar cells demonstrate to the public that the Opera House is focusing on renewable energy and is concerned with the environment.

Figure 5.24 Solar cell inverters

Figure 5.25 PV panels on south façade of Opera House and solar converters

Table 5.26 Production of electricity from PV-panels - monitoring results 2009 and budget for 2010

	ECO Budget	Monitored 2009 After 12/2-09	Budget 2010
Solar cells	20 618 kWh	18000 kWh	24000 kWh

5.12.3 Feasibility

The expected energy production of the façade is 20,618 kWh/year. The total extra investment costs were 2,800,000 NOK. This gives a simple payback of 135 years.

6 Conclusion including socio-economic relevance, strategic aspects and policy implications

This report presents the main conclusions from the project "Demonstration and dissemination of ECO-concepts for high-performing European cultural buildings" with the acronym ECO-Culture. In the project, three large cultural buildings centrally located in three European capitals have been designed and built with the purpose of showing that for cultural buildings low-energy consumption and an appealing architecture can go hand in hand. The three landmark cultural buildings are:

- The Royal Danish Playhouse in Copenhagen, Denmark
- The Amsterdam Public Library in Amsterdam, The Netherlands
- The Oslo Opera House in Oslo, Norway.

The buildings have been designed using a concept called the "whole building approach", which is characterised by the fact that in order to achieve low energy consumption, it is necessary to include all parts of the building design. This is also a necessity to achieve the desired indoor climate.

The buildings include a number of ECO-concepts or technologies to ensure the low energy consumption. These are among others intelligent control systems integrated in the Building Energy Management System, seawater cooling, long-term energy storage in an aquifer, heat pumps, thermo-active slabs, demand-controlled ventilation and building-integrated photovoltaic systems. The overall goals of the project have been to demonstrate that it is possible to:

- Reduce the energy consumption and CO_2 emission related to cooling by 75-80%.
- Reduce the heat consumption and related CO_2 emission by 35-50%.
- Reduce the energy for ventilation and related CO_2 emission by 35-50%.
- Use renewables; seawater, ground water and solar energy.
- Use intelligent control for maximised utilisation of the use technologies.

The buildings have each become integrated parts of the cultural life in the cities where they have been built. This can be seen by the fact that the buildings have had more visitors than expected, and there have been more shows and more hours of operation than expected. In total it is expected that, well over 4 million people have paid the buildings a visit during the first year of operation. This should be compared to an expected number of visitors of 2.4 million.

Dissemination of results

The main dissemination of the ECO-Culture project is the buildings themselves. Each of the buildings is daily used by a large number of guests, users and employees as described above; in total, over 4 million. Also a large number of these guests have participated in guided tours of the buildings. In total, this equals 130.000 thousand together with over 300.000 visitors to shows in the Opera and Playhouse. All numbers are valid for 2009.

The project has disseminated the used ECO-concepts of the high-performing cultural buildings throughout Europe and beyond. The project and the buildings have been presented in numerous occasions for all kinds of audiences. This includes newspapers, TV, technical magazines, conferences, websites, meetings and on-site during the guided tours.

The Royal Danish Playhouse

In the Royal Danish Playhouse, focus has been on heat pumps, seawater cooling, thermo-active slabs and the use of environmental concrete. Of the 10 defined target values in the project, six have been achieved directly, one would have been met if the operation time of the building had been as expected. The final three cannot be shown to have been achieved due to a problem in the layout of the cooling central. However, the initial measurements that are available indicate that the last three targets will be met. This includes a reduction in cooling consumption and CO_2 emission by 71%, compared to an expected value of 75%. The reduction in heating consumption is 42%, and 67% of the related CO_2 emission. This large drop is partially helped by lower emission related to the distributed district heating.

Among the new technologies, especially the combination of thermo-active slabs and heat pumps for heating and cooling using seawater as the reservoir has been adopted in new building projects. Variations of this concept using groundwater or LTES have also been designed in more recent projects.

Finally, even with the impressive results that have already been reached, there is still a potential for improvement. This improvement will be facilitated by the large amount of metering equipment.

The Amsterdam Public Library

In the Amsterdam Public Library, focus has been on energy storage using double aquifer in external system, building-integrated PV system and intelligent ventilation including BEMS and benchmarking.

So far, only very limited data exist for the Library and therefore final conclusions cannot be made concerning energy consumption for heating, cooling and electricity consumption as well as reductions in CO_2-emissions.

However, the target for the total energy use has not been met. The main deviation is in the electricity use, where further analysis is necessary. Heat and cold usage are within the target range. Additional cold usage can be explained by the larger electricity use and extra heat usage.

The Oslo Opera House

In the Oslo Opera House, focus has been on intelligent demand-controlled ventilation, Building energy Management as well as a building-integrated photovoltaic system, which at the same time functions as solar shading.

After one year of adjustments and improvements all the technologies have shown to work well. One important result is that a good result requires testing and continuous work on improvements by the operators. This process is well documented and it would be useful to continue this process of documentation.

For this type of building demand controlled ventilation has shown to be extremely well working and energy efficient. The same technologies will be used further in schools and other cultural building.

The BEMS have a similar impact on the energy consumption as the Demand Controlled Ventilation. It has already shown to be å powerful tool to reduce the energy consumption. The potential is not still fully explored. The combination of interested and skilled operators and leaders together with the BEMS may lead to an even better result than the ECO culture target.

The solar cells are a brilliant example of integrated solar energy in architecture. They are expected to produce slightly above target value. Their relative potential to reduce energy in this building is limited, but the technology is important to develop and demonstrate. It is the only Norwegian demonstration of this kind and scale.

7 Dissemination and exploitation of the results

7.1 Dissemination carried out

The main dissemination activity in the ECO-Culture project is the buildings themselves. The large number of visitors to the buildings both as users in the Library and as guests attending shows in the Opera House and Playhouse as well as the visitors participating in the guided tours are all experiencing that architecturally appealing buildings can very well be environmentally friendly.

Below, a list of the actual dissemination activities is shown for each of the five years of the project. However, firstly a shortlist of some important milestones is shown:

- The buildings each have guided tours and can offer technical tours for interested visitors.
- The buildings have won several prices for both architecture and environmentally friendly solutions.
- The buildings have been presented in newspapers, technical magazines and local as well as national television. This dissemination has taken place both during planning, erection and operation.
- The buildings have a larger number of visitors than expected and have become integrated into the cultural life of each of the cities where they are placed.
- The buildings have been promoted on the website www.ecobuildings.info. The website has now been transferred to new EU-funded projects on Eco-buildings.

Table 7.1 List of dissemination activities during the project

No.	Date	Media	Type of media/ audience	Language/ Distribution	Duration/ audience	Partners
61	Oct 2009	Lecture for building owners in NAL, ECO BoxBærum kommune	Engineers	Norway	10	E&H
60	Oct 2009	Lecture for building owners in NAL, ECO BoxBærum kommune	Engineers	Norway	10	E&H
59	May 2009	The energy concept of the Royal Danish Playhouse. Presentation at Elforsk Prisen 2009	Guests at the award ceremony	Denmark	200	COWI and DKT
58	Mar 2009	Bæredygtig Beton Pris. Award for Sustainable Concrete by Danish Concrete	Technicians and engineers	Denmark	100	COWI and DKT
57	Mar 2009	www.cowi.dk "Royal Playhouse receives Award for Sustainable Concrete"	Guests to www.cowi.dk	Denmark	20,000	COWI and DKT
56	Mar 2009	Award to Royal Danish Playhouse. News in two papers: Teknik og Viden and Building Supply	Technicians and engineers	Denmark	1,000	COWI and DKT
55	2009	Guided technical tours	Engineers, students, politicians	UK and Norway	1000	Statsbygg/Opera
54	2009	Lectures and guided tours at technical college of Oslo	Students and university staff	Norway	80	E&H
53	2009	Sustainable Urban Design	Book	Dutch	?	Ecofys
52	Nov 2008	The Public Library won the Sustainability Award for Most Sustainable user friendly Building of Amsterdam. Awarded by Dutch Green Building Council and Municipality of Amsterdam and Province of North Holland	All	Dutch	?	Ecofys and CoA
51	Nov 2008	Internet ECO Design web page-NAL ECO Box: http://www.arkitektur.no/?nid=98843&filter=costbenefit&pid1=151835	Architects/engineers Continous all norwegian architects	Norwegian	Unknown	E&H
50	Oct 2008	The Royal Danish Playhouse receives "Nordisk Lyspris" (Nordic Lighting Award). Article in Licitationen	Technicians and engineers	Denmark	30,000	COWI and DKT
49	July 2008	Event organised by WWF at the Library	All	Dutch	?	Ecofys and CoA
48	July 2008	Article in I Astma og allergi nr 3 2008-07-03	People with asthma and allergy, doctors	Norwegian	10-30000	E&H
47	May 2008	Water in the floor. Article in Politiken	All. National newspaper	Denmark	100,000	COWI and DKT
46	April 2008	Symposium on ecology using the Library as case	Professionals	The Netherlands	?	Ecofys
45	Apr 2008	Oral presentation of ECO culture	2nd Common Symposium of EU FP6 ECO buildings projects in Stuttgart	All European countries	100	COWI and E&H
44	Mar 2008	Article in paper Dagens næringsliv	Public, business	Norwegian	50 000	E&H

43	Mar 2008	Lecture IEA Exco solar cells	Researchers, officials	English	30	E&H
42	2008	Guided technical tours	Engineers, students, politicians	Enlish and Norwegian	1000	Statsbygg
41	2008	Lectures and guided tours at technical college of Oslo	Students and university staff	Norwegian	80	E&H
40	Nov 2007	Oral presentation: The new Royal Danish Playhouse Theatre in Copenhagen - A practical example of energy conscious design	Technicians and engineers	Singapore	20	COWI
39	Jul 2007	TV feature in TV2 Lorry	Broad Public	Greater Copenhagen	Unknown (+50,000)	COWI
38	Apr 2007	Presentasjon av Veileder glassfasader. Nytt Operahus som Case v/ Rolf Hagen og Erichsen & Horgen	Engineers and architects	Norway	70	E&H
37	Feb 2007	PPP conference	Architects, engineers	Denmark	35	COWI
36	Jan 2007	Oral presentation i.c.w. tour	Architects, engineers	The Netherlands	35	Ecofys
35	2007	Renergi newsletter nr 4 2007	Research	Norwegian	Unknown	E&H
34	July 2007	Aftenposten Aften, article about the solar cells	Major norwegian-newspaper	Norwegian	Unknown	E&H
33	June 2007	Norwgian broadcasting NRK Perspektiv	Television (30 min/ broadcasting national)	Norwegian	Unknown	E&H
32	2007	Articles in Ukeavisen ledelse, Byggeindustrien, RIF hjemmeside	Technical magasines	norwegian	Unknown	E&H
31	Oct 2006	Energy conference, Poland	Architects, engineers, city planners,facility managers	Poland	50	COWI
30	Aug 2006	Public visit to Playhouse	Broad Public	Denmark	70	DKT
29	Jun 2006	Opera - kostymerte konserter eller levende musikkteater: Den Norske Opera fra Bjørnson til Giske Operasjef Bjørn E. Simensen, Den Norske Opera Direktør, Bernt Bauge, Den Norske Opera Leiv Atle Sand, siv.ing., Byggeledelsen i Operaprosjektet, Statsbygg Ida H. Bryn, dr.ing., Erichsen & Horgen AS	Scientists, professors, industry leaders	Norway	60	Statsbygg + E&H
28	May 2006	Miljøhensyn i opera-innkjøp Ny Teknikk	Journal www.nyteknikk.no/index.php?artikkelid=1606&back=1	Norway	50,000	Statsbygg
27	May 2006	Miljøhensyn i opera-innkjøp Ny Teknikk	Journal www.nyteknikk.no/in	Norway	50,000	Statsbygg

			dex.php?artikkelid=1606&back=1			
26	Apr 2006	Lecture for high school teachers to promote the use of physics	Teachers	Norway	30	Statsbygg + E&H
25	Apr 2006	Lecture for high school teachers to promote the use of physics	Teachers	Norway	30	Statsbygg + E&H
24	Apr 2006	Oral Presentation at Energy Efficiency Conference, Copenhagen	Technicians and public decision makers	Denmark	240	COWI
23	Apr 2006	Oral and poster presentation at the Solar Cities conference, Oxford	Technicians	EU	100	COWI
22	Mar 2006	Får Norges største solcellepanel Firdaposten	Newspaper	Norway	5,000	Statsbygg
21	Mar 2006	Miljøhensyn i Opera-innkjøp Energisk	Journal http://www.energisk.no/news/showarticle.asp?AId=40&NId=19119	Norway	5,000	Statsbygg
20	Mar 2006	Boarding, 25.03.2006,	Web site *www.boarding.no/art.asp?id=20892*	Norway	5,000	Statsbygg
19	Jan 2006	Solkraft til den nye Bjørvika-operaen Aftenposten Aften	Largest newspaper in Oslo	Norway	500,000	Statsbygg
18	Jan 2006	Common Newsletter	Newsletter	EU	?	COWI (part of common dissemination lead by SARA)
17	Dec	Article in the Danish HVAC magazine	HVAC Engineers	Denmark	8,000 (copies)	COWI
16	Nov 2005	Publication of ECO Culture at Statsbygg's homepage: http://www.statsbygg.no/opera/bygget/Energitiltak/	Public	Norway	100,000	Statsbygg
15	Nov 2005	Oral and poster presentation at the Eco-building symposium, Berlin	Technicians	EU	100	COWI
14	Sep 2005	Web-portal www.ecobuildings.info	Professionals, Broad public	EU	18 visits per day (average spring 2006)	COWI (part of Common Dissemination)
13	Jul 2005	Common Newsletter	Newsletter	EU	?	COWI (part of common dissemination, lead by SARA)
12	Jul 2005	Article in Dutch building magazine 'Urban development & Architecture'	Architects, Building industry, Housing associations	The Netherlands	9,000	Ecofys
11	Apr 2005	Conference on Energy Management in Buildings. Presentation	Energy industry	Denmark	35	COWI

10	Apr 2005	Oral Presentation at Norwegian Architectural Society	Architects	Norway	100	COWI
9	Apr 2005	Article in "El & Energi" , 1 page.	Energy industry, mainly electricity	Denmark	20,000	COWI interviewed
8	Feb 2005	Article in "Teknikeren"	Engineers and constructors	Denmark	10,000	COWI interviewed
7	Dec 2004	Article in "Energinyt". 2 pages.	Energy industry	Denmark	20,000	COWI interviewed
6	Nov 2004	Article "Byg.Tek", 1 page.	Building industry	Denmark	20,000	COWI interviewed
5	Oct 2004	Press release in COWIfeature	News media, building & energy industry	Denmark	20,000	COWI
4	Oct 2004	Notice on www.ing.dk (homepage for professional engineers in Denmark)	Engineers	Denmark		Based on press release
3	Oct 2004	Berlingske.net (internet site of large national news paper	All	Denmark		Based on press release
2	Jun 2004	Paper and Presentation at PV conference in Paris "ECO-Culture: high performing cultural Eco-buildings with PV".	European PV sector	Europe	?	Ecofys
1	Mar 2004	Article in "BYGGENYTT"	Building industry	Norway	15,000	EH and Statbygg

7.2 Exploitation of results

Thermo-active slabs

The use of thermo-active components has become an integrated part of the building design in a large number of new buildings. The use and functionality go very well in hand with renewable energy supply. Based on the outcome of the project, at least one Danish company has started the production of prefabricated hollow-core thermo-active slabs.

Energy supply through seawater and energy storage

Seawater cooling and heating are being used extensively in new buildings where there is a need for cooling - where the heating system can be added "for free" in the building design through the use of thermo-active slabs. The use of free cooling and heat pump driven cooling is saving considerable amounts of energy, and the cost is very low, especially with the expected increase in energy prices. This is the case in both the Playhouse and the Library, which are equipped with two different types of systems capable of delivering both heating and cooling. In both places, the systems are drawing considerable interest among professionals who are interested in testing the systems.

Ventilation and BEMS

For the ventilation design, including the connection to the BEMS, the project has shown that there are very large saving potentials, even in buildings like these, where the system is already well designed with low energy consumption. The use of advanced feedback through a large number of energy metering devices gives invaluable data, which can be used for building operation optimization.

PV panels

The use of PV panels is still not completely accepted in the built environment. However, the steady increase in prices means that the results from the ECO-

Culture project can easily be exploited by other partners when combining electricity production and solar shading.

Technological Implementation Plan

See also Technological Implementation Plan for further information on the planned exploitation of the results from the ECO-Culture project. This has been attached as an appendix to this report.

7.3 Expected impact

Playhouse

The project has been a huge success for COWI. Especially the combination of thermo-active slabs and heat pumps for heating and cooling using seawater or ground sources as reservoir has been adopted in new building projects. This has formed and continue to form the basis for several projects where sustainability and low energy consumption have been in focus. In more recent projects, focus has been on variations using groundwater or LTES in combination with the remaining low-energy building design. The newest addition to the use of heat pumps has been to use heat driven heat pumps that do not use electricity but rather district heating to supply heating and cooling to the building.

At the same time, there is a growing trend for other consultants in Denmark to also use heat pumps and some sort of seawater, ground water or LTES as reservoir when designing low-energy buildings. The combination with thermo-active slabs is also catching on, and in general, the use of thermo-active slabs has become a selling point in many new office buildings.

For cultural buildings, the Playhouse has shown that it is possible to combine attractive architecture, good functionality and low energy consumption in the same building.

Library

The Library has become a well known building in the Amsterdam area, and the low-energy design and the use of renewable energy sources have gained considerable interest in the public.

Opera House

Figure 7.1 shows which popular tourist attraction the Opera House has become. The staff has given the Opera House the nickname "The Tourist Machine". Every day, especially in the summer, the roof is full of people exploring the building, enjoying a glass or a meal in the restaurants, or just admiring the beautiful scenery of Oslo city and the Oslo fjord. It was not expected that the building would be such a famous tourist attraction. An example to illustrate the popularity of the Opera House is the fact that the budget for toilet paper was exceeded within three months after the Opera House opened.

The fact that the Opera house is one of Oslo's most visited sites emphasizes which perfect arena this is for demonstrating energy-effective technologies such as the south-facing glass façade with solar cells.

Figure 7.1 Opera House full of tourists exploring the building

7.4 Prices won

The three buildings have won a number of prices. A few of these are specifically mentioned here.

Playhouse

The Playhouse has been awarded the Bæredygtig Beton Pris. The award for Sustainable Concrete was given by the organisation Danish Concrete in March 2009.

Further, the building has been awarded the Nordisk Lyspris (Nordic Lighting Award) in October 2008.

Library

The Library has been awarded the WAN award in 2009 in the category "Civic Building of the year".

Opera House

The Opera House has won several international architectural prices and is highly appreciated by the public, owners and the users. The users are proud of their Opera House, but they also feel the pressure on the building and the consequences of that. http://www.snøhetta.no/#/news/: 2009: Designers Saturday, Best Interior, Mies Van der Rohe Award, Nordic Selected, Travel + Leisure Award: best cultural place, 2008: Archip, Russia, World architecture festival, Barcelona, The state building Tradition award.

8 Appendices

Technological Implementation Plan

TECHNOLOGICAL IMPLEMENTATION PLAN

A Framework for the further development, dissemination and use of the results of EC RTD Projects (including also thematic networks and concerted actions)

DATA SHEETS

Preliminary version at mid-term (optional, programme per programme)

X Final version before final term (contractual obligation)

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Part 1: Overview and description of your project and its results *One form per project*	Publishable

1.1: Executive summary (to be used for an accurate update of the programme synopsis of projects)
1.2: Overview of all results
1.3: Quantified data on the project
1.4.: Assessment of the European interests : This section enables the co-ordinator to explain the interest for the European Union (the competitiveness of its industries, the usefulness for (part of) its population,…) of the achieved results and of their foreseen impacts.
1.5.: Expected project impact

Part 2: Description of each Result - Search for collaboration through Commission services *One form per Result*	Publishable

This section will be used to document your result(s) in CORDIS and to inform any appropriate audience

2.1 : Description of the result(s)
2.2 : Quantified data about the result
2.3 : Further collaboration, dissemination and use of the result : This section enables each partner – individually or as a consortium – to describe its needs in further collaboration in view of the dissemination an use of its results(s).

Part 3: Description of the intentions by each partner *One form per partner*	Confidential

This section enables each partner – individually or as a consortium – to describe its use and dissemination intentions (including a timetable of its future activities).
3.1 : Description of the use and the dissemination of result(s), partner per partner
3.2 : Quantified data for each partner's main result

- The Technological Implementation Plan data sheets are available as a predefined form in Microsoft Word format. The file may be downloaded from the European Commission's CORDIS web site at: http://www.cordis.lu/fp5/tip.htm or may be obtained by e-mail from your EC programme help desk or your Project Officer.
- The form should be completed electronically and returned preferably by e-mail to your project officer (Firstname.Lastname@cec.eu.int). Alternatively it can be sent on a diskette to the address provided by your Project Officer :
  - ✓ Part 1, 2 by the project co-ordinator;
  - ✓ Part 3 by the project co-ordinator or by each partner individually, as preferred.

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Part 1 Overview and description of your project and its results

EC PROGRAMME :	
PROJECT TITLE & ACRONYM:	Demonstration and dissemination of ECO-concepts for high performance European cultural buildings ECO-culture
CONTRACT NUMBER :	TREN/04/FP6EN/S07.30902/503079
PROJECT WEB SITE (if any) :	**www.ecobuildings.info**
PARTNERS NAMES :	**COWI A/S** **Royal Danish Theatre** **Ecofys Netherlands bv** **City of Amsterdam** **Erichsen & Horgen A/S** **Statsbygg**

1.1 Executive summary

Please, synthesise (in 1 or 2 pages) your project original objectives and final outcome.

a) Original research objectives

This project addresses demonstration of energy efficient technologies integrated into three high-performing cultural ECO-buildings. All the buildings have been designed using a "Whole Building Design Approach" in order to ensure the largest energy saving potential possible. The methodology of the Whole Building Design Approach has been to:

1. Reduce the demand for heating, cooling, electricity and ventilation, and
2. Supply the necessary heating, cooling, electricity and ventilation in the most efficient way using renewables.
3. Always consider the impact on a whole building level.

The overall energy objectives of the ECO-culture buildings are to:

- Reduce the energy consumption and CO_2 emission related to cooling by 75-80% (DK).
- Reduce the heat consumption and related CO_2 emission by 35-50%.
- Reduce the energy for ventilation and related CO_2 emission by 35-50%.
- Use renewables; sea water (DK), ground water (NL) and solar energy (NL & NO)
- Use intelligent control for maximised utilisation of the use technologies
- Disseminate the used ECO-concepts of the high-performing cultural buildings throughout Europe and beyond.

Focus has been on investigations, demonstration and testing of the following technologies, which have been selected out of the integrated ECO-concepts as being especially innovative and contributing to further development:

- Energy Storage (DK-"climate belt" with thermo-active slabs, NL-double aquifers)
- Heat Pump (DK-sea water, NL-ground water)
- Demand controlled hybrid ventilation (DK)
- Demand controlled, energy efficient ventilation (NO)
- Building integrated PV systems (NL & NO)
- Building Energy Management Systems (BEMS) (NO, DK, NL)
- Use of Environmental Friendly Concrete for thermal storage in thermo-active slabs (DK).

Expected impact
The ECO-concepts have been demonstrated in three high-profile cultural buildings:

- The Danish Royal Theatre (DK)
- The Amsterdam Library, Amsterdam (NL)
- The New Opera House, Oslo (NO).

About 2,400,000 people will visit the cultural buildings every year. Thus, the project will contribute significantly to increasing the awareness of new ECO-solutions. Other cultural buildings will be reached through the network of the cultural institutions. It is expected that the demonstration and documentation of the ECO-concepts will contribute significantly to the further adoption of the solutions in cultural buildings in Europe.

b) Expected deliverables

The main deliverable is the demonstration of the ECO concepts technologies in the three cultural buildings as described above. Main deliverables in relation to dissemination includes a monitoring report, site visits, brochures, symposiums, newsletters, posters and web-page.

c) Project's actual outcome ***(in terms of technical achievements or if appropriate task per task)***

Outcome:

- Energy storage using "Climate Belt" with thermo-active slabs (Playhouse)
- Heat pump using seawater as reservoir (Playhouse)
- Intelligent ventilation including BEMS (Playhouse)
- Use of environmentally-friendly concrete for thermal storage in thermo-active slabs (Playhouse)
- Energy storage using double aquifer in external system (Library)
- Building-integrated PV system (Library)
- Intelligent ventilation including BEMS and benchmarking (Library)
- Demand-controlled ventilation (Opera House)
- Control strategies, BEMS and benchmarking (Opera House)
- Building-integrated PV system (Opera House)

The construction of three buildings is finalized. Monitoring data is available and monitoring is continuous on a constant basis.

The project development can be monitored at the web-page www.ecobuildings.info.

d) Broad dissemination and use intentions for the expected outputs *(such as industrial development, standards, regulations and norms, improvement of environment, health, working conditions, employment, net economic benefits, etc)*

The project intentions and design results have been disseminated at several presentations, in national TV and in numerous articles in newspapers and magazines.

A list of the main dissemination activities can be found below:

Main presentations (target group):
Architects
Consulting engineers
Designers
Manufacturers
Students
Building owners
University professionals

Main public events:
Opening events

- The energy concept of the Royal Danish Playhouse. Presentation at Elforsk Prisen 2009, COWI/DKT, May 2009
- Bæredygtig Beton Pris. Award for Sustainable Concrete by Danish Concrete, COWI/DKT, March 2009
- www.cowi.dk "Royal Playhouse receives Award for Sustainable Concrete", COWI/DKT, March 2009
- Public visit to Playhouse, DKT, August 2006
- Lecture for high school teachers to promote the use of physics, Statsbygg + E&H, April 2006
- Opera - kostymerte konserter eller levende musikkteater: Den Norske Opera fra Bjørnson til Giske, Operasjef Bjørn E. Simensen, Den Norske Opera, Direktør, Bernt Bauge, Den Norske Opera, Leiv Atle Sand, siv.ing., Byggeledelsen i Operaprosjektet, Statsbygg, Ida H. Bryn, dr.ing., Erichsen & Horgen AS, Statsbygg + E&H, June 2006

Main publications:
Publications technical journals

- Miljøhensyn i opera-innkjøp Ny Teknikk, Statsbygg, May 2006
- Miljøhensyn i Opera-innkjøp Energisk, Statsbygg, March 2006
- Article in the Danish HVAC magazine, COWI, December 2005
- Article in Dutch building magazine 'Urban development & Architecture', Ecofys, July 2005
- Article in "El & Energi" , 1 page, COWI inter-viewed, April 2005
- Article in "Teknikeren", COWI inter-viewed, February 2005
- Article in "Energinyt". 2 pages, COWI interviewed, December 2004
- Article "Byg.Tek", 1 page, COWI interviewed, November 2004
- Article in "BYGGENYTT", E&H + Statsbygg, February 2004

Appearance in news media

- Award to Royal Danish Playhouse. News in two papers: Teknik og Viden and Building Supply, COWI/DKT, March 2009
- The Royal Danish Playhouse receives "Nordisk Lyspris" (Nordic Lighting Award). Article in Licitationen, COWI/DKT, October 2008
- Water in the floor. Article in Politiken, COWI/DKT, May 2008
- TV feature in TV2 Lorry, COWI, July 2007
- Får Norges største solcellepanel Firda-posten, Statsbygg, March 2006
- www.boarding.no/art.asp?id=20892, Statsbygg, March 2006
- Solkraft til den nye Bjørvika-operaen Aftenposten Aften, Statsbygg, January 2006
- Common Newsletter, COWI (part of common dis-semination lead by SARA), January 2006
- Publication of ECO Culture at Statsbygg's homepage, Statsbygg, November 2005

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- Web-portal www.ecobuildings.info, COWI (part of Common Dis-semination), July 2005
- Common Newsletter, COWI (part of common dis-semination, lead by SARA), July 2005
- Press release in COWIfeature, COWI, October 2004
- Notice on www.ing.dk (homepage for professional engineers in Denmark), Based on press release, October 2004
- Berlingske.net (internet site of large national news paper, Based on press release, October 2004
- 30 min programme (Title: Som en kilde klar og ren) on national television (NRK) in Norway

Main conferences:

- PSO elforsk conference in Copenhagen, 2009
- Symposium in Stuttgart, 2008
- Oral presentation of ECO culture, COWI/E&H, April 2008
- Oral presentation: The new Royal Danish Playhouse Theatre in Copenhagen - A practical example of energy conscious design, COWI, November 2007
- Presentasjon av Veileder glassfasader. Nytt Operahus som Case v/ Rolf Hagen og Erichsen & Horgen, E&H, April 2007
- PPP conference, COWI, February 2007
- Oral presentation i.c.w. tour, Ecofys, January 2007
- Energy conference, Poland, COWI, October 2006
- Symposium in Berlin, 2006
- Oral and poster presentation at the Solar Cities conference, Oxford, COWI, April 2006
- Oral Presentation at Energy Efficiency Conference, Copenhagen, COWI, April 2006
- PVSEC conference in Barcelona, 2005
- Oral and poster presentation at the Eco-building symposium, Berlin, COWI, November 2005
- Oral Presentation at Norwegian Architectural Society, COWI, April 2005
- Conference on Energy Management in Buildings. Presentation, COWI, April 2005
- PVSEC conference in Paris, 2004
- Paper and Presentation at PV conference in Paris "ECO-Culture: high performing cultural Eco-buildings with PV", Ecofys, June 2004

Internet sites:
www.ecobuildings.info
www.cowiprojects.com/ecoculture/index.html

Project portal:
www.cowi.dk/projectportal

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1.2 Overview of all your main project results

No.	Self-descriptive title of the result	Category A, B or C*	Partner(s) owning the result(s) (referring in particular to specific patents, copyrights, etc.) & involved in their further use
1	The new Playhouse, Copenhagen: Knowledge, know-how, experience and documented energy saving potential of "Integrated 'climate belt' energy storage using thermo-active slabs". Design & demonstration.	A	Owning: All Future use: The Royal Danish Theatre, COWI
2	The new Playhouse, Copenhagen: Knowledge, know-how, experience and documented energy saving potential of "Optimised heat pump and seawater cooling". Design & demonstration.	A	Owning : All Future use: The Royal Danish Theatre, COWI
3	The new Playhouse, Copenhagen: Knowledge, know-how, experience and documented energy saving potential of "Optimised and intelligent controlled ventilation system, including BEMS". Design & demonstration.	A	Owning: All Future use: The Royal Danish Theatre, COWI
4	The new Playhouse, Copenhagen: Knowledge, know-how, experience and documented energy saving potential of "Environmental friendly building materials - environmental friendly concrete ("green concrete")". Design & demonstration.	A	Owning: All Future use: The Royal Danish Theatre, COWI
5	The Opera house, Oslo: Knowledge, know-how, experience and documented energy saving potential of "Demand controlled and energy efficient distribution of ventilation, including humidity control". Design & demonstration.	A	Owning: All Future use: Statsbygg, Erichsen & Horgen, Technical College Oslo.

6	The Opera house, Oslo: Knowledge, know-how, experience and documented energy saving potential of "Control strategies for glass facade, light, ventilation, heating and cooling to improve use of daylight and passive heating and cooling". Design & demonstration.	A	Owning: All Future use: Statsbygg, Erichsen & Horgen, Technical College Oslo.
7	The Opera house, Oslo: Knowledge, know-how, experience and documented energy saving potential of "A south facing glass façade with solar cells". Design & demonstration.	A	Owning: All Future use: Statsbygg, Erichsen & Horgen, Technical College Oslo.
8	The New Central Library, Amsterdam: Knowledge, know-how, experience and documented energy saving potential of "Energy storage in an aquifer". Design & demonstration.	A	Owning: All Future use: City of Amsterdam, Ecofys NetherlandsBV
9	The New Central Library, Amsterdam: Knowledge, know-how, experience and documented energy saving potential of "Advanced ventilation system, incl. Building Energy Management System - BEMS and lighting". Design & demonstration.	A	Owning: All Future use: City of Amsterdam, Ecofys Netherlands
10	The New Central Library, Amsterdam: Knowledge, know-how, experience and documented energy saving potential of "Solar façade and roof". Design & demonstration.	A	Owning: All Future use: City of Amsterdam, Ecofys Netherlands

* A: results usable outside the consortium / B: results usable within the consortium / C: non usable results

1.3 Quantified Data on the dissemination and use of the project results

Items about the dissemination and use of the project results (consolidated numbers)	Currently achieved quantity	Estimated future* quantity
# of product innovations (commercial)		
# of process innovations (commercial)		3
# of new services (commercial)		
# of new services (public)		
# of new methods (academic)		
# of scientific breakthrough		
# of technical standards to which this project has contributed		1
# of EU regulations/directives to which this project has contributed		1
# of international regulations to which this project has contributed		
# of PhDs generated by the project		
# of grantees/trainees including transnational exchange of personnel		

*# = number of ... / * "Future" means expectations within the next 3 years following the end of the project*

1.4. Comment on European Interest

All projects are expected to meet European interests. This section should provide an appraisal of your project in terms of European added value and support to the implementation of European Union policies.

1.4.1. Community added value and contribution to EU policies

a. European dimension of the problem
(The extent to which the project has contributed to solve problems at European level)

The project has addressed the ambitious European goals concerning reduction of energy consumption and environmental impact in buildings.

- Reduce the energy consumption and CO_2 emission related to cooling by 75-80%.
- Reduce the heat consumption and related CO_2 emission by 35-50%.
- Reduce the energy for ventilation and related CO_2 emission by 35-50%.
- Use renewables; sea water, ground water and solar energy

b. Contribution to developing S&T co-operation at international level. European added value
(Development of critical mass in human and financial terms; combination of complementary expertise and resources available Europe-wide)

The project addresses the EU - Green paper "Towards a European strategy for the security of energy supply" and proposed Directive on RE. The project contributes to the aim of using more RUE and diversified RE to reduce CO_2 emissions etc. by 12 % in 2010. The project further contributes to the deployment of stated EU energy policies, hereunder the 20-20-20 targets.
The project demonstrates RUE on all levels and RE by use of thermo-active slabs, LTES, natural ventilation, demand controlled ventilation, energy efficiency in HVAC systems, heat pump and seawater cooling, BIPV, Advanced BMS and Green concrete.

c. Contribution to policy design or implementation
(Contribution to one or more EU policies; RTD connected with standardisation and regulation at Community and/or national levels)

The project has supported the implementation of the new EPBD in the European countries as a best practice example. Designers will look to the demonstration to learn one efficient way to cope with the new directive. The demonstration in the three cultural buildings can therefore be used as cases of an early impact study of the EPBD.
The three buildings are used by the public. The buildings are not only visited by the local public, but also by tourists and foreign people. In this way the knowledge about the eco-concepts will spread widely.

1.4.2. Contribution to Community social objectives

a. Improving the quality of life in the Community :

Improving the quality of life and health and safety with special focus on working conditions and social objectives is given as high a priority as the environmental issues. The aims are better health, better working environment, higher user satisfaction, which by experience lead to higher working efficiency and less sickness days.

Key-issues are:

- Healthy building materials.
- The indoor climate is optimised regarding air quality (CO2 control), acoustics and visual and thermal qualities.
- Democratic architecture with extensive public access to the facilities.

b. Provision of appropriate incentives for monitoring and creating jobs in the Community (including use and development of skills) :

Many new technologies are being tested in the demonstration. Thus new industries are expected to flourish as part of the commercial development of these technologies.

c. Supporting sustainable development, preserving and/or enhancing the environment (including use/conservation of resources) :

The project supports the sustainable development with its direct focus on energy savings and use of renewable energy.

1.5.	Expected project impact (to be filled in by the project coordinator)

Remark: by replying to the following questions, the coordinator is asked to express his best estimation regarding the impact of the project.

Overall Policy Impact[1]

EU Policy Goals	I SCALE OF EXPECTED IMPACT OVER THE NEXT 10 YEARS[2] -1 0 1 2 3	II other: Not applicable to project	II other: Project Impact too difficult to estimate
1. Improved sustainable economic development and growth, competitiveness Θ	2		
2. Improved employment Θ	0		
3. Improved quality of life and health and safety Θ	1		
4. Improved education Θ	2		
5. Improved preservation and enhancement of the environment Θ	1		
6. Improved scientific and technological quality Θ	1		
7. Regulatory and legislative environment Θ	2		
8. Other Θ		x	

[1] Coordinator should respond to section I or, if appropriate, to section II. If the project has had no impact, a "0" should be entered in section I. Scores other than zero in section I will prompt a more detailed subquestion on a separate screen. However, you may access in any case the subquestions by clicking on the symbol" Θ "following each main question.

[2] Indication for scale as follows: -1 represents negative impact, 0 no impact, 1 small positive impact, 2 medium positive impact , 3 is a strong positive impact

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Indicate your replies below by putting in each box the number corresponding to the score you chose:

1. Economic development and growth, competitiveness	Scale of Expected Impacts over the next 10 years (2) By Project End -1 0 1 2 3	After Project End -1 0 1 2 3
a) Increased Turnover for project participants - national markets	0	0
- international markets	0	0
b) Increased Productivity for project participants	0	0
c) Reduced costs for project participants	0	1
d) Improved output quality/high technology content	2	2
d)		
e)		

2. Employment	Scale of Expected Impacts over the next 10 years (2) By Project End -1 0 1 2 3	After Project End -1 0 1 2 3
a) Safeguarding of jobs	0	0
b) Net employment growth in projects participants staff	0	0
c) Net employment growth in customer and supply chains	0	1
d) Net employment growth in the European economy at large	0	0

3. Quality of Life and health and safety	Scale of Expected Impacts over the next 10 years (2) By Project End -1 0 1 2 3	After Project End -1 0 1 2 3
a) Improved health care	1	1
b) Improved food, nutrition	0	0
c) Improved safety (incl. consumers and workers safety)	0	0
d) Improved quality of life for the elderly and disabled	0	0
e) Improved life expectancy	0	0
f) Improved working conditions	1	1
g) Improved child care	0	0
h) Improved mobility of persons	0	0

4. Improved education	Scale of Expected Impacts over the next 10 years (2) By Project End -1 0 1 2 3	After Project End -1 0 1 2 3
a) Improved learning processes including lifelong learning	1	1
b) Development of new university curricula	0	0

5. Preservation and enhancement of the environment	Scale of Expected Impacts over the next 10 years (2) By Project End -1 0 1 2 3	After Project End -1 0 1 2 3
a) Improved prevention of emissions	1	2
b) Improved treatment of emissions	0	0
c) Improved preservation of natural resources and cultural heritage	1	1
d) Reduced energy consumption	2	2

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6. S&T quality	Scale of Expected Impacts over the next 10 years (2): By Project End -1 0 1 2 3	After Project End -1 0 1 2 3
a) Production of new knowledge	2	2
b) Safeguarding or development of expertise in a research area	1	1
c) Acceleration of RTD, transfer or uptake	1	0
d) Enhance skills of RTD staff	1	1
e) Transfer expertise/know-how/technology	1	2
f) Improved access to knowledge-based networks	0	0
g) Identifying appropriate partners and expertise	1	1
h) Develop international S&T co-operation	0	0
i) Increased gender equality	0	1

7. Regulatory and legislative environment	Scale of Expected Impacts over the next 10 years (2): By Project End -1 0 1 2 3	After Project End -1 0 1 2 3
a) Contribution to EU policy formulation	1	1
b) Contribution to EU policy implementation	1	2

8. Other (please specify)	Scale of Expected Impacts over the next 10 years (2): By Project End -1 0 1 2 3	After Project End -1 0 1 2 3

I, **project co-ordinator**, confirm the published information contained in this part 1 of the TIP.

Signature: P. Weit[illegible] **Name:** PETER WEITZMANN for JENS OLE HA[illegible]

Date: Feb 11 - 2010 **Organisation:** COWI A/S

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Part 2 Description of each result

A separate part 2 must be completed for each result. This may be done by the partner responsible for the result or by the project co-ordinator.

The part 2 must be consolidated at the consortium level and transmitted to the Commission by the co-ordinator.

PARTS 2 WILL BE DISSEMINATED BY THE COMMISSION

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2.1 : Description of the result(s), one form per result

No. & TITLE OF RESULT (same as in table 1.2)

No.	Self-descriptive title of the result
	Monitoring data.

CONTACT PERSON FOR THIS RESULT

Name	Jens Ole Hansen
Position	Project coordinator
Organisation	COWI A/S
Address	Parallelvej 2, DK-2800 Lyngby, Denmark
Telephone	+4545972211
Fax	+4545972212
E-mail	jha@cowi.dk
URL	www.cowi.dk
Specific Result URL	www.ecobuildings.info www.cowiprojects.com/ecoculture/index.html

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SUMMARY *(200 words maximum)*

The ECO-Culture project is concerned with the Royal Play House in Copenhagen, Denmark, the Opera House in Oslo, Norway, and the Amsterdam Public Library, The Netherlands.

The objectives have been to demonstrate reductions in energy consumption and CO_2-related emission related to cooling by 75-80% and to heating by 35-50%. Further, to show integration of renewable energy and intelligent control in high-profile buildings. The technologies include energy storage, seawater cooling, heat pumps, demand-controlled ventilation, building-integrated PV, advanced Building Energy Management Systems and green concrete.

A whole building design approach was used to show to the public and professionals that it is possible to build high-profile low-energy buildings with appealing architecture and high-level functionality.

The overall objectives have to a very large extent been met already during the first years of operation. In the Playhouse and Opera expectations have nearly all been met. In the Library, investigations are ongoing, with promising results.

The buildings have become integral parts of the cities cultural life, and are thus Eco-buildings ambassadors. They have been presented on national television, on the internet, in conferences and in reports. The buildings have won several prices. It is estimated that over 4 million have visited the buildings during 2009.

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Provide an overview of the result which gives the reader an immediate impression of the nature of the result, its relevance and its potential; Briefly describe the current status/applications of the result (if appropriate) with non confidential information on entities potentially involved.

The design and construction of the three buildings with eco-technologies are concluded.

The Playhouse in Copenhagen

- Thermoactive slabs:

The project has been the breakthrough for using TABS in connection with precast concrete elements. The system can be used generally in office buildings and many tertiary buildings. Further it is the key to integrate renewable energy supply due to the operation temperature close to room temperature.

The manufacturer SpænCom has now started a production of precast elements with TABS as precast elements with TABS as standard prestressed hollow core elements. This has been developed in further R&D projects following the ECO-Culture project.

- Optimised heat pump and sea water cooling

The project has shown that seawater cooling is suitable for condenser cooling but not for free cooling in the hottest period. As many new town developments happen in old harbour areas it is a solution with big replication potential.

- Optimised and Intelligent controlled ventilation system, including BEMS

The project has shown that natural ventilation is not always enough to ensure sufficient low room temperatures, but it can with good result be combined with TABS and together this can be widely used in public buildings as well as in offices.

- Environmental friendly concrete ("green concrete")

Continuous work is being done to reduce embedded energy and CO_2-emission of cement in concrete. Green concrete can be used indoor in many secondary structures and the air is to reach 30 % CO_2-reduction.

The Opera house in Oslo

- Demand controlled and energy efficient distribution of ventilation, including humidity control

The demand controlled, energy efficient ventilation reduce the energy consumption as planned. The SFP of most of the systems are when running are in average around 1. The heating energy for ventilation is within the target.

- Control strategies for glass façade, light, ventilation, heating and cooling to improve use of daylight and passive heating and cooling

The BEMS help improve the energy performance of the building. Energy reduction from 2008 to 2009 is 38 % on district heating and 25 % on electricity for HVAC. The energy consumption for heating and cooling is below target the second half part of 2009.

- A south facing glass façade with solar cells

The integrated solar cells work perfectly as solar shading. The foyer behind is a place where people enjoy being in the summer heat. The solar cells work and produce energy as planned.

The new Central Library in The Netherlands

- Long-term energy storage in aquifer

The LTES systems provides cold and heat to these large public buildings with a very low energy use and thus large CO2 emission reduction.

- Renewable energy systems - solar façade and roof

The solar façade and solar roof system provide renewable electricity to the library. The façade system raises awareness for renewable energy to a large public.

- BEMS and lightning

The BEMS improves the energy performance of the building. The ventilation is CO2 controlled and lighting is switched off when no people are around. LED lighting is used to provide low energy lighting on the book shelves.

Please categorise the result using codes from Annex 1

Subject descriptors	197	199	203	210	477

CURRENT STAGE OF DEVELOPMENT

Please tick one category only

Scientific and/or Technical knowledge (Basic research)	☐
Guidelines, methodologies, technical drawings	☐
Software code	☐
Experimental development stage (laboratory prototype)	☐
Prototype/demonstrator available for testing	☐ X
Results of demonstration trials available	☐
Other (please specify.):	☐

DOCUMENTATION AND INFORMATION ON THE RESULT

List main information and documentation, stating whether public or confidential.

Documentation type	Details (Title, ref. number, general description, language)	Status: *PU*=Public *CO*=Confidential
Internet site www.ecobuildings.info	Internet site	PU
Monitoring Report	Monitoring report for all buildings, Internet Site	PU
Final Report	Internet site	PU
Final Management	Final Management Report	CO
Tender Documents	Tender Documents and bill of quantities	CO
Buildings	The three actual buildings	PU

INTELLECTUAL PROPERTY RIGHTS

Type of IPR	KNOWLEDGE: Tick a box and give the corresponding details (reference numbers, etc) if appropriate — Current				Foreseen	Pre-existing know-how Tick a box and give the corresponding details(reference numbers, etc) if appropriate	
	Tick	NoP [1]	NoI [2]	Details	Tick	Tick	Details
Patent applied for	☐				☐	☐	
Patent granted	☐				☐	☐	
Patent search carried out	☐				☐	☐	
Registered design	☐				☐	☐	
Trademark applications	☐				☐	☐	
Copyrights	☐				☐	☐	
Secret know-how	☐				☐	☐	
Other - please specify :	☐				☐	☐	

1) Number of Priority (national) applications/patents
2) Number of Internationally extended applications/patents

MARKET APPLICATION SECTORS

Please describe the possible sectors for application using the NACE classification in Annex 2.

Market application sectors	29	40	45		

2.2. Quantified data about the result

Items (about the results)	Actual current quantity [a]	Estimated (or future) quantity [b]
Time to application / market (in months from the end of the research project)	10	20
Number of (public or private) entities potentially involved in the implementation of the result :	6	40
of which : number of SMEs :	5	10
of which : number of entities in third countries (outside EU) :	0	0
Targeted user audience: # of reachable people	20.000	1.000.000
# of S&T publications (referenced publications only)		
# of publications addressing general public (e.g. CD-ROMs, WEB sites)	2	5
# of publications addressing decision takers / public authorities / etc.		
Visibility for the general public	Yes	Yes

[a] *Actual current quantity = the number of items already achieved to date.*
[b] *Estimated quantity = estimation of the quantity of the corresponding item or the number of items that you foresee to achieve within the next 3 years.*

2.3. Further collaboration, dissemination and use of the result

(Optional: to be completed if partner is willing to set up new collaborations, and seeking dissemination support from the CORDIS services.)

COLLABORATIONS SOUGHT

Please tick appropriate boxes (■) corresponding to your needs.

R&D	Further research or development	☐ X	**FIN**	Financial support	☐
LIC	Licence agreement	☐	**VC**	Venture capital/spin-off funding	☐
MAN	Manufacturing agreement	☐	**PPP**	Private-public partnership	☐
MKT	Marketing agreement/Franchising	☐	**INFO**	Information exchange	☐
JV	Joint venture	☐	**CONS**	Available for consultancy	X
			Other	(please specify)	☐

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POTENTIAL OFFERED FOR FURTHER DISSEMINATION AND USE

Please, clearly describe your input, the value and interest of the applications and the dissemination and use opportunities that you can offer to your potential partner.

Knowledge transfer of the gained knowledge. Partnership in further development, especially within energy system design.

The developed technologies have been further implemented in House of Science, Middelfart Sparekasse new domicile of a bank, Danish Radio, Harbour house office, to mention a few.

The technologies from the Operahouse are implemented in several schoolbuildings, Oslo consert hall, DNB Nor (a major Norwegian bank 100 000 m2), New Hospital in Østfold and all relevant new projects.

Ecofys Netherlands provides energy concepts to develop low energy or zero energy buildings. Knowledge of techniques like heat and cold storage, bio CHP, solar and ventilation are available. Building simulations can be carried out to optimise a building design.

PROFILE OF ADDITIONAL PARTNER(S) FOR FURTHER DISSEMINATION AND USE

Please, clearly describe the profile and the expected input from the external partner(s).

Consultants and building owners for the use of the developed and demonstrated technologies.

The manufacturer SpænCom now has introduced an industrialised product with prefab prestressed hollow core concrete elements produced as TABS.
COWI together with Erichsen & Horgen A/S is now working for introducing of TABS on the Norwegian market.

I confirm the information contained in part 2 of this Technological Implementation Plan and I authorise its dissemination to assist this search for collaboration.

Signature: P. Weitz **Name:** PETER WEITZMANN FOR JENS OLE HANSEN

Date: Feb 11/2010 **Organisation:** COWI A/S

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